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EFFECTS OF ENDURANCE TRAINING ON HEAT-EXERCISE TOLERANCE IN MEN WEARING NBC PROTECTIVE CLOTHING

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Protective clothing imposes significant physiological and psychological stresses on the human body and may limit work tolerance, especially in hot environments. The additional strains imposed by protective clothing arise mainly because it is difficult for sweat to evaporate through relatively impermeable fabrics. Endurance training is a commonly adopted tactic to improve tolerance times when individuals must work in the heat. Potential benefits include improved physical fitness, increased sweating, and expanded plasma volume. However, it is unclear whether such responses develop and/or are helpful when wearing protective garments with limited vapor permeability. The purpose of this study was therefore to examine the influence of endurance training on exercise tolerance in a hot environment when subjects were wearing either normal light combat clothing or clothing offering protection against nuclear, biological and/or chemical (NBC) agents.

Sixteen unacclimatized males were assigned to either an 8-week treatment of endurance training (n = 7) or control (n = 9). The training program consisted of four 45-min running sessions per week at 80% of maximal aerobic power ($\dot{V}O_{2max}$), performed at < 25°C. Subjects were tested before and after treatment wearing either standard combat clothing or NBC protective clothing. Test sessions involved treadmill walking at 4.8 $km \cdot h^{-1}$ and 2% grade in a climatic chamber maintained at 40°C and 30% rh. The heat-exercise tolerance time (HETT) was defined as the time to the first of: (1) a rectal temperature (T_{re}) of 39.3°C, (2) a heart rate (HR) ≥ 95% of the subject's observed maximum for 3 min, (3) unwillingness of the subject to continue, or (4) elapse of 2 h.

Endurance training increased $\dot{V}O_{2max}$ (+16%) and plasma volume (+8%), but HETT was unchanged in either clothing ensemble. When wearing standard combat clothing, training slowed the rate of increase in HR and T_{re}, and decreased mean subjective rating of perceived exertion, with a trend to decreased mean skin temperature ($\bar{T}_{sk}$). When wearing NBC protective clothing, in contrast, the only significant change was a higher post-training $\bar{T}_{sk}$. A training-induced increase of sweat secretion in NBC protective clothing (+19%) and a parallel but non-significant trend in standard combat clothing (+9%) were not accompanied by any statistically significant increase in sweat evaporation. Evaporative efficiency thus tended to decrease (-4% in NBC protective clothing; $p < 0.05$ and -3% in standard combat clothing; NS). The results suggest that endurance training in a relatively cool environment has little effect on the physiological and psychological stresses imposed by wearing NBC protective clothing in hot environments, because added sweat secretion decreases blood volume and increases discomfort without augmenting body cooling.

ABSTRACT

Sixteen unacclimatized males (27 ± 1 yr, 1.76 ± 0.01 m, 82 ± 3 kg) were assigned to either an 8-week treatment of endurance training (n = 7) or control (n = 9). The training program consisted of four 45-min running sessions per week at 80% of maximal aerobic power ($\dot{V}O_{2max}$), performed at < 25°C. Subjects were tested before and after treatment wearing either standard military combat clothing (4.4 kg, 1.4 clo) or nuclear, biological and/or chemical (NBC) protective clothing (8.2 kg, 2.5 clo). Test sessions involved treadmill walking at 4.8 $km \cdot h^{-1}$ and 2% grade in a climatic chamber maintained at 40 ± 0.5°C and 30 ± 1% rh. The heat-exercise tolerance time (HETT) was defined as the time to the first of: (1) a rectal temperature (T_{re}) of 39.3°C, (2) a heart rate (HR) ≥ 95% of the subject's observed maximum for 3 min, (3) unwillingness of the subject to continue, or (4) elapse of 2 h. Endurance training increased $\dot{V}O_{2max}$ (39.9 ± 1.7 vs. 46.3 ± 2.3 $mL \cdot kg^{-1} \cdot min^{-1}$) and plasma volume (+8 ± 2%), but HETT was unchanged in either clothing ensemble. When wearing standard combat clothing, training slowed the rate of increase in HR and T_{re}, and decreased mean subjective rating of perceived exertion, with a trend to decreased mean skin temperature ($\bar{T}_{sk}$). When wearing NBC protective clothing, in contrast, the only significant change was a higher post-training $\bar{T}_{sk}$. A training-induced increase of sweat secretion in NBC protective clothing (1.16 ± 0.20 vs. 1.38 ± 0.19 $kg \cdot h^{-1}$) and a parallel but non-significant trend in standard combat clothing (0.76 ± 0.06 vs. 0.83 ± 0.07 $kg \cdot h^{-1}$) were not accompanied by any statistically significant increase in sweat evaporation. Evaporative efficiency thus tended to decrease (25.3 ± 3.5 vs. 21.0 ± 2.6% in NBC protective clothing; $p < 0.05$ and 76.8 ± 2.3 vs. 74.2 ± 2.3% in standard combat clothing; NS). The results suggest that endurance training in a relatively cool environment has little effect on the physiological and psychological stresses imposed by wearing NBC protective clothing in hot environments, because added sweat secretion decreases blood volume and increases discomfort without augmenting body cooling.

INTRODUCTION

The human body normally compensates well for moderate climatic heat stress by cardiovascular and thermoregulatory defence mechanisms, equilibrating heat gains and losses according to the First Law of Thermodynamics as expressed in the heat balance equation:

$$S = M - (\pm W) - E_{res} \pm C_{res} - E_{sk} \pm R \pm C \pm K \qquad \text{(Eq. 1)}$$

where S is the heat storage; M is the internal heat produced by metabolism; W is any external work performed; E_{res} is the evaporative heat loss from the respiratory tract; C_{res} is the heat exchange by convection through the respiratory tract; E_{sk} is the evaporative heat loss from the skin surface; R, C, and K are the heat exchanges by radiation, convection, and conductance through the skin surface. However, physiological defence mechanisms can be overwhelmed under extreme conditions, including (1) combinations of high air temperature and an extreme radiant heat load or elevated wet bulb temperature (Nunneley 1988), (2) combinations of more moderate heat stress with a high metabolic rate (Rowell 1974), and (3) clothing worn for protection from nonthermal hazards (McLellan et al. 1992). The additional physiological strain imposed by protective clothing arises mainly because it is difficult for sweat to evaporate through relatively impermeable fabrics.

In a hot, dry environment, where the ambient temperature is higher than that of the airway or the skin surface, a lowering of metabolism and/or an increase of sweat evaporation offer limited possibilities for an individual to slow the rate of increase in body temperature. Endurance training is one tactic to increase the rate of sweat production in response to a given level of thermal stress. Trained individuals show an increased sweat rate at a given core temperature (Nadel et al. 1974) and possibly a decrease in the threshold core temperature at which sweating starts (Taylor 1986), but little or no change in the metabolic cost of an unskilled submaximal task such as treadmill walking or cycle pedalling (Sawka et al. 1983). Thus, endurance training should improve heat tolerance, provided that the additional sweat can be evaporated.

Sweat evaporation is likely to be compromised by the wearing of protective clothing, and it is unclear whether a training-induced increase of sweat production would be helpful in such circumstances. The trained individual might indeed become dehydrated at a faster rate, especially if the intake of fluid was restricted. The purpose of this study was thus to compare the influence of endurance training on exercise tolerance in a hot environment when subjects were wearing either normal light combat clothing or clothing offering protection against nuclear, biological and/or chemical (NBC) agents.

