HEAT STRAIN IN CLOTHED, HYPOHYDRATED PERSONNEL

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INTRODUCTION

Factors that enhance heat gain (e.g., physical exercise) or that reduce heat loss (e.g., clothing) affect heat balance. Heat strain therefore arises from different combinations of work rate, clothing and environmental conditions and results in a rise in deep-body and skin temperatures. The resultant sweating may lead to hypohydration. Sweatrate is lower in hypohydrated individuals, which may compromise their ability to thermoregulate by evaporative cooling. The situation is further exacerbated because clothing impedes the evaporation of sweat and consequently reduces the evaporative cooling available. There are few data on the effect of hypohydration on thermoregulation in clothed individuals, especially in conditions in which evaporative cooling is essential to maintain thermal balance.

METHODS

Overview. Heat strain was measured in subjects who undertook a "work-in-heat" test in a climatic chamber on 4 occasions. For 2 of the tests, subjects wore British Army combat clothing; for the other 2 they wore British Forces chemical protective clothing over combat clothing. During 1 test in each clothing condition, subjects were fully hydrated; in the other test they were acutely dehydrated by 2.5% of body weight. The experiment was approved by the local Ethics Committee.

Subjects. The anthropometric details of the 8 male subjects were as follows: mean age 26.0 (1 standard deviation = 3.1) years; height 1.76 (0.08) m; weight 76.7 (8.9) kg; DuBois surface area 1.93 (0.2) m^2; Dumin and Womersley body fat 14.5 (5.0) %.

Clothing. British Army combat clothing: a single layer of clothiig over underwear: total weight = 4.7 (0.3) kg; ratio of Woodcock Moisture Permeability Index (i_m) to total clothing insulation (IT) = 0.44 (airspeed = 1.1 $m \cdot s^{-1}$). Chemical protective clothing: multi-layered, charcoal-impregnated garments, covering the torso, head, arms and legs, plus respirator, rubber gloves and boots; total weight (includes combat clothing) = 8.8 (0.3) kg; ratio of i_m to I_T = 0.17 (airspeed = 1.1 $m \cdot s^{-1}$).

Environmental conditions. Dry-bulb temperature = globe temperature = 35°C; relative humidity = 50%; airspeed = 1.1 $m \cdot s^{-1}$; wet-bulb globe temperature (WBGT) index = 29°C.

Exercise. Treadmill walk at 4.8 $km \cdot h^{-1}$, 0% incline, for 100 min maximum (mean measured oxygen consumption was about 1 $L \cdot min^{-1}$, 160 $W \cdot m^{-2}$).

Heat strain: Heat strain was measured during the tests by recording deep-body (rectal) temperature, Ramanathan 4-point mean **skin** temperature and total water loss. The ratio water evaporated to total water loss (E/P %) was calculated from nude and clothed weights before and after the tests, adjusted for urine voided. Heart rates were recorded for safety reasons but are not reported here. Exercise tolerance time was recorded as the time to volitional withdrawal or to reaching a rectal temperature of 39.0°C or heart rate of 180 bpm.

Hydration levels. Hydration levels were adjusted as follows: during the morning before each of the **4** afternoon "work-in-heat" tests, subjects exercised wearing cotton shorts and T-shirt in the experimental conditions described above. Subjects were weighed at 15-min intervals and were removed from the chamber when they had lost 2.5% of their starting body weight. "Hydrated" subjects only were rehydrated to their starting body weight by drinking water immediately (i.e., 2 h before the afternoon test). Subjects did not *drink* during either the morning exposure or the afternoon test.

Data analysis. Data are expressed **as** mean (1 standard deviation). ANOVA tests were performed and statistical significance was accepted at $P < 0.05$.

RESULTS

Rectal temperature. Figure 1 shows that when the subjects wore combat clothing alone, rectal temperature rose to steady-state values. In hydrated subjects this plateau value was 37.8 (0.39)°C, but in hypohydrated subjects the heat strain was significantly greater, with a mean rectal temperature of 38.4 (0.25)°C. When the subjects wore chemical protective clothing in addition to combat clothing, mean rectal temperature rose steadily throughout the exposure, never reaching a steady-state value. Dehydration had no significant effect on this response.

