

PHYSIOLOGICAL RESPONSES TO WEARING A FIRE FIGHTER'S TURNOUT SUIT WITH AND WITHOUT A MICROPOROUS MEMBRANE IN THE HEAT

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INTRODUCTION

The wearing of heavy permeable protective clothing imposes heat strain on fire fighters even under mild thermal conditions (1). In many countries, however, fire fighters' protective clothing is required to have a water barrier liner that protects fire fighters from water, steam and toxic chemicals, but complicates evaporative body cooling. No significant difference was found in cardiorespiratory or thermal strain in fire fighters during 25 min of submaximal physical work under high thermal radiation simulating entering into the smoke while wearing a turnout suit either with or without a microporous water barrier (2). This study was done to determine the physiological responses to wearing a permeable turnout suit and a suit manufactured with a microporous membrane in the heat during 1 hour of moderate physical work equivalent to damping down operations.

METHODS

Subjects and study design: Two healthy men and four healthy women aged 24-47 years and with $\dot{V}O_2$ max ranging from 33.9 to 42.1 ml/min·kg volunteered as subjects and signed an informed consent before the experiments, which were conducted according to the principles of the Declaration of Helsinki (3). The subjects were randomly exposed to two wear trials in a climatic chamber consisting of a standardized 60-min treadmill test of moderate physical work with predicted (4) $\dot{V}O_2$ of about 1 l/min at T_a of 40 °C with an initial radiant heat P of 258 W/m² that decreased to 114 W/m². The exposure was arranged in two 30-min work periods (4 km/h on a level) interrupted by a 3-min pause for weighing, preceded by a 30-min rest and followed by a 30-min recovery in a neutral climate. The minimum time interval between the experiments for each subject was at least one day.

Turnout suits: Two different types of brand-new 2-piece multilayer turnout suits evaluated in this study were representative samples of the designs currently worn in Finnish fire brigades. Suit A was equipped with a microporous Gore-Tex® membrane, and Suit B was permeable. The specifications for the turnout suits are reported elsewhere (2). Each suit was worn over *standard test clothing* (STC) consisting of a cotton underwear with long sleeves and long legs, a cotton college type sweater and trousers with two layers, and having three layers in the shoulder area, leather safety boots without liners, leather gloves, a wool underhood and a CMB helmet, and a tool belt. The total weight of the fire protective clothing was ca. 10 kg, and the I_{cl} measured with a sweating mannequin was 1.57 clo for STC with suit A, and 1.67 clo with suit B. The water vapour permeability M_e was 34.3 and 38.4 %, respectively.

Measurements: Continuous monitoring on a video screen included ECG, HR, rectal temperature (T_{re}) measured at the depth of 10 cm (YSI 401), and skin temperature (T_{sk}) at seven sites (YSI 427). HR and body temperatures were averaged for every consecutive minute, and the individual skin temperatures were condensed to an unweighted mean (\bar{T}_{sk}). Mean body temperature (\bar{T}_b) was calculated using the equation $\bar{T}_b = 0.9 \times T_{re} + 0.1 \times \bar{T}_{sk}$. Sweat production was determined from the changes in body weight (Sauter E 1200), corrected for fluid intake and accounting for the amount of sweat absorbed into the clothing. *Subjective evaluations* of perceived exertion (RPE) using the Borg scale from 6-20 (3), thermal comfort and thermal sensation modified from Fanger (4), as well as skin wettedness (scale from 1-5) were requested at the end of the work and rest periods.

Statistics: Means, standard deviations and ranges were used for the description of the data. The differences between the suits were calculated using t-test for dependent samples in case of normally distributed variables, otherwise and for RPE, thermal comfort, thermal sensation and skin wettedness, applying the Wilcoxon test. The 1-tailed probability of errors of $p \leq 0.05$, ≤ 0.01 , and $\leq 0.001\%$ was indicated.