METHODS

Subjects

Sixteen healthy males (21-34 years) were recruited from military personnel and university students in accordance with a protocol approved by the Human Ethics Committees of the University of Toronto and the Defence and Civil Institute of Environmental Medicine. Prior to inclusion in the study, they underwent a medical examination, and signed an informed consent statement. Eleven of the 16 subjects were initially relatively sedentary, but 5 had previously taken part in various sports, such as ice hockey, basketball, or weight lifting. The highest initial maximal oxygen intake ($\dot{V}O_{2max}$) was 50.9 $mL \cdot kg^{-1} \cdot min^{-1}$. Subjects were arbitrarily allocated to either endurance training (ET; n = 7) or control (UT; n = 9) treatments.

Experimental design

Testing was conducted from November through March, to avoid any possible initial heat acclimatization through casual exposure to high ambient temperatures. All subjects completed four submaximal exercise tests in an environmental chamber that was maintained at 40 ± 0.5°C and 30 ± 1% rh. They wore each of two clothing ensembles before and after 8 weeks of endurance training or a corresponding control period. The order of wearing of the two types of clothing was assigned randomly, with a minimum of 48 h separating each test. Since the issue of interest was the relationship between endurance training, protective clothing, and performance in the heat, exercise tests without heat exposure were not included.

Determination of maximal aerobic power ($\dot{V}O_{2max}$)

$\dot{V}O_{2max}$ was determined by open-circuit spirometry, using a graded exercise procedure. All subjects began running on a motor-driven treadmill set at 0% incline and a self-selected pace that ranged from 8.0 to 14.5 $km \cdot h^{-1}$, depending on the subject's aerobic fitness. After 3 min, the treadmill grade was increased $1\% \cdot min^{-1}$, up to a maximum of 10%. The treadmill speed was then increased 0.8 $km \cdot h^{-1}$ each minute to exhaustion of the subject. Tests were normally completed in 12-15 min. $\dot{V}O_{2max}$ was defined as the highest 30 s oxygen consumption ($\dot{V}O_2$) observed during the incremental test. Heart rate (HR) was monitored throughout the test, using a telemetry unit (Sport Tester, Polar Electro PE3000). The highest value (5 s average) recorded during (and normally in the final 5 s of) the exercise test was considered as the individual's maximal HR (HR_{max}).

Clothing

Each subject was tested wearing two types of clothing - standard light military combat clothing or clothing protecting against nuclear, biological and/or chemical (NBC) agents:

(1) Standard Combat Clothing - underwear, socks, combat shirt and trousers, and leather boots (mass 4.4 kg, insulation 1.4 clo or 0.9 TOG, permeability index 0.44, and pumping coefficient 0.25) or

(2) NBC Protective Clothing - underwear, socks, combat shirt and trousers, NBC overgarment, NBC rubber gloves, leather and rubber boots, and respirator (mass 8.2 kg, insulation 2.5 clo or 1.6 TOG, permeability index 0.19, and pumping coefficient 0.08).

Submaximal exercise

Subjects walked on a motor-driven treadmill at a speed of 4.8

$km \cdot h^{-1}$ and a 2% grade. The heat-exercise tolerance time (HETT) was defined as the time to onset of the first of the following criteria: (1) a rectal temperature (T_{re}) of 39.3°C, (2) a maintained HR ≥ 95% of the subject's previously observed maximum for 3 min, (3) unwillingness of the subject to continue the experiment due to dizziness, nausea or other reasons, or (4) the elapse of 2 h.

Temperature measurements

A computerized data acquisition system (Hewlett-Packard 3497A control unit, 236-9000 computer, and 2934A printer) processed data from rectal and skin temperature sensors recorded at one minute intervals. Rectal temperature (T_{re}) was measured using a flexible vinyl-covered probe (Pharmaseal APC 400 Series) inserted approximately 12 cm above the anal sphincter. Local skin temperatures were measured at 12 sites, using uncovered copper-constantan thermistors (Yellow Springs Instruments thermistor bead 44004). The mean skin temperature ($\overline{T}_{sk}$) was calculated from weighted individual temperatures (Vallerand et al. 1989). Initial and final mean body temperatures ($\overline{T}_b$) during the heat-exercise tolerance test were estimated from T_{re} and $\overline{T}_{sk}$, using equations applicable to thermally neutral ($0.66T_{re} + 0.34\overline{T}_{sk}$) and hot ($0.79T_{re} + 0.21\overline{T}_{sk}$) environments, respectively (Colin et al. 1971).

Heart rate (HR) measurements

HR was monitored utilizing a telemetry unit (Sport Tester) clipped to an elasticized electrode belt that was fitted around the chest. The receiver, taped to the outside of the clothing, provided a continuous display of HR (5 s average) throughout each trial. HR values were recorded every 5 min.

Subjective measurements

Two subjective ratings were completed by the subjects every 10 min. throughout the treadmill walking: (1) rating of perceived exertion (revised RPE scale; Borg 1982) and (2) rating of thermal discomfort (McGinnis RTD scale; Hollies 1977).

Respiratory gas exchange measurements

Open-circuit spirometry was used to determine expired minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), and carbon dioxide output ($\dot{V}CO_2$) during submaximal exercise. An adaptor attached to a low-resistance Hans-Rudolf respiratory valve (for standard combat clothing) or the respirator (for NBC protective clothing) collected expired air at minutes 13-15, 28-30, 43-45, and 58-60 of each hour. Expired gases were directed into a 5-L mixing box and then through an Alpha Technologies VMM 110 Series ventilation module for the determination of $\dot{V}_E$. A sampling line passed dried expired gases to Ametek S-3A O_2 and CD-3A CO_2 analyzers. The ventilation meter was calibrated with a syringe of 2 L volume and the gas analyzers were calibrated using precision-analyzed gas. After analogue-to-digital conversion (Hewlett-Packard 59313A A/D converter), $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, and respiratory quotient (RQ) were calculated and printed on-line every 60 s, using a Hewlett-Packard 9825A microcomputer.

Weight measurements

Subjects were weighed nude (but fitted with the rectal temperature thermistor and connecting cable) and when dressed (also fitted with the rectal probe) before and after heat exposure. The electronic scale (Electroscale Model 921) was sensitive to the nearest 0.01 kg. Assuming that the contribution of insensible perspiration to the weight loss was similar ($0.02\ kg \cdot h^{-1}$; McArdle et al. 1991) for all subjects, the losses due to respiratory evaporation (m_e) and CO_2-O_2 exchange (m_r) were estimated using the equations of Mitchell et al. (1972) and Snellen (1966), respectively. Values for m_e and m_r were subtracted from the nude and dressed weight losses to give sweat production (SP, the sum of sweat evaporated plus sweat still soaking the clothing) and a weight loss due to sweat evaporation (SE) alone. Evaporative efficiency (EE) was calculated as $[(SE \cdot SP^{-1}) \cdot 100]$.

Heat balance analysis

A first estimate of heat storage (S_1) was calculated by the equation of Burton (1935):

$$S_1 = 3.47 \cdot BM \cdot (\Delta\overline{T}_b \cdot \Delta t^{-1}) \cdot A_D^{-1} \qquad \text{(Eq. 2)}$$

where 3.47 is the average specific heat of the body tissues ($kJ \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$); BM is the body mass (kg); $\Delta\overline{T}_b \cdot \Delta t^{-1}$ is the rate of change in mean body temperature ($^{\circ}C \cdot h^{-1}$); and A_D is the DuBois estimate of body surface area (m^2; Dubois and Dubois 1916).

