PHYSICAL AND PHYSIOLOGICAL STRESS DURING FIREFIGHTING ACTIVITIES

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INTRODUCTION

Firefighting includes many physically demanding activities (1). Therefore, firefighters are subjected to medical examination and tests of physical performance before, as well as during, employment. Ideally, the demands of those tests should reflect the requirements of the profession. This has become even more important because of the wish to include more women in the rescue forces. Moreover, the average age of firefighters tends to increase. The present study was conducted to elucidate the demands of some activities that firefighters have to perform.

MATERIALS AND METHODS

The subjects were 11 male recruits trained for firefighting. Their age, mass, and stature were (mean ± SD): 21 ± 1 years, 76 ± 7 kg and 179 ± 6 cm, respectively. In pairs, subjects carried a stretcher (13 kg) with an 83-kg dummy, 3 times for 2 min with a 1-min rest between bouts. This was performed indoors as well as outdoors on slightly hilly terrain, the speed being 1 $m \cdot s^{-1}$ and 0.9 $m \cdot s^{-1}$, respectively. One at a time, the subjects carried one 32-kg hose container in each hand on level, tufty terrain. After 100 m, the subjects stopped and connected the hose to a hose connection and continued to walk until the 1st hose container was empty. Then the next hose was connected, and the subject continued to walk until the 2nd container was empty, and then he returned to the starting point. Aerobic power and heart rate (HR) were recorded at least every minute with portable devices (own manufactured device and Sports Tester Polar; Finland, respectively). The subjects rated their perceived exertion (RPE) according to the Borg CR-10 scale (2) for arms, legs and respiration after each bout of walking with the stretcher, when both hose containers were empty, as well as upon return to the starting point.

A dummy including air containers was dragged on a concrete floor in 4 different modes: maximum effort for 20 m with the dummy lying either directly on the floor or on a blanket, submaximal effort pulling the dummy with either a short or a long sling. The force was measured continuously by means of a force transducer placed between the dummy and the handle by which the dummy was pulled. The angle between floor and the pulling direction was calculated from videotape recordings. Force vectors were calculated from data on pulling angle and pulling force. Power for each 4-m section was derived on basis of force, time and distance data.

Two subjects pulled a 35-mm, pressurized, hose up 3 flights of stairs at a time. The 1st one held the nozzle (fogfighter), and the 2nd one helped to transport the hose around comers. After the 1st bout, they changed positions and repeated the exercise. Force, HR and **RPE** were monitored with methods mentioned previously.

The subjects' maximal muscle strength was evaluated by measuring mechanical power during leg cycling and during **arm** cranking on a mechanically braked ergometer (Monark). The subject worked maximally for **10** full pedal revolutions, of which the one displaying the highest power was used. Moreover, isometric handgrip force for each hand was measured.

RESULTS

Peak power during cycling and arm cranking was **777 ± 103 W** and **558 ± 78 W,** respectively. Handgrip force was **637 ± 60** N and **601 ± 67** N for the right and the left hand, respectively.

The aerobic power, while carrying a stretcher, averaged approximately 700 **W** indoors and **900** W outdoors, **HR** being **152** and **161** bpm, respectively. **RPE** for finger flexor muscles was very **high** for most subjects. On average, carrying hose containers required **1125** W. **HR** was **168** bpm (Table 1).

Dragging the dummy on a blanket took more time than without the blanket **(16.2 s** compared with **11.4 s).** Mechanical power was lower at the end than in the beginning. Using the short sling required more force but less power than the long sling, **392** N and **115 W** compared with **337 N** and **133** W at **0.5** ms (Table **2).**

Table **1.** Aerobic Power, **force,** .HR and RPE **for** firefighter tasks*

	Stretcher Carry		Hose Pull		Hose Carry
	indoors	*outdoors*	*nozzle*	*hose*	*containers*
Aerobic power (W)	**696 ± 77**	**913 ± 68**			**1125 ± 95**
HR (bpm)	152 ± 13	161 ± 12	146218	161 ± 7	168 ± 9
Energy (J·m^{-1}·kg^{-1})	**5.8 ± 1.3**	**7.5 ± 0.8**			**9.1 ± 1.5**
RPE	5 (2-7)	7 (44)	3 (1-4)	3 (2-4)	4 (3-7)

***Values are** means ± SD, except for RPE where median **and** extreme values are given

Table 2. Mechanical power, force, HR and **RPE** associated with the dummy drags*

	Sub-maximal effort		Maximal effort	
	short sling	*long sling*	*blanket*	*no blanket*
Mechanical Power **(W)**	**115 ± 18**	**133 +27**	**527 +92**	**445 ± 59**
Force **(N)**	**392 ± 59**	**339 ± 59**	**493 ± 12**	**465 ± 22**
HR (bpm)			**150 ± 14**	**159 ± 14**
Time **(s)**			**16.2± 2.4**	**11.4± 1.3**
RPE		-	**4 (3-5)**	**3 (2-4)**

*Values are means ± SD, except for RPE where median and extreme values are given.

