THERMAL RESPONSES TO CONSECUTIVE STRENUOUS FIRE-FIGHTING AND RESCUE TASKS IN THE HEAT

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INTRODUCTION

Increased cardiorespiratory and thermal strain and a risk of exhaustion and heat-related disorders in simulated fire-fighting and rescue tasks in thermoneutral conditions have been well documented (1-4). It is likely that in actual fire-fighting repeated enterings into the smoke (smoke-diving) jeopardise fire fighters' health, because in extreme thermal conditions the risk of lethal heat stroke increases (5).

The purpose of the present study was to investigate the effects of 1) the length of recovery time between smoke-divings and 2) the air temperature during recovery, on thermal strain in fire fighters in two consecutive strenuous tests simulating fire-fighting and rescue tasks in the heat.

MATERIALS and METHODS

Subjects: Twelve medically screened experienced professional male fire fighters aged 24-46 years (Table 1) volunteered as subjects, and they signed an informed conset before the experiments, which were conducted according to the principles of the Declaration of Helsinki (6).

Protective equipment system consisted of a brand-new two-piece multilayer turnout suit fulfilling EN 469: 1994 (7), cotton underwear with long sleeves and legs, a polyester fleece sweat shirt and trousers, leather safety boots without a liner, leather gloves, a woollen underhood, helmet, a tool belt and a self-contained breathing apparatus (SCBA) manufactured by Drager with one air container and a full face-mask. The total mass of the protective equipment system averaged 25.9 kg and the measured thermal insulation I_{cl} of the protective clothing system was 1.85 clo.

Procedure: Thermal strain was assessed in two consecutive tests simulating strenuous fire-fighting and rescue tasks in the heat. Both tests involved the same heavy dynamic work (estimated $\dot{V}O_2$: 25 ml/min·kg), hot dry environment (Ta : 50°C, *P* : 1000 W/m², RH: 20 %, va: < 0.3 m/s), and the use of protective equipment system. The consecutive tests (15+15 min) were repeated with four combinations of the length of recovery and Ta (va: < 0.2 m/s) during recovery between the tests (15/0=SC, 15/20=SW, 30/0=LC, and 30 min / 20°C=LW). The tests were preceded by a 10-min rest period and followed by a 30-min recovery in a neutral climate, during which water drinking *ad libitum* was allowed. The minimum time interval between the test days was at least one day.

Table 1. Physical characteristics of the subjects

	Age, years	Height, cm	Weight, kg	Body Fat, %	A_{Du}, m^2	$\dot{V}O_2max$, ml/kg·min
Mean	32.1	180.2	85.6	14.3	2.1	46.9
Ranoe	26-46	174-187	69-101	10-20	1.9-2.2	33.4-73.3

Physiological measurements: Rectal temperature (Tre) at the depth of 10 cm (YSI 401) and skin temperature (Tsk) at neck, scapula, hand, and shin (YSI 427) were continuously monitored on a video screen and averaged for every consecutive minute. 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 thermal comfort and thermal sensation modified from ISO 10551 (8), as well as skin wettedness (scale 1-5) were requested at the end of the work and rest periods. The criteria for termination of the test was: 1) HR 90 % of HRmax, 2) Tre ≥39.0°C, 3) any individual Tsk ≥45°C, 4) objective signs of severe discomfort or fatigue or 5) subjective feelings of exhaustion.

Statistics: Means ± SD and ranges were used for the description of the data. The statistical differences between the test conditions were calculated using the t-test for dependent and independent samples, two-way analysis of variance with repeated measurements, and the Wilcoxon-test. The 0.05 level of probability was accepted as significant.

RESULTS

Only 7 subjects completed the second test followed by the 15-min recovery at SC and 5 at SW, 8 at LC and 7 at LW, respectively. All terminations were because of HR over 90 % of HRmax. All four recovery combinations were too short for sufficient body cooling; Tre during the second test period was therefore significantly ($p<0.001$) higher than during the first one (Figure 1). The average Tre increase was significantly affected by the length ($p<0.001$) and Ta ($p<0.05$) of the recovery periods. At the end of the second test followed by SC, mean Tre was 38.2±0.4°C, 37.9±0.3°C for LC, 38.3±0.3°C for SW, and 38.1±0.3°C for LW, respectively. The corresponding values for mean skin temperature were 38.4±0.5°C, 37.8±0.5°C 38.5±0.5°C, and 38.3±0.5°C and they were significantly affected by the length ($p<0.01$) and Ta ($p<0.01$) of the recovery periods. On the contrary, the length and/or Ta of the recovery periods did not significantly affect mean sweat production, which was 1118 ± 199 g for SC and 1095 ± 262 for LC, 1149 ± 220 for SW, and 1103 ± 218 g for LW, respectively. Neither was significant benefit reported for the length and/or Ta of the recovery periods in the subjective evaluations on average. The second test was perceived as *'very hot'* and *'very uncomfortable'* in all four test combinations.