An alternative estimate (S_2) was derived from the heat balance equation (Eq. 1; all units are in $kJ \cdot m^{-2} \cdot h^{-1}$). Metabolic rate (M) was determined by the equation of Gagge and Nishi (1983), using measured $\dot{V}O_2$ and RQ values. External power (W) was calculated from the treadmill speed and slope (Givoni and Goldman 1972). The latent (E_{res}) and dry (C_{res}) components of the respiratory heat exchange were calculated from the metabolic rate, according to the equation presented by Fanger (1970), allowing for the average temperature (38°C) and vapor pressure (49 Torr) in the upper respiratory tract. The latent heat loss from the skin surface (E_{sk}) was calculated from the rate of sweat evaporation ($kg \cdot h^{-1}$):

$$E_{sk} = 2425 \cdot SE \cdot A_D^{-1} \qquad \text{(Eq. 3)}$$

where 2425 is the energy equivalent of sweat evaporated ($kJ \cdot kg^{-1}$). The combination of dry heat gains by radiation and convection (R+C) was predicted by the following equation of Oohori et al. (1984):

$$R + C = (F_{cl} \cdot f_{cl} \cdot h) \cdot (\overline{T}_{sk} - T_a). \qquad \text{(Eq. 4)}$$

F_{cl} is Burton's thermal efficiency factor (non-dimensional), calculated as:

$$F_{cl} = (1 + 0.043 \cdot I_{clo} \cdot f_{cl} \cdot h)^{-1} \qquad \text{(Eq. 5)}$$

in which I_{clo} is the average thermal resistance of the clothing (CLO; 1 clo = 0.043 $m^2 \cdot h \cdot {}^{\circ}C \cdot kJ^{-1}$); f_{cl} is the ratio of the surface area of the clothing layer to the Dubois skin surface area (a value of approximately 1.2 for standard combat clothing and 1.4 for NBC protective clothing; Gagge and Nishi 1983); and h is the combined dry heat transfer coefficient (43.9 $kJ \cdot m^{-2} \cdot h^{-1} \cdot {}^{\circ}C^{-1}$) as described for the nude case by a combination of radiation (h_r, 17.7 $kJ \cdot m^{-2} \cdot h^{-1} \cdot {}^{\circ}C^{-1}$) and convection ($h_c$, 26.2 $kJ \cdot m^{-2} \cdot h^{-1} \cdot {}^{\circ}C^{-1}$). The linear values of h_r (Nishi 1981) and h_c (Nishi and Gagge 1970) can be approximated as:

$$h_r = 4 \cdot \sigma \cdot \varepsilon \cdot [(\bar{T}_{sk} + T_r) \cdot 2^{-1} + 273.15]^3 \cdot (A_r \cdot A_D^{-1}) \quad \text{(Eq. 6)}$$

$$h_c = 23.4 \cdot v_{tw}^{0.39} \quad \text{(Eq. 7)}$$

in which σ is the Stefan-Boltzmann constant ($20.4 \cdot 10^{-8}$ $kJ \cdot m^{-2} \cdot h^{-1} \cdot {}^{\circ}K^{-4}$); ε is the emissivity of the body (1); $\bar{T}_{sk}$ is the average observed mean skin temperature (36°C); T_r is the mean radiant temperature (40°C; T_r = the ambient temperature T_a, given an equal temperature of the chamber wall to the ambient environment); $A_r \cdot A_D^{-1}$ is the ratio of the effective radiating area of the body surface over its Dubois total surface area (a value of $0.72 \cdot A_D$ for A_r of a standing clothed person; Gonzalez 1988); and v_{tw} is the treadmill walking speed ($1.34\ m \cdot s^{-1}$).

Another variable, the dry heat exchange by conductance, was assumed to be negligible, given the small extent of contact between the garment and the skin surface and the minimal difference between the average observed temperatures of skin and clothing surface.

Blood measurements

Blood was sampled by finger prick. The hematocrit (Hct) was measured in duplicate, using a microhematocrit centrifuge. Hemoglobin (Hb) was determined in duplicate by spectrophotometry, cross-checked against the cyanmethemoglobin method, using Coulter 4C Plus cell control standards. Assuming no change of red cell packing with exercise or heat (Plyley et al. 1987), the percentage changes in blood volume (BV), red cell volume (CV), and plasma volume (PV) were calculated from values for Hb and Hct before and after treatment, using the equations of Dill and Costill (1974).

Endurance training program

Following the first two clothing trials, the 7 subjects who had been assigned to the ET group completed an 8-week endurance training program. This consisted of walking and/or running at an intensity ranging from 60 to 80% of $\dot{V}O_{2max}$ for 30 to 45 $min \cdot day^{-1}$, 3 to 4 $days \cdot week^{-1}$. The starting point was determined by each subject's initial aerobic fitness. Both the quality and quantity of exercise were increased progressively throughout the training period. Training was performed on a treadmill or an indoor running track at an ambient temperature not greater than 25°C, and was supervised on one of the 3-4 days each week. The intensity of training was monitored by HR measurements.

Statistics

Data are presented as mean values and standard errors of the mean (SEM). Paired *t*-tests compared pre- and post-treatment anthropometric, physiological, and subjective variables. Differences of sweat rate between pre- and post-treatments were compared before and after covariance adjustment for the confounding variables T_{re} and $\bar{T}_{sk}$. The relationships between RPE and RTD for the two clothing ensembles were tested by linear correlation calculations, including all data points for each subject. A two-factor (subject [averaged over exposure] and treatment) repeated measures analysis of variance analyzed changes in cardiorespiratory and thermoregulatory measures for each type of clothing. When a significant *F* value was obtained for the time x treatment interaction (after adjustment for the repeated measures factor by the Greenhouse-Geisser method), the *post-hoc* Newman-Keuls multiple comparisons procedure was used to locate significant differences. All statistical contrasts were accepted at the 0.05 level of significance.

RESULTS

Subject characteristics

Paired *t*-tests showed no significant changes in anthropometric variables over the 8 weeks of observation (Table 1). The $\dot{V}O_{2max}$ of the ET group significantly increased by 16 ± 3% after training (Table 1), but values for the UT group remained unchanged. The final values for the ET group did not differ significantly from those classed as UT; nevertheless, the responses of the ET group serve to illustrate the impact of participation in an endurance training regimen.

The ET group also developed a small decrease of hematocrit (-

2%; $p < 0.05$) and hemoglobin (-5%; $p = 0.06$) over the 8 week period (Table 2), resulting in a small but significant increase of estimated plasma volume (+8%) and a trend toward an increase of blood volume (+5%; $p = 0.06$), with little change of red cell volume.

Heat-exercise tolerance time

Neither group showed any significant difference in heat-exercise tolerance time over the experiment (Table 3).

Cardiorespiratory variables

Gas exchange variables were unaffected by treatment, except that the UT subjects showed a higher mean RQ when wearing standard combat clothing after control treatment (Table 4).

Pooling data over time, training significantly decreased the overall mean HR by about 18 beats·min^{-1} when wearing standard combat clothing (Figure 1). Furthermore, the average rate of increase in HR over 30 min of chamber exposure was significantly smaller after training. However, the trend to a lower post-training HR (around 7 beats·min^{-1}) throughout the NBC protective clothing trial was not statistically significant. The UT group showed no effect of control treatment on HR.

Rectal and skin temperatures

When wearing standard combat clothing, no treatment effect on T_{re} was observed during the first 40 min of heat exposure (Figure 2), but over longer periods, the rate of increase in T_{re} was slower after training (significantly so at 110 and 120 min). However, when wearing NBC protective clothing, training had no effect on the rate of increase in T_{re}. No significant treatment effects were seen in the UT group.

