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Physical work capacity of firemen

With special reference to demands during fire fighting

by Åsa Kilbom, MD¹

KILBOM Å. Physical work capacity of firemen: With special reference to demands during fire fighting. *Scand j work environ health* 6 (1980) 48—57. During work in hot environments with a self-contained compressed air line breathing apparatus (SCCALBA) firemen perform physically arduous work and are exposed to severe heat loading. In view of the overloading risk involved, firemen should receive regular medical checkups with exercise tests and electrocardiography (ECG). Four hundred and seventeen firemen from 20 to 59 a of age in the Stockholm Fire Service performed exercise tests, including ECG, at intensities of 100, 150 and 200 W. The calculated maximal aerobic power declined with increasing age. Forty-seven firemen (11 %) were unable to complete the exercise test. Thirty of these men were in the oldest age group (50—59 a), of which 34 % failed to complete the test. The test was usually stopped prematurely because of physical exhaustion, but ECG changes, high blood pressure, and joint pain were also common causes of interruptions in the oldest age group. On the basis of the above results and earlier measurements during simulated fire fighting in a SCCALBA, recommendations on the future examinations of the physical work capacity of firemen are discussed. Thus, a fireman should be capable of performing bicycle ergometer work for 6 min at an intensity of 200 W. In order to allow for the age-induced decline in physical work capacity, a prospective fireman should be able to perform exercise at 250 W in the preemployment examination. It is suggested that exercise tests with ECG recordings should be performed every fifth year up to the age of 40 and every other year thereafter. Moreover, no fireman over the age of 50 should be allowed to perform fire fighting in a SCCALBA. Efficient physical training at least twice a week should be a part of every fireman's regular duties.

Key terms: electrocardiographic changes, fireman, physical work capacity, self-contained compressed air line breathing apparatus, training.

Fire fighting requires excellent physical and mental capacity. Physical demands are especially stringent during work inside a building on fire, where a self-contained compressed air line breathing apparatus (SCCALBA = smoke mask) is used. Moving around inside buildings on fire while simultaneously handling heavy equipment or carrying an injured person imposes severe demands on respiratory and circulatory organs and on muscular strength. The

circulatory organs in particular are subjected to additional loading as a result of high internal and external heat production. The aggregate load in