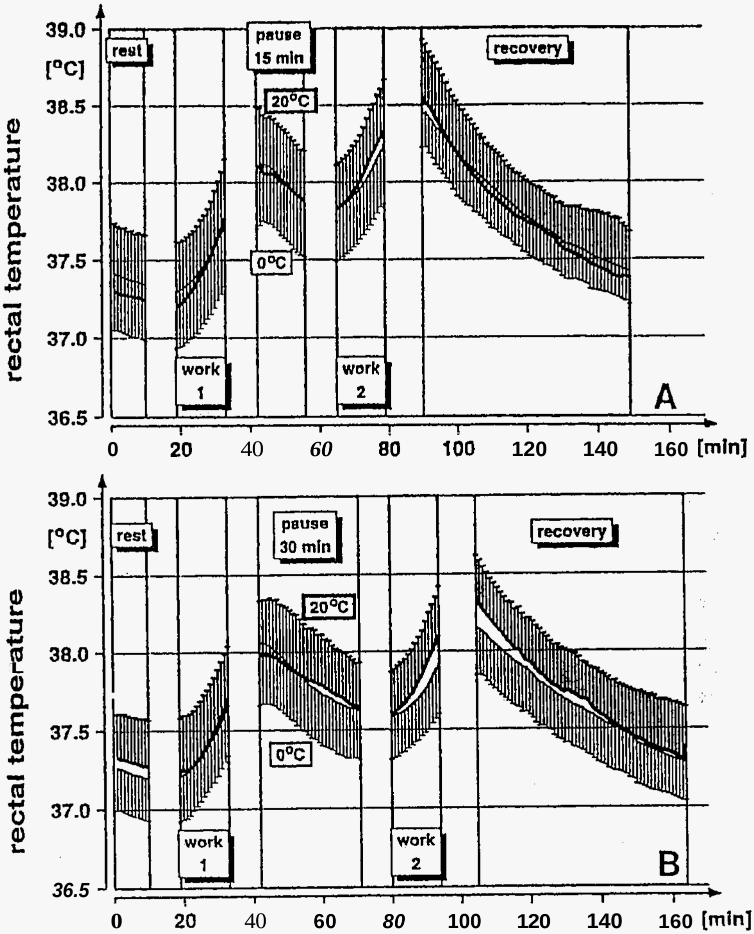

Figure 1 ***A*** *and* ***B.*** Time courses for rectal temperature during two consecutive treadmill tests with 15-min **(A)** and 30-min pause (B) in Ta of 0 "**C** with 50-70 % RH and va < 0.2 m/s (-)— and 20 "C with ~ 35 % RH and va 0.1 m/s (-)— between the tests. The values are means (N = 12) and SD.

CONCLUSIONS

Our results indicate that when the actual fire-fighting or rescue tasks involve repeated exposure to strenuous dynamic work and the use of heavy protective clothing and **SCBA,** a prolonged recovery period and preferably in a cool environment is necessary, especially during warm seasons to prevent intolerable heat strain and exhaustion.

REFERENCES

1. Ilmarinen, R. and Koivistoinen, K. 1995. Physiological strain of fire fighters in a job-related training drill. *Pflügers Archiv-European Journal of Physiology.* Supplement to Volume 430, 4, R 131.

2. Louhevaara, **V.,** Ilmarinen, R., Griefahn, B., Kunemund, C. and Mäkinen, H. 1995, Maximal work performance with European standard based fire-protective clothing system and equipment in relation to individual characteristics. *European Journal of Applied and Occupational Physiology. 71, 223-229.*

3. White, M.K. and Hodous, T.K. 1987, Reduced work tolerance associated with wearing protective clothing and respirators. *American Industrial Hygiene Association.* 48 (4) 304-310.

4. Lusa, S. 1994, Job demands and assessment of the physical work capacity of fire fighters. Doctoral Thesis, *Studies **in Sport,** Physical education and Health* 33, University of Jyväskylä, 99 pp.

5. Mäkinen, H., Ilmarinen, R., Griefahn, B., and Kunemund. C. 1996, Physiological comparison of fire fighter turnout suits with and without microporous membrane in the heat. In: James S. Johnson and S.Z Mansdorf (eds.), *Performance of Protective Clothing: Fifth Volume, ASTM STP 1237*, (American Society for Testing and Materials, Philadelphia) 396-407.

6. Declaration of Helsinki. 1976, *Medical Journal of Australia.* 7(1) 206-207

7. European Standard EN 469. 1995, Protective clothing for fire fighters. Requirements and test methods for protective clothing for firefighting. *European Committee for Standardisation*, Brussels.

8. ISO 10551. 1995, Assessment of the influence of the thermal environment using subjective judgement scales. *International Organization for Standardization Publications,* Geneva.