When the ET subjects were wearing standard combat clothing, there was an insignificant trend toward a lower $\overline{T}_{sk}$ after 50 min of exercise (Figure 3). In contrast, the $\overline{T}_{sk}$ in the first 15 min of the NBC protective clothing trial was significantly higher after training, but there was no treatment effect thereafter. The initial increase of $\overline{T}_{sk}$ after treatment resulted in a significant overall increment of $\overline{T}_{sk}$ (approximately 0.5°C) for the exposure. Control treatment had no significant effect on $\overline{T}_{sk}$ in the UT group.

Relative work load and subjective ratings

In the ET group, endurance training significantly decreased the relative work intensity (RWI) during both standard combat clothing (-7%) and NBC protective clothing (-8%) trials (Table 5), but RPE was significantly lower (-24%) only when wearing normal combat clothing. Perhaps because of habituation to the test environment, the UT group showed a significant decrease in RTD when wearing standard combat clothing during the post-control trial.

RPE and RTD were closely correlated in all conditions. Correlation coefficients for the ET group were 0.91 ± 0.03 (pre-treatment) and 0.83 ± 0.07 (post-treatment) when wearing standard combat clothing and 0.85 ± 0.09 (pre) and 0.94 ± 0.02 (post) when wearing NBC protective clothing. In the UT group, the corresponding values were 0.84 ± 0.03 (pre) and 0.75 ± 0.10 (post) when wearing standard combat clothing and 0.92 ± 0.02 (pre) and 0.93 ± 0.02 (post) when wearing NBC protective clothing.

Sweat data

There was an insignificant trend to a training-induced increase in sweat production (+9%) with a decrease in evaporative efficiency (-3%) when wearing standard combat clothing (Table 6). The unadjusted between-treatment difference of mean sweat production of 0.07 $kg \cdot h^{-1}$ was increased to an adjusted value of 0.09 $kg \cdot h^{-1}$ after covariance adjustment for changes in the central and peripheral sweating drive, although our data were insufficient to test the linearity of these effects (Table 7). Training significantly increased sweat production during the NBC protective clothing trial (+19%), but this benefit was offset by a significantly decreased evaporative efficiency (-4%), so that there was no change in sweat evaporation. The unadjusted difference of sweat production (0.22 $kg \cdot h^{-1}$) was reduced to 0.16 $kg \cdot h^{-1}$ by covariance adjustment for central and peripheral sweating drive, although unfortunately the data were insufficient to test the linearity of these effects. There were no significant changes in sweat production or evaporative efficiency for the UT group.

Heat balance

Training significantly decreased S_1 (-13%) when wearing standard combat clothing and R+C (-16%) when wearing NBC protective clothing (Table 8). Apparent changes in S_2 (-28%) and E_{sk} (+5%) when wearing standard combat clothing were not statistically significant. The UT group showed no significant treatment effects.

DISCUSSION

An 8-week endurance training program decreased both physiological (HR, T_{re}, and $\bar{T}_{sk}$) and psychological stresses (RPE and RTD) when wearing standard combat clothing, but it had little effect when wearing NBC protective clothing.

A number of factors adversely affect exercise tolerance when wearing NBC protective clothing. Perhaps the most important are the vapor permeability and insulative characteristics of the clothing ensemble. An extra load is also imposed by the mass of the protective equipment (Duggan 1988), the effect of which depends on the distribution of the added mass (Soule and Goldman 1969). Other negative influences are the hobbling effect of multilayered clothing (Teitlebaum and Goldman 1972) and the added respiratory resistance and external dead space imposed by the respirator (Louhevaara 1984). In the present study, the NBC protective ensemble increased metabolism by about 12% (9-14%), relative to lightly clothed subjects exercising at the same speed and grade.

Endurance training normally increases plasma volume (Harrison 1985; Fellmann 1992), augmenting the overall cardiac output and skin blood flow, and allowing a greater sweat production. However, our heart rate data suggest that the tendency to plasma volume expansion had less impact upon circulatory function with NBC protective clothing than when wearing standard combat clothing. Hydration status has a major influence upon the performance of muscular exercise in hot environments (Sawka 1988). Our subjects were not allowed to drink water, and it was thus critical to their performance that the body made effective use of secreted sweat. When wearing NBC protective clothing, they faced the negative circulatory consequences of a larger increase (+19%) in sweat rate than that (+9%) which occurred in the standard combat clothing trial.

Thermoregulatory responses can normally be correlated with an appropriately weighted combination of core temperature (for example, rectal, tympanic membrane or esophageal temperature) and mean skin temperature (Sawka and Wenger 1988). Since the body has only a very limited ability to store heat, the ability to sustain vigorous exercise in a hot environment depends upon a matching of sweat production with the total amount of heat (H) to be dissipated, calculated by algebraic summation of metabolic heat production (M) and external work (W), that is, $H = M \pm W$ (Nielsen 1969). The 8 weeks of endurance training induced little change in metabolic heat production, in agreement with the majority of research literature (Sawka et al. 1983) and external work, also, was unchanged. Thus, the training-induced increase of sweat rate reflects an enhanced sensitivity of the sweat glands to a given thermal stimulus (Nadel et al. 1974), rather than any alteration in the amount of heat to be dissipated. When wearing the NBC protective clothing, a further factor is an earlier and larger increase of $\overline{T}_{sk}$; this may reflect some increase of skin blood flow, augmenting the rate of convective heat transfer from the deep body tissues to the skin and at the same time reducing heat gains by radiation and convection. In the untrained subjects, circulatory regulation probably took precedence over temperature regulation (Nadel et al. 1979), so that skin blood flow was relatively small during the early part of heat exposure. After training, it was likely easier for them to maintain cardiac filling, cardiac output, and arterial pressure in the face of heat-exercise stress, cutaneous vasodilatation and a sweating-induced decrease of plasma volume.

The training-induced increase of sweat secretion did not yield a proportional increase of sweat evaporation, because evaporative efficiency decreased. However, when wearing the standard combat clothing, there was a slight trend to an increase in the total volume of sweat evaporated ($\approx$ 0.03 $kg \cdot h^{-1}$), facilitating heat dissipation. As a result, the rate of elevation in T_{re}, $\overline{T}_{sk}$, and thus $\overline{T}_b$ was slowed, $\Delta\overline{T}_b \cdot \Delta t^{-1}$ being approximately 0.2 $^\circ C \cdot h^{-1}$ less after training. In rough accordance with this, resolution of the heat balance equation indicated a total decrease in body heat storage of 45 $kJ \cdot m^{-2} \cdot h^{-1}$ (S_2), corresponding to a $\Delta\overline{T}_b \cdot \Delta t^{-1}$ value of approximately 0.3 $^\circ C \cdot h^{-1}$ (45 $kJ \cdot m^{-2} \cdot h^{-1} \div 140$ $kJ \cdot m^{-2} \cdot {}^\circ C^{-1}$). The lower post-training values of $\overline{T}_b$ (T_{re} and $\overline{T}_{sk}$) during the standard combat clothing trial could have arisen largely from a 5 % increase in evaporative heat loss from the skin (E_{sk}, -33 $kJ \cdot m^{-2} \cdot h^{-1}$) and a small decrease in metabolic cost (M, -13 $kJ \cdot m^{-2} \cdot h^{-1}$). These findings lead to speculation that training might help the cooling process in a subject who was wearing NBC protective clothing, if a longer time allowed a greater permeation and evaporation of any additional sweat that was secreted. Depending on the eventual ratio of evaporative heat loss to heat gained from other sources, individuals who must wear NBC protective clothing in the heat might profit from short work periods, with frequent and prolonged rest periods to allow sweat evaporation.

