PHYSICAL DEMAND AND PHYSIOLOGICAL LOAD WHEN SMOKE DIVING

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INTRODUCTION

Smoke diving in a warm environment often causes a great physiological load. There are 2 major reasons for this: (1) the external heat exposure and (2) the metabolic power needed for the rescue and fire fighting. According to Lusa et al. (1), smoke diving requires a considerable physical capacity that is similar for firefighters of all ages. It is known that a large physical capacity is important for performing successful rescue-related activities. Swedish firefighters must pass a physical work test (treadmill or cycle ergometer) each year, requiring an aerobic capacity of roughly 3 L of O_2 per min to insure that a minimum level of physical capacity is maintained. However, especially among full-time employed firefighters, it is suggested that this level does not satisfy the actual demands of smoke diving. In addition, the fire and rescue services are facing challenges with an increasing age of their Corps and more women applying for jobs as firefighters. Traditionally, these 2 populations—women and older firefighters—can have difficulty passing the work test. Consequently, there are disputes about the physical demands of smoke diving and whether non-task-related activities can predict the individualal's capacity for smoke diving well enough to be used as a tool for dismissal or recruitment. If the level or type of test is not relevant for the job requirements, then the test will be considered as a tool that discriminates by gender and age.

The purpose of the present study was to estimate the physical work capacity needed for smoke diving and to identify physiological reactions when smoke diving in a warm environment. The aim was also to investigate the power demands for various smoke diving activities. This information could be used for choosing tactics and equipment, and the procedures for training and selecting firefighters.

MATERIALS AND METHODS

A comprehensive study was carried out on 282 full-time (n = 214) and part-time (n = 68) firefighters who perform rescue and fire fighting operations. The characteristics (mean SD) of the full-time employed firefighters (F) was 38 ± 8 years (age), 83 ± 9 kg (weight) and 180 6 cm (height). The corresponding data for the part-time employees (P) were 35 ± 9 years, 81 ± 11 kg and 181 ± 6 cm, respectively. Voluntary maximum physical work capacity was tested on a treadmill. After 2 min of warm-up, each subject walked 6 min at a speed of 1.25

m·s^{-1} with a slope of 8° (minimum physical requirement). After this stage, the subjects breathed through the apparatus while walking and after 2 min the speed was increased to 1.56 m·s^{-1}. Treadmill (TM) walking time, perceived exertion and heart rates (HR) were measured. The subjects wore their ordinary turnout gear that included 24 kg of equipment.

The following day, a smoke diving exercise that included 2 rescue tasks and 1 fire extinguishing task was run in a smoke-filled, heated 2-story building. The air temperature ranged from about 50°C (ground floor) to 130°C with an average temperature of about 90°C. Vision was greatly reduced by the smoke from the burning diesel fuel. The tasks were designed by experienced rescue instructors, and 2 smoke divers and a commander formed a smoke diving team. The smoke divers entered the building from the roof with the hose and advanced downstairs 1 floor to search for, and rescue, a victim back to the roof. After a few minutes of rest, the team reentered the building and descended 2 floors downstairs to look for, and rescue, another victim. In both cases, the victim was a firefighter weighing 100 kg. After another short rest, the smoke divers entered the house to cool the combustion gases and to extinguish the open fires on the ground floor. Elapsed times for the rest and work periods were registered, and HRs were recorded every 15 s. Tympanic temperatures, nude body weights and air bottle weights were measured before and after the whole procedure.

The operations were followed by instructors, who were inside the building and marks were given for tactics and communication, and for search, rescue and extinguishing techniques. Immediately after the completed mission the participant provided a self-estimation of their effort. If the smoke diver team failed to complete the exercise because of the heat, lack of air, hose burst or other factors, the firefighters could be rescued through exit doors at each floor. To pass the test, all 3 tasks had to be performed, and the team had to return to the roof with all of their equipment.

Based on this study, another 10 full-time employed firefighters did the same tasks. They were also equipped with an apparatus measuring their metabolic rate (MR). The characteristics of these subjects were 36 ± 8 years (age), 83 ± 7 kg (weight) and 183 ± 6 cm (height). They were instructed to use the same average time for the tasks and rest periods as the initial group. The same victim was used and the smoke-filled building was both heated (average air temperature about 55°C) and cool. Physiological and psycho-physiological measures were taken. The MR was calculated every 30 s from information on ventilation (V_I), respiration rate, the oxygen fraction of expired air and the inspired air temperature.