During the hose-pulling **task,** HR was 146 bpm for the one who held the nozzle and 161 bpm for the other subject. The calculated mechanical power was 160 W, corresponding to a metabolic power of about 750 **W,** for the one who held the nozzle. There was no difference in RPE between these activities. Peak power when dragging the dummy was positively related to peak power during cycling (r = 0.76 without, and 0.47 with the blanket). No significant relationship was found between handgrip force and power during dragging the dummy.

DISCUSSION

The aerobic power, HR and RPE increased during the first few minutes of exercise. Therefore the values presented are the ones obtained after **3** to 5 minutes of exercise. Still, the demands of these tasks might be slightly underestimated. However, under realistic conditions, a firefighter has to repeat and/or perform more than one of these tasks during a mission. Thus, the demands on the firefighter will be higher than indicated by the requirement of each single task. Moreover, the climate was very favorable, the temperature ranging from -3°C to +15°C. Warmer climates will increase the load on the firefighter and hence the physical demands.

The investigators carrying the stretcher and the sub-maximal dragging of the dummy set the tempo. In other instances, the subjects were instructed to choose a realistic intensity. However, the stronger person tends to work at a higher intensity, thus requiring more power. This problem is avoided, in part, if the data are expressed as energy cost per unit of distance and mass. **This** group of subjects had an estimated maximal aerobic power of 1240 W, which is not far from that of the average 20 **to** 25-year-old male.

While carrying the stretcher, the aerobic power **as** well as the energy demands per kg and meter was higher outdoors than indoors probably because the outdoor course was rougher and the terrain was partly uphill. Carrying the hose containers was even more demanding. The average 20 to 25-year-old male can attain these levels of aerobic power, whereas most females cannot **(3).**

The load on the oxygen transporting system can be decreased by performing the job at a reduced pace. Thus, a greater fi-action of the population would be able to perform these tasks. On the other hand, it takes longer time to finish the job, which may induce greater risks to both firefighters and victims.

The limiting factor for carrying objects like stretchers is, most often, the endurance of finger flexor muscles. Assuming an even distribution of the load between hands would mean that each hand had to exert a force of about 250 N, which was about 40% of maximum isometric hand grip strength of these subjects. This level can be sustained for about 2 min according to Rohmert (4). Consequently, it would be an advantage to cover a given distance in a shorter period of time. Hence, persons who have a relatively high maximal aerobic power, or anaerobic leg power, might in part compensate for a limited endurance of finger flexor muscles.

It was much faster to drag the dummy directly in contact with the floor than using a blanket, probably due to the lower coefficient of friction, 0.5 compared with 0.65. However, other combinations of dress material and floor surface material may give other results.

Using the short sling required more force (resultant) but less power than the long sling. This may appear as a contradiction. The explanation is that with the short sling, the angle between the upper body of the dummy and the floor is greater than with the long sling, thus the dummy is lifted more with the short sling. This will reduce the normal force, and hence the frictional force and the power required to move the dummy at a given speed (power = force • velocity). A practical consequence, is that persons who are unable to lift a victim's upper body will need more power to drag a victim at a given speed. This might explain the finding that the difference between male and female performance is greater in this task (5), than one would expect from the difference in muscle strength.

During the hose-pulling task, HR was slightly lower when holding the nozzle. The force measurements indicated that the "nozzle holder" applied very little force, indicating that the "hose holder" did most of the job. Part of his job included arm work, which induces a higher HR for a given aerobic power.

CONCLUSIONS

It was concluded that (1) carrying a stretcher or heavy hose containers for more than a few minutes is limited by fatigue of the finger flexors; (2) the power requirement for dragging a person becomes substantially elevated if the firefighter is unable to lift the upper body of the victim; (3) the energy cost per unit of distance and transported mass is quite high for some activities, especially carrying hose containers and (4) the maximal aerobic power required for these activities was in the same order of magnitude as that of the average 20-year-old male.

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