Many formulae have been proposed to estimate $\overline{T}_b$ from measurements of skin and core temperature, but no one formula seems to remain valid under all conditions and for all species (Bligh and Johnson 1973). Based on a comparison of the estimated change in heat storage and the change of $\overline{T}_b$ as calculated by the classical coefficients, Colin et al. (1971) presented the following equation to estimate the change of $\overline{T}_b$ in resting subjects at ambient temperatures from 30 to 45°C:

$$\Delta\overline{T}_b = 0.8 \cdot \Delta T_{re} + 0.2 \cdot \Delta\overline{T}_{sk} + 0.4 \qquad \text{(Eq. 8)}$$

The introduction of the constant 0.4 implies that $\overline{T}_b$ cannot be calculated from fixed coefficients and measurements of T_{re} and $\overline{T}_{sk}$ alone. Problems arise because of the sluggish variation of T_{re} and the fact that T_{re} is not always representative of temperatures in other deep tissues such as the aorta and the active muscles (Snellen 1966). Colin et al. (1971) pointed out that the common practice of using invariant coefficients when the body passes from a neutral environment to a hot one leads to an underestimation of the change in $\overline{T}_b$; it is for this reason that the constant of 0.4 is introduced. Alternatively, the change in $\overline{T}_b$ could be estimated by formulae with differing coefficients; for instance, some have used final weightings of 0.9 and 0.1 when exercising in the heat (Shvartz et al. 1977). The minor difference (-9%; -78 to -20 $kJ \cdot m^{-2} \cdot h^{-1}$) between our two estimates of heat storage (S_1 and S_2)

suggests the general appropriateness of the two sets of weighting factors proposed by Colin and co-workers (0.66, 0.34; 0.79, 0.21) when exercising in NBC protective clothing. The slight underestimate given by S_1 may relate to heat-exercise tolerance times that were shorter than 60 min; ΣT_{re} may thus have yielded less than the equilibrium values that would have been seen in a longer experiment.

In contrast, the discrepancy between S_1 and S_2 when wearing standard combat clothing was substantial (+40%; 39 to 72 $kJ \cdot m^{-2} \cdot h^{-1}$). Latent heat loss from the skin surface (E_{sk}) was determined from clothed weight loss (calculated by weighing the clothed subject before and after heat exposure). This procedure assumes that all secreted sweat either evaporates or is retained by the clothing, thus ignoring the possibility of external dripping. Goldman (1985) has indicated that at a 60% level of skin-wettedness, sweat frequently drips from the skin unless the ambient vapor pressure is low, the subject is wearing minimal clothing and/or there is a high rate of air movement. In the present investigation, the dripped sweat was not quantified. Nunneley (1989) has further suggested that sweat must be vaporized at the skin for a maximal cooling effect. Evaporation from clothing limits body cooling, because the site of the phase change is remote from the skin and much of the heat comes from the environment rather than the body (Craig and Moffitt 1974). Thus, significant dripping plus evaporation from clothing rather than skin ($\approx$ 0.05 $kg \cdot h^{-1}$) may explain why S_2 is smaller than S_1 when wearing standard combat clothing. In the NBC protective clothing ensemble, dripped sweat probably accumulated inside the garment and was included in the final weight. Finally, the coefficients proposed by Colin et al. (1971) may be more appropriate to the NBC protective clothing than to the standard clothing condition.

The relative work intensity is a critical determinant of perceptual ratings (Sargeant and Davies 1973), although numerous other physiological and neuromuscular responses to exercise have been proposed as the primary sensory input underlying the perception of effort (Mihevic 1981). Endurance training increased the original $\dot{V}O_{2max}$ by about 16%, so that the relative intensity of the treadmill walk decreased significantly (from 45% to 38% of $\dot{V}O_{2max}$ when wearing standard combat clothing and from 51% to 43% of $\dot{V}O_{2max}$ when wearing NBC protective clothing). When wearing standard combat clothing, there was a significant decrease in ratings of perceived exertion after training, probably reflecting a 6% trend to a decrease in thermal strain. However, endurance training in relatively cool environments (< 25°C) had only a minor impact on the psychological burden imposed by wearing NBC protective clothing in the hot environment; preparation for exercise under hot conditions requires training in a hot environment.

CONCLUSIONS

Conclusions are limited by the lack of a significant difference of post-training $\dot{V}O_{2max}$ from values observed in the untrained subjects. Nevertheless, participation in an endurance training program under cool conditions apparently does little to improve exercise tolerance when wearing NBC protective clothing in the heat. The explanation seems a lack of evaporation of any increase in sweat volume when working, due to the low vapor permeability of the clothing ensemble. Exercise tolerance in the heat might still be improved, if the individuals were first trained in a hot environment and then worked at a lower intensity and for a longer duration so that sweat could permeate their NBC protective clothing.

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Table 1. Physical characteristics and maximal aerobic power ($\dot{V}O_{2max}$) of subjects before and after endurance training (ET) or control (UT) treatments

Group	Condition	Age (yr)	Height (cm)	Body Mass (kg)	A_D (m^2)	$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
UT	Pre-control	25±1	176±2	83.6±3.8	2.00±0.05	43.9±1.7
	Post-control	25±1	176±2	84.4±4.1	2.01±0.05	45.1±1.5
ET	Pre-training	31±1	176±1	79.3±4.1	1.96±0.04	39.9±1.7
	Post-training	31±1	176±1	79.2±3.9	1.96±0.04	46.3±2.3*

Values are means ± SEM. n = 9 for the UT group and n = 7 for the ET group. A_D, DuBois body surface area. *, significantly different from pre-training value ($p < 0.05$).

Table 2. Observations on the blood of subjects before and after endurance training (ET) or control (UT) treatments

Group	Condition	Hct (%)	Hb ($g \cdot 100\ mL^{-1}$)	ΔBV (%)	ΔPV (%)	ΔCV (%)
UT	Pre-control	49.0±0.7	17.3±0.3			
	Post-control	48.8±0.6	17.3±0.3	0.2±1.0	0.6±1.5	-0.1±1.5
ET	Pre-training	47.8±0.9	17.2±0.4			
	Post-training	46.4±0.6*	16.3±0.3	5.1±2.2	8.0±2.3*	2.2±2.5

Values are means ± SEM. n = 9 for the UT group and n = 7 for the ET group. Hct, hematocrit; Hb, hemoglobin; ΔBV, blood volume changes; ΔPV, plasma volume changes; and ΔCV, red cell volume changes.

*, significantly different from pre-training value ($p < 0.05$).

Table 3. Heat-exercise tolerance time (HETT) and reasons for test termination. Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing					
		HETT		Reason for test termination			
		(min)		HR	RT	SD	TL
UT	Pre-control	116±3	(92-120)	1	1	0	7
	Post-control	117±3	(95-120)	0	2	0	7
ET	Pre-training	119±1	(113-120)	0	0	1	6
	Post-training	120±0		0	0	0	7

Group	Condition	NBC Protective Clothing					
		HETT		Reason for test termination			
		(min)		HR	RT	SD	TL
UT	Pre-control	50±3	(39- 68)	5	2	2	0
	Post-control	48±2	(34- 60)	4	0	5	0
ET	Pre-training	51±2	(45- 60)	2	1	4	0
	Post-training	48±2	(40- 56)	2	2	3	0

Values for "HETT" are means ± SEM, with range of observations in parentheses. Figures for "Reason for test termination" are the number of subjects. n = 9 for the UT group and n = 7 for the ET group. HR, heart rate (≥ 95% HR_{max} for 3 min); RT, rectal temperature (39.3°C); SD, subject's desire; and TL, time limit (120 min).