RESULTS

The average, total smoke-diving time was 21.4 min for F while 25.4 min were needed by P. The difference was in the rest periods because the time for each task was similar for the 2 groups: 3.5 min for the 1st rescue, 5.8 min for the 2nd rescue and 7.8 min for the fire fighting. Nine percent of F and 18% of P did not smoke dive, although they had passed the treadmill test. The mean age of these subjects were 50 ± 6 years and 41 ± 12 years for F and P, respectively. Of the participants, 21% of F and 45% of P failed in the smoke-diving exercise. Success or failure was related to physical capacity, measured as TM time completed. For the same capacity, F subjects were more successful than P subjects. Of the F who performed 6 min (minimum requirement) to 8 min at 1.25 $m \cdot s^{-1}$ and 8° slope, 46% were successful in the smoke-diving exercise. Of the F who performed at the 1.56 $m \cdot s^{-1}$ for 1 min or longer, 80% managed to complete the smoke-diving exercise. The corresponding figures for P were 32% and 53%, respectively. These percentages were higher if the number of successful smoke divers were related to those who actually smoke dived rather than to those who passed the TM test. The improvement was found mainly in the low-performance groups in both F and P. HR increased during the smoke diving; the lowest peak HR was obtained during the 1st rescue task, and the highest HR was found during fire fighting. Compared with the peak HR observed during TM walking, the HR during the 1st rescue task was lower, in general, for both F and P. During the 2nd rescue, the peak HR was similar or slightly higher than the TM peak HR. During fire fighting, the peak HR was greater than TM walking.

The MR during smoke diving differed greatly depending on the type and intensity of the activity. Walking downstairs pulling the hose demanded about 400 W, whereas dragging the victim upstairs required 1400 W. The average MR during the 1st rescue was about 60% of that required during TM walking (about 1100 W) at 1.25 $m \cdot s^{-1}$ and 8° slope. The average power demand was about 65% of the TM value during the 2nd rescue, whereas during fire fighting the mean MR reached about 50%. The average power demanded during the various activities was similar whether the building was cool or heated. Data from TM walking at a speed and grade providing a MR similar to that of the smoke-diving tasks, resulted in a MR/HR of 5.8 $W \cdot bpm^{-1}$ at 20°C and 30% RH. The MR/V_I ratio was 15.6 $W/(L \cdot min^{-1})$ (STPD). During the smoke diving in the cooler temperature, MR/HR was approximately 5.1 $W \cdot bpm^{-1}$ during the rescue tasks and 4.3 $W \cdot bpm^{-1}$ during the fire fighting. The MR/V_I was roughly 12.2 $W/(L \cdot min^{-1})$ during the rescue activities and 10.9 $W/(L \cdot min^{-1})$ during the fire fighting. Smoke diving in the warmer room produced a MR/HR of about 4.1 $W \cdot bpm^{-1}$ during the rescue activities and 3.4 $W \cdot bpm^{-1}$ during the fire fighting. The MR/V_I changed from 12.4 $W/(L \cdot min^{-1})$ to 11.6 $W/(L \cdot min^{-1})$ during the 2 rescue activities and reached 10.8 $W/(L \cdot min^{-1})$ during fire fighting.

DISCUSSION

The total smoke-diving period for P was longer than that for F mainly due to longer rest periods. This could indicate the need for slightly longer rest periods before continuing a mission. For those firefighters who were successful in smoke diving, P had lower performance values than F, assessed by maximum time sustained on the TM. Those who failed, either because of heat exhaustion or lack of air, walked a shorter time on the TM than those who managed the smoke diving. It was found that success or failure in smoke diving was related to physical capacity. A clear measure of success or failure was indicated by the difference between those who could continue walking at the increased TM speed using the breathing apparatus and those who were only able to walk 6 to 8 min at the lower speed. The same pattern was found for F and P. Also, for the same capacity, F were more successful. One important reason was that P were more inclined to quit the smoke-diving tasks when complications occurred (e.g., hose burst), probably as a result of less experience, training and education. The fraction of successful firefighters was greater when the calculation was based on the number of subjects who actually smoke dived. Those who did not smoke dive, in spite of their TM results, were found to be older (around 50) and had a mean capacity that was close to the minimum requirement. The hypothesis that the older firefighters used their experience to compensate for their lower capacity could not be tested.

The MR measurements showed clearly that the mean power required for the various smoke-diving activities was significantly lower than the minimum power required on the TM. Even if the effective smoke-diving time was about 3 times longer than the minimum TM time, and some parts of the activities demanded a high peak power output, a mean power requirement of roughly 65% of the TM demand should have been tolerated by most firefighters in a cool environment. The HR confirmed that a significant part of the physiological load was related to the temperature. The MR/HR ratio during smoke diving was roughly 50% of that when walking on a TM in a cool environment, which indicates a significant loss of available work capacity due to the heat. Temperature, however, hardly affected V_I. The type of work was of greater importance for V_I because smoke diving increased the V_I by 30 to 40%, relative to the MR—a consequence that should be considered when estimating possible time of action based on the air bottle volume.

CONCLUSIONS

A firefighter involved in rescue work and fire fighting needs a maximum oxygen uptake of about 3 $L \cdot min^{-1}$ (1000 W) to manage these activities in a cool environment. Warm/hot environments require considerably higher capacity, especially if the firefighter is not skilled. One implication is that the majority of older males and most females will be disqualified for this type of work, based on this minimum capacity. If a change in action and/or the addition of technical devices could reduce the heat load, then a lower physical capacity could probably be accepted.

REFERENCE

1. Lusa, S., Louhevaara, V. and Kinnunen K. 1994, Are the job demands on physical work capacity equal for young and ageing firefighters?, *Journal of Occupational Medicine*, 36, 70-74.