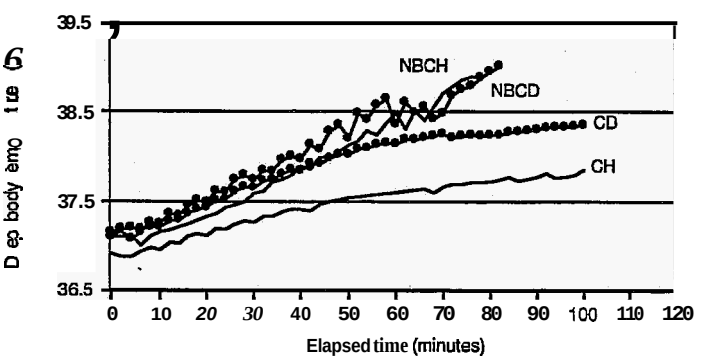

Figure 1. The effects of 2.5% hypohydration on exercise rectal temperature.
CH = Combat clothing/dehydrated;
CD(•) = Combat clothing hypohydrated;
NBCH = Combat clothing + chemical protective clothing/dehydrated;
NBCD(•) = Combat clothing + chemical protective clothing/hypohydrated

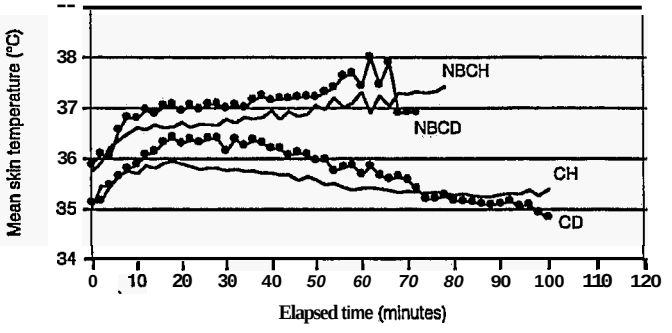

Figure 2. The effects of 2.5% hypohydration on exercise mean skin temperature

CH = Combat clothing/hydrated;
CD(•) = Combat clothing hypohydrated;
NBCH = Combat clothing + chemical protective clothing/hydrated;
NBCD(•) = Combat clothing + chemical protective clothing hypohydrated

Mean skin temperature. When wearing chemical protective clothing, the subjects began the tests with a mean skin temperature about 0.6°C higher than when wearing combat clothing alone (Figure 2). This was due to the higher insulation and/or the lower water vapor permeability of the chemical protective garments, which resulted in a lower heat loss during the dressing phase.

At the beginning of the "work-in-heat" test, the mean skin temperatures in all dress and hydration states rose sharply for the first 10 to 15 min. The responses after this initial rise depended on the type of clothing worn. The mean skin temperature **of** the subjects wearing combat clothing alone gradually declined for the remainder of the test. Hypohydration had no effect on this response. The progressive reduction in skin temperature shows that the high evaporation through the clothing cooled the skin, allowing the rectal temperature to reach a steady-state value. When subjects wore chemical protective clothing, mean skin temperature remained at constant levels for most of the test and then rose slightly towards the end. The state of hydration did not affect the response.

Exercise tolerance time. All subjects wearing combat clothing alone achieved the 100-min exercise duration. When wearing chemical protective clothing, tolerance time was ***59*** min when hydrated, but 19% less when hypohydrated.

Total water loss and evaporative cooling. Table **1** shows that in both clothing states hypohydration reduced total water loss but did not influence the E/P ratio. This indicates that clothing was the major factor influencing evaporative cooliig.

Table 1. The effect of 2.5% hypohydration on water loss and evaporative cooling during exercise

	Mean water produced (P) $g \cdot hour^{-1}$	Mean water evaporated (E) $g \cdot hour^{-1}$	Mean E/P %
Combat clothing			
• hydrated	1140 (240)	730 (90)	66 (10)
• hypohydrated	1060 (240)	710 (150)	67 (8)
Combat clothing.+ chemical protective clothing			
• hydrated	1220 (380)	390 (120)	31 (14)
• hypohydrated	950 (410)	280 (100)	34 (4)

DISCUSSION

This study showed that in subjects wearing combat clothing alone, moderate hypohydration resulted in greater heat strain than in hydrated subjects. Of particular interest is that hypohydration did not exacerbate the heat strain in subjects wearing chemical protective clothing, presumably because evaporative cooling in the hypohydrated subjects was maximal, so the additional sweat produced by hydrated subjects could not further reduce the heat strain.

These findings suggest that for light work of short duration, moderate hypohydration does not impair thermoregulation when clothing of a high water vapor resistance is worn and implies that safe work times for hypohydrated workers wearing this type of clothing need not necessarily be lower than those for fully hydrated workers. However, exercise tolerance time was reduced by 19% in hypohydrated subjects, mainly because they reached the heart rate withdrawal criterion. Similar results have been reported by Cheung and McLellan (1) who quantified this increased cardiovascular strain in subjects exposed to very similar heat stress, clothing and work conditions to those used in this study. These findings imply that when setting safe work times for workers who may become hypohydrated, both cardiovascular strain and thermal strain must be considered.

REFERENCE

1. Cheung, S.S. and McLellan, T.M. 1998, Influence of hydration status and fluid replacement on heat tolerance while wearing NBC protective clothing, *European Journal of Applied Physiology*, 77, 139-148.

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Funded by Technology Group 5 (Human Sciences and Synthetic Environments) of the UK Ministry of Defence Corporate Research Programme.