Table 4. Respiratory gas exchange measurements. Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing			
		$\dot{V}_E$ ($L \cdot min^{-1}$)	$\dot{V}O_2$ ($L \cdot min^{-1}$)	$\dot{V}CO_2$ ($L \cdot min^{-1}$)	RQ
UT	Pre-control	28.9±1.4	1.46±0.07	1.17±0.05	0.80±0.01
	Post-control	30.0±1.9	1.43±0.07	1.21±0.06	0.85±0.02*
ET	Pre-training	29.7±1.2	1.41±0.06	1.19±0.04	0.85±0.01
	Post-training	28.8±1.7	1.36±0.05	1.15±0.04	0.85±0.02

Group	Condition	NBC Protective Clothing			
		$\dot{V}_E$ ($L \cdot min^{-1}$)	$\dot{V}O_2$ ($L \cdot min^{-1}$)	$\dot{V}CO_2$ ($L \cdot min^{-1}$)	RQ
UT	Pre-control	33.0±2.4	1.54±0.10	1.32±0.07	0.86±0.01
	Post-control	34.9±1.3	1.57±0.07	1.35±0.06	0.86±0.01
ET	Pre-training	35.6±2.0	1.59±0.07	1.41±0.06	0.89±0.01
	Post-training	36.5±2.2	1.56±0.07	1.40±0.08	0.90±0.02

Values are means ± SEM, observed during 90-120 min in standard combat clothing and 30-45 min in NBC protective clothing. $n = 9$ for the UT group and $n = 7$ for the ET group. $\dot{V}_E$, expired minute ventilation; $\dot{V}O_2$, oxygen consumption; $\dot{V}CO_2$, carbon dioxide production; and RQ, respiratory quotient. *, significantly different from pre-control value ($p < 0.05$).

Table 5. Work intensity relative to maximal aerobic power (RWI) and subjective ratings of perceived exertion (RPE) and thermal discomfort (RTD). Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing		
		RWI (%)	RPE	RTD
UT	Pre-control	40.2±1.5	3.0±0.4	8.9±0.3
	Post-control	38.0±1.0	3.1±0.3	8.2±0.3*
ET	Pre-training	45.1±1.5	3.7±0.5	8.8±0.4
	Post-training	37.8±1.9*	2.8±0.4*	8.3±0.2

Group	Condition	NBC Protective Clothing		
		RWI (%)	RPE	RTD
UT	Pre-control	42.1±1.6	3.5±0.3	8.9±0.3
	Post-control	41.6±0.8	3.9±0.2	8.9±0.4
ET	Pre-training	50.7±1.8	3.7±0.3	9.3±0.2
	Post-training	43.1±1.5*	3.2±0.2	8.9±0.1

Values are means ± SEM. n = 9 for the UT group and n = 7 for the ET group. *, significantly different from pre-treatment value ($p < 0.05$).

Table 6. Sweat data. Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing		
		SP ($kg \cdot h^{-1}$)	SE ($kg \cdot h^{-1}$)	EE (%)
UT	Pre-control	0.79±0.06	0.60±0.04	76.5±1.9
	Post-control	0.75±0.05	0.58±0.03	78.8±2.2
ET	Pre-training	0.76±0.06	0.58±0.03	76.8±2.3
	Post-training	0.83±0.07	0.61±0.04	74.2±2.3

Group	Condition	NBC Protective Clothing		
		SP ($kg \cdot h^{-1}$)	SE ($kg \cdot h^{-1}$)	EE (%)
UT	Pre-control	1.09±0.10	0.29±0.01	28.5±2.3
	Post-control	1.07±0.13	0.28±0.02	29.0±3.5
ET	Pre-training	1.16±0.20	0.26±0.01	25.3±3.5
	Post-training	1.38±0.19*	0.26±0.01	21.0±2.6*

Values are means ± SEM. n = 9 for the UT group and n = 7 for the ET group. SP, rate of sweat production; SE, rate of sweat evaporation; and EE, evaporative efficiency. *, significantly different from pre-training value ($p < 0.05$).

Table 7. Sweat rate, unadjusted and adjusted for rectal temperature (T_{re}) and mean skin temperature ($\bar{T}_{sk}$). Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing			
		SP ($kg \cdot h^{-1}$)	SP_{adj} ($kg \cdot h^{-1}$)	T_{re} (°C)	$\bar{T}_{sk}$ (°C)
UT	Pre-control	0.79±0.06	0.78±0.06	38.1±0.1	36.0±0.1
	Post-control	0.75±0.05	0.76±0.06	38.0±0.1	36.1±0.1
	Δ	-0.04	-0.02	-0.1	+0.1
ET	Pre-training	0.76±0.06	0.75±0.03	38.1±0.1	36.0±0.1
	Post-training	0.83±0.07	0.84±0.03	38.0±0.1	35.9±0.2
	Δ	+0.07	+0.09	-0.1	-0.1

Group	Condition	NBC protective Clothing			
		SP ($kg \cdot h^{-1}$)	SP_{adj} ($kg \cdot h^{-1}$)	T_{re} (°C)	$\bar{T}_{sk}$ (°C)
UT	Pre-control	1.09±0.10	1.08±0.13	37.9±0.1	36.3±0.1
	Post-control	1.07±0.13	1.07±0.13	37.8±0.1	36.4±0.1
	Δ	-0.02	-0.01	-0.1	+0.1
ET	Pre-training	1.16±0.20	1.19±0.19	37.7±0.1	35.9±0.2
	Post-training	1.38±0.19	1.35±0.19	37.8±0.1	36.4±0.2
	Δ	+0.22*	+0.16	+0.1	+0.5*

Values are means ± SEM. n = 9 for the UT group and n = 7 for the ET group. SP, unadjusted sweat production and SP_{adj}, sweat production adjusted for the average T_{re} and $\bar{T}_{sk}$ observed during mean exposure time of 112 min (range: 90-120 min) in standard combat clothing and mean exposure time of 44 min (range: 30-50 min) in NBC protective clothing for the UT group and mean exposure time of 119 min (range: 110-120 min) in standard combat clothing and mean exposure time of 45 min (range: 40-55 min) in NBC protective clothing for the ET group. *, significant differences between pre- and post-training ($p < 0.05$).

Table 8. Energy balance data. Subjects wearing standard combat clothing and NBC protective clothing before and after endurance training (ET) or control (UT) treatments

Group	Condition	Standard Combat Clothing							
		S_1	S_2	M	W	E_{res}	C_{res}	E_{sk}	R+C
UT	Pre-control	213±12	156±25	882±23	41±1	-56±1	7±0	-689±33	52±1
	Post-control	205±11	166±19	873±26	41±1	-55±2	7±0	-668±30	50±2
ET	Pre-training	217± 6	161±15	882±22	40±1	-56±1	7±0	-684±31	52±2
	Post-training	188±10*	116±24	869±23	40±1	-55±1	7±0	-717±36	52±2

Group	Condition	NBC Protective Clothing							
		S_1	S_2	M	W	E_{res}	C_{res}	E_{sk}	R+C
UT	Pre-control	504±18	524±39	957±32	43±1	-60±2	8±0	-359±16	22±1
	Post-control	487±20	544±26	961±18	43±1	-61±1	8±0	-342±18	21±1
ET	Pre-training	549±17	612±19	999±28	42±1	-63±2	8±0	-316±12	25±1
	Post-training	505±21	583±25	986±31	42±1	-62±2	8±0	-328±16	21±1*

Values are means ± SEM in $kJ \cdot m^{-2} \cdot h^{-1}$. n = 9 for the UT group and n = 7 for the ET group. S_1 and S_2, rates of heat storage (estimated by the predictive equation and by resolving the heat balance equation, respectively); M, metabolic rate; W, external work rate; E_{res}, rate of evaporative heat loss from the respiratory tract; C_{res}, rate of convective heat gain through the respiratory tract; E_{sk}, rate of evaporative heat loss from the skin through the clothing; and R+C, rate of dry (radiative and convective) heat gain through the clothed skin. *, significantly different from pre-training value ($p < 0.05$).

