

## HEAT STRAIN IN FIRE-FIGHTING DRILLS

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### INTRODUCTION

Fire protective clothing and associated respiratory equipment impose significant heat stress on fire fighters resulting in discomfort, performance decrement and heat illnesses. Risk of heat-induced physical exhaustion and heat stroke grows when rectal temperature ( $T_r$ ) rises above 38.9 to 39.2 °C (1, 2). A number of authors (3,4,5) have reported  $T_r$  values above the risk level in laboratory studies on men wearing fire-fighter clothing under neutral and warm thermal conditions. However, the information about body temperature responses in actual fire fighting is scanty. The objective of the study was to evaluate fire fighters' heat strain in job-related drills.

### METHODS

*Subjects:* The subjects were 27 healthy and physically active male fire-fighting students (aged 18-23 a) from the Finnish State Fire Institute, and respectively, 6 (aged 20-31 a) from the Kuopio Fire Brigade Training School.

*Drills:* The drills consisted of (A) a maximal physical work training of about 1.5 h including typical fire-fighting tasks (indoors and outdoors), (B) operational training of about 25 to 30 min in a flashover facility with air temperature of 600 to 700 °C at head level, 250 to 300 °C at waist level, and 60 to 70 °C at floor level, and (C) operational work training during wintertime ( $T_a$  from -5 to +1.5 °C) in small burning houses lasting several hours and including 1 to 3 enterings of 10 to 30 min into the smoke for one fire-fighter.

*Clothing:* During all training drills the subjects wore a self-contained breathing apparatus (SCBA) and fire protective clothing of cotton (CO) panties, long flame-retardant (FR) woollen underwear, 3-layer CO sweat shirt and sport trousers, two-piece turnout suit made of 3-layer aramid fabric, a commando-type FR woollen cap, a helmet, woollen socks, rubber safety boots and a tool belt. The total weight of the equipment was 25 kg.

*Measurements:* For the evaluation of heat strain, rectal temperature ( $T_r$ ) at a depth of 10 cm (YSI 427) and skin temperature ( $T_{sk}$ ) at 7 sites (YSI 401) was registered every minute (Grant Squirrel meter/logger 1200) for 5 subjects in drill A, for 4 subjects in drill B, and for 4 subjects in drill C, respectively. At the beginning and at the end of each work session the  $T_r$  of 3 subjects was registered (YSI 2100 Tele-Thermometer) in drill A, and correspondingly of 5 subjects in drill B. Heart rate (HR) was continuously recorded (Sport Tester PM 3000) for 10 subjects in drill A, for 6 subjects in drill B, and for 16 subjects in drill C, respectively. Sweat loss was determined by weight changes of the nude subjects recorded (Datex WM 204, accuracy  $\pm 10$  g) before and after the drills, for 20 subjects in drill A and for 6 subjects in drill B.

### RESULTS

$T_r$  increased steadily over the duration of drill A and B. The range of  $T_r$  was 38.5-41.4°C at the end of drill A, and 38.1-39.3 °C at the end of drill B, respectively. During drill C  $T_r$  fluctuated depending on the work tasks. The lowest  $T_r$  of 37.2-37.6 °C were registered outside the burning houses during preparations, and the highest  $T_r$  of 39.95 °C at the end of 20 min spent in the burning house. Figures 1 and 2 show the continuous recordings of  $T_r$  for 4 subjects in drills B and C.

The individual  $T_{sk}$  varied in the range of 25-38 °C in drill A, 29-46 °C in drill B, and 24-46 °C in drill C, respectively. The lowest values were registered for the hands and lower limbs during preparations outdoors. The highest  $T_{sk}$  values as well as visible skin damage and subjective feelings of pain were registered for upper arm, shoulder and knee in drills B and C. In spite of  $T_{sk}$  variation the uniformity of  $T_{sk}$  distribution was prominent at around 37 to 38 °C during all work sessions in heat and over the duration of maximal physical training indoors.

The average sweat loss was 1.9 l (range 1.0-4.2 l) during drill A and 0.8 l (range 0.2-1.6 l) during drill B.

HR varied in the range of 98 - 208 bpm in drill A, 80 - 203 bpm in drill B, and 80 - 189 bpm in drill C, respectively. In drill A, the HR of each subject remained near the subjective maximal HR for a prolonged time, in some cases for 20 to 25 min. The mean peak HR was 197 bpm for drill A, 183 bpm for B, and 170 bpm for C, respectively.

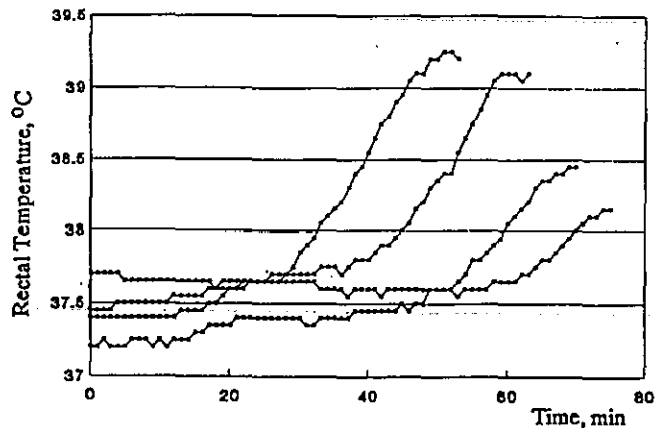


Figure 1. Time courses for  $T_r$  of four subjects during operational work training in a flashover facility.

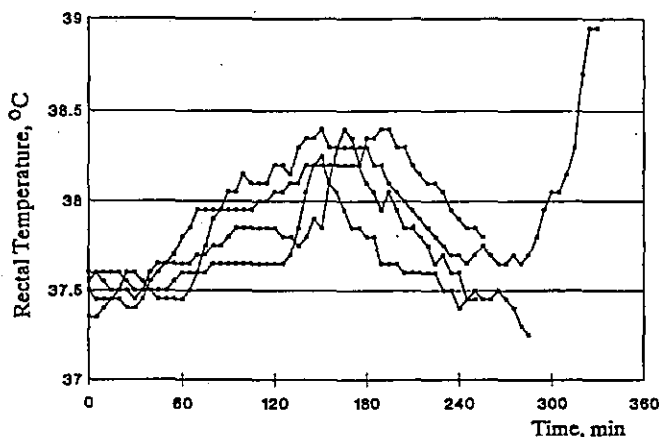


Figure 2. Time courses for  $T_r$  of four subjects during operational work training in small burning houses.

## CONCLUSIONS

The results of the study indicate that in an actual fire-fighting situation there is a risk for heat-related disorders and even for death from heat stress. It is concluded that the heat tolerance test should be included in the selection of fire-fighting students for occupational training. The present results emphasize the need for regular evaluation of the fire fighters' ability to work in heat. The collected data provide also useful information for clothing manufacturers for the development for fire protective clothing.

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