RESULTS

Regardless of the suit worn, HR and T_{re} increased steadily during the work period, up to individual tolerance limits (Figs. 1 and 2). The mean increases were more pronounced for suit A but the differences were not significant. At the end of the work period the mean HR exceeded 163 (9.6 SD) for suit A and 159 (17.4 SD) bpm for suit B (Fig. 1) the mean T_{re} 39.1 °C (0.4 SD) and 38.9 °C (0.5 SD) (Fig. 2), the mean \bar{T}_b 38.9 °C (0.3 SD) and 38.7 °C (0.5 SD), the mean \bar{T}_{sk} 38.1 °C (0.2 SD) and 37.9 °C (0.5 SD), respectively.

No significant benefit for the suit without a water barrier (B) was measured in evaporation (Fig. 3) or reported in subjective evaluations. Physical work in the heat was perceived as being very strenuous (Fig.4), and both suits were perceived as being hot, wet and very uncomfortable.

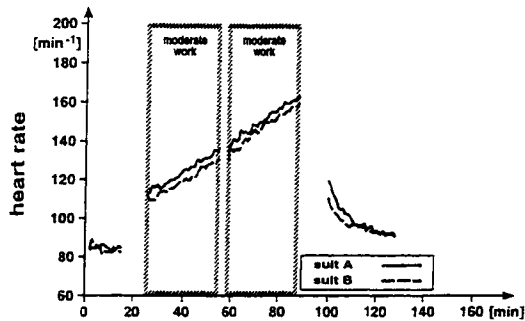


Figure 1. Time courses for heart rate.

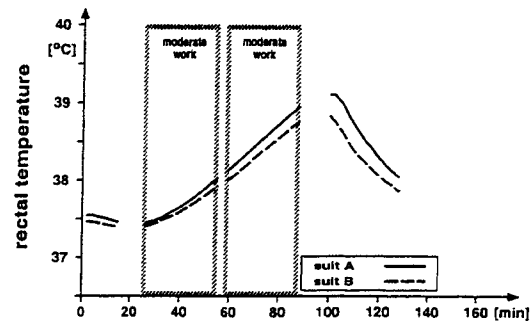


Figure 2. Time courses for rectal temperature.

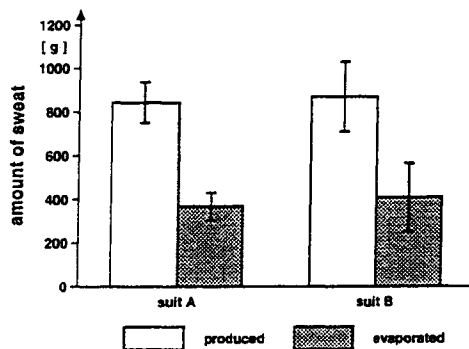


Figure 3. Produced and evaporated amounts of sweat.

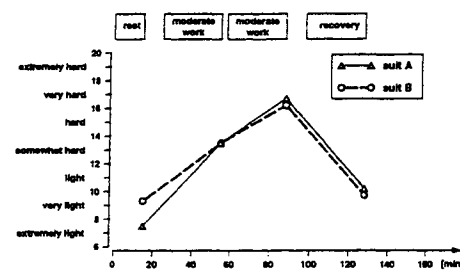


Figure 4. Ratings for perceived exertion.

CONCLUSIONS

No significant differences that would have been caused by a turnout suit with or without a microporous membrane were observed in the subjects' physiological responses during one hour of moderate physical work performed in the heat. However, the tendency of the turnout suit with a water barrier to induce more pronounced heat strain indicates the need for further studies on turnout suits with a barrier liner worn during physical work lasting for several hours, i.e. the actual conditions during extinguishing, damping down and rescue operations.

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Physiological stress in fire fighters caused by a turnout suit with and without a water barrier composed of a microporous membrane was measured during simulated fire fighting work. Eight experienced fire fighters (23 – 47 years old) were randomly exposed to three wear trials consisting of a standardized treadmill test of 25 min of hard work at Ta of 50 °C, and P of 1440 W/m², interrupted by a 25-min break at Ta of 22 °C, and followed by 30 min of moderate work at Ta of 40 °C, and P of 258 - 177 W/m². The body temperatures were higher when the suit with a membrane was worn. The difference in rectal temperature was not significant, but the difference in mean skin temperature was statistically significant at the end of the hard work (p=0.05).