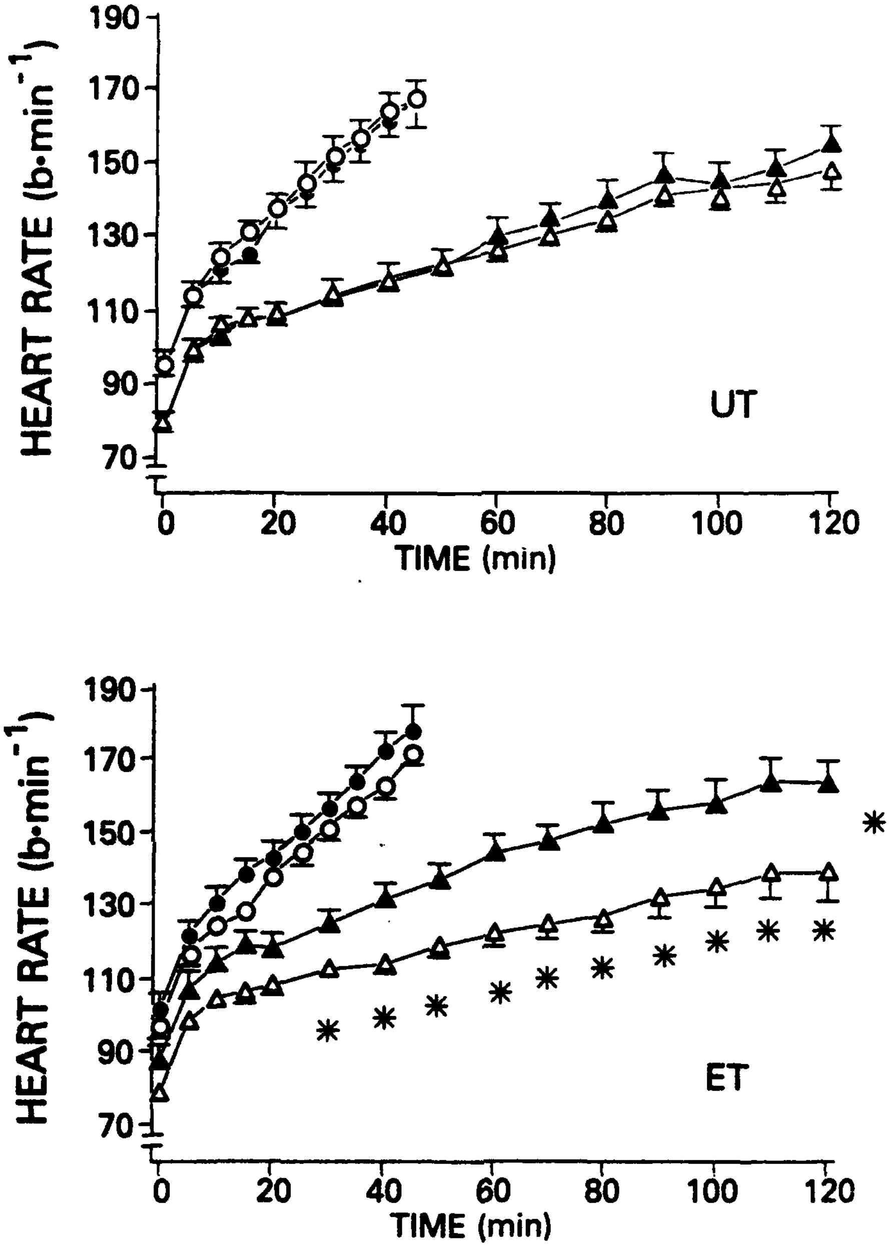

Figure 1. Changes in heart rate during treadmill walking at 40°C. Subjects wearing standard combat clothing (triangles) and NBC protective clothing (circles) before (filled) and after (unfilled) endurance training (ET) or control observation (UT). For the UT group, n = 9 until 90 min; n = 7 at 100 and 110 min; and n = 6 at 120 min for the standard combat clothing trial and n = 9 until 30 min; n = 8 at 35 and 40 min; and n = 6 at 45 min for the NBC protective clothing trial. For the ET group, n = 7 until 110 min and n = 6 at 120 min for the standard combat clothing trial and n = 7 until 40 min and n = 5 at 45 min for the NBC protective clothing trial. *, significant differences between pre- and post-training ($p < 0.05$).

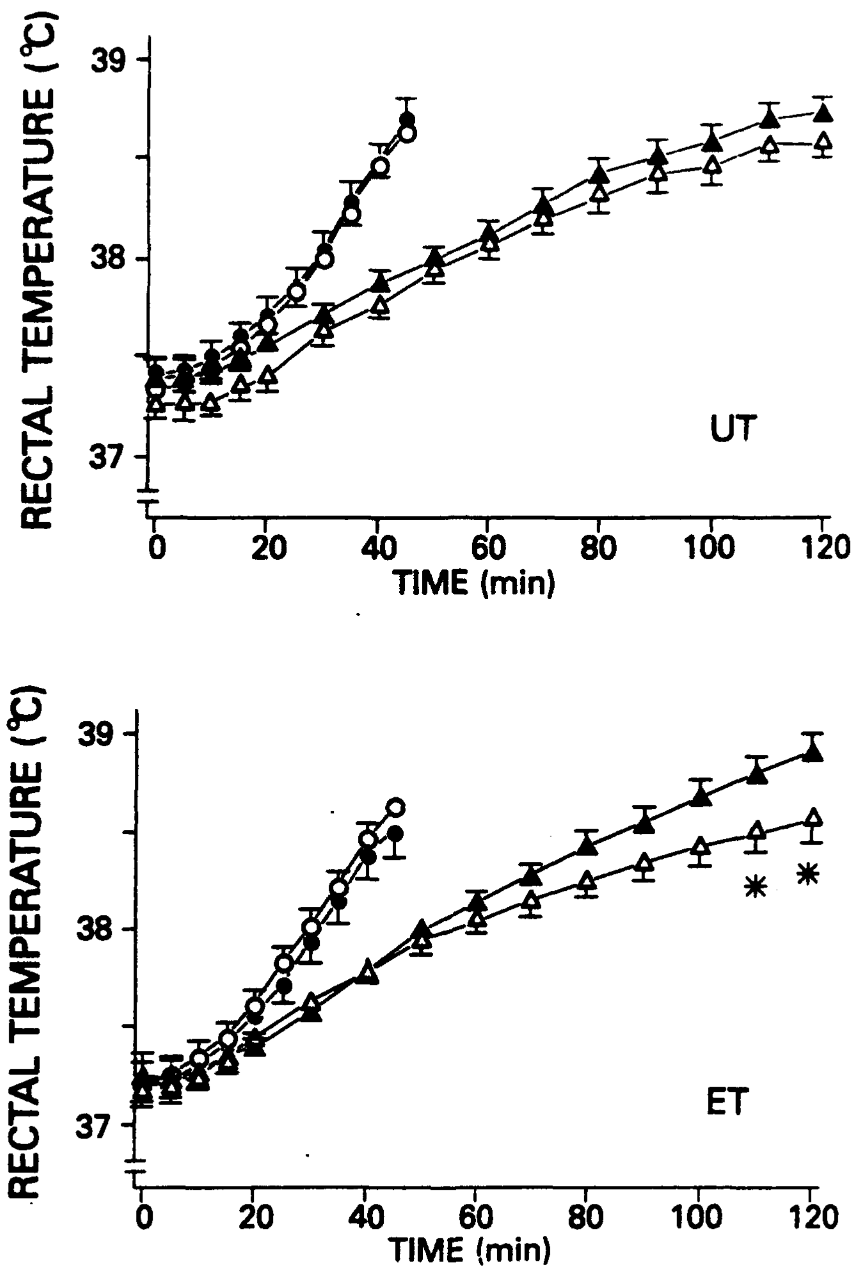

Figure 2. Changes in rectal temperature during treadmill walking at 40°C. Subjects wearing standard combat clothing (triangles) and NBC protective clothing (circles) before (filled) and after (unfilled) endurance training (ET) or control observation (UT). Subject numbers and symbols for statistical differences are as in Figure 1.

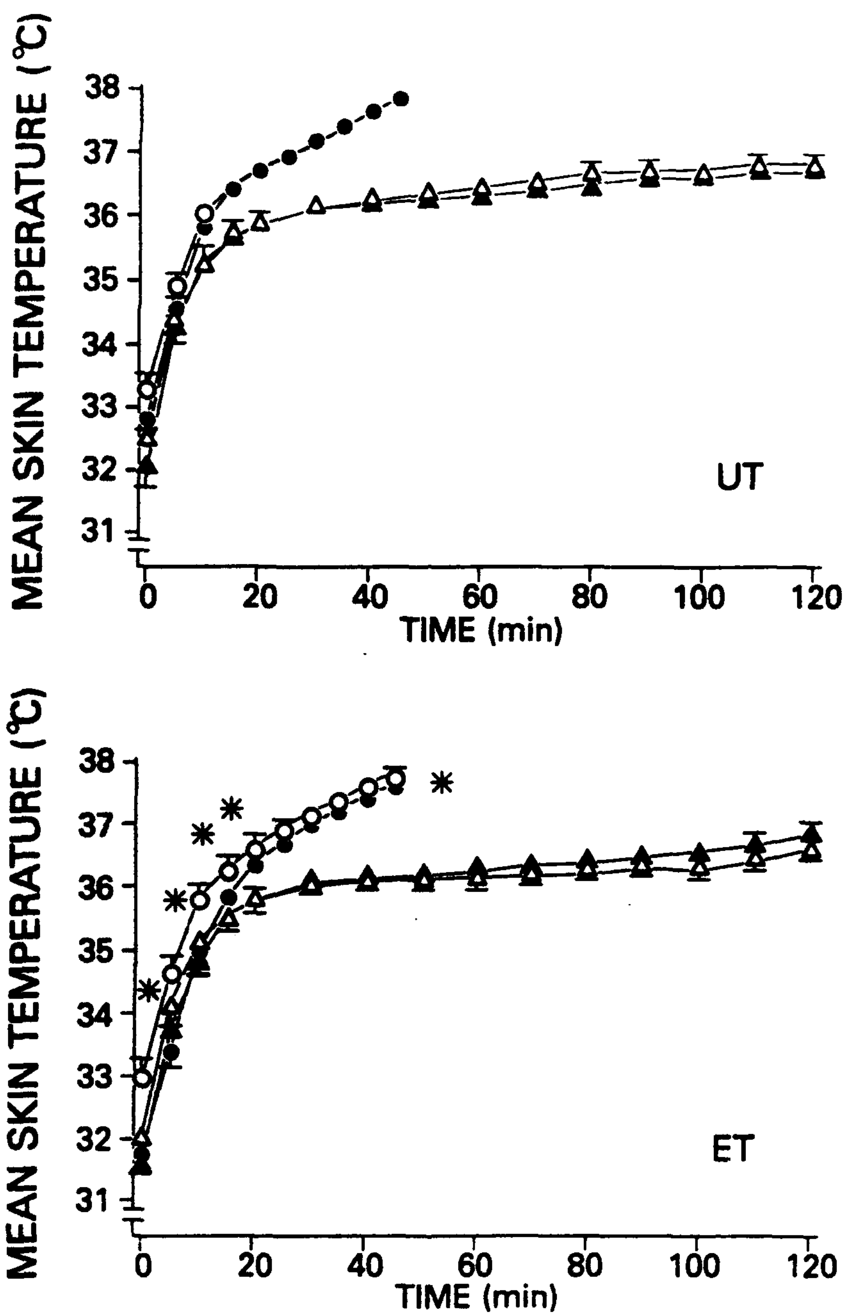

Figure 3. Changes in mean skin temperature during treadmill walking at 40°C. Subjects wearing standard combat clothing (triangles) and NBC protective clothing (circles) before (filled) and after (unfilled) endurance training (ET) or control observation (UT). Subject numbers and symbols for statistical differences are as in Figure 1.

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Sixteen unacclimatized males (27 ± 1 yr, 1.76 ± 0.01 m, 82 ± 3 kg) were assigned to either an 8-week treatment of endurance training (n = 7) or control (n = 9). The training program consisted of four 45-min running sessions per week at 80% of maximal aerobic power ($\dot{V}O_{2max}$), performed at < 25°C. Subjects were tested before and after treatment wearing either standard military combat clothing (4.4 kg, 1.4 clo) or nuclear, biological and/or chemical (NBC) protective clothing (8.2 kg, 2.5 clo). Test sessions involved treadmill walking at 4.8 $km \cdot h^{-1}$ and 2% grade in a climatic chamber maintained at 40 ± 0.5°C and 30 ± 1% rh. The heat-exercise tolerance time (HETT) was defined as the time to the first of: (1) a rectal temperature (T_{re}) of 39.3°C, (2) a heart rate (HR) ≥ 95% of the subject's observed maximum for 3 min, (3) unwillingness of the subject to continue, or (4) elapse of 2 h. Endurance training increased $\dot{V}O_{2max}$ (39.9 ± 1.7 vs. 46.3 ± 2.3 $mL \cdot kg^{-1} \cdot min^{-1}$) and plasma volume (+8 ± 2%), but HETT was unchanged in either clothing ensemble. When wearing standard combat clothing, training slowed the rate of increase in HR and T_{re}, and decreased mean subjective rating of perceived exertion, with a trend to decreased mean skin temperature ($\bar{T}_{sk}$). When wearing NBC protective clothing, in contrast, the only significant change was a higher post-training $\bar{T}_{sk}$. A training-induced increase of sweat secretion in NBC protective clothing (1.16 ± 0.20 vs. 1.38 ± 0.19 $kg \cdot h^{-1}$) and a parallel but non-significant trend in standard combat clothing (0.76 ± 0.06 vs. 0.83 ± 0.07 $kg \cdot h^{-1}$) were not accompanied by any statistically significant increase in sweat evaporation. Evaporative efficiency thus tended to decrease (25.3 ± 3.5 vs. 21.0 ± 2.6% in NBC protective clothing; $p < 0.05$ and 76.8 ± 2.3 vs. 74.2 ± 2.3% in standard combat clothing; NS). The results suggest that endurance training in a relatively cool environment has little effect on the physiological and psychological stresses imposed by wearing NBC protective clothing in hot environments, because added sweat secretion decreases blood volume and increases discomfort without augmenting body cooling.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Sweat production, Sweat evaporation, Rectal temperature, Skin temperature, Heart rate, Blood volume, Discomfort, Metabolic rate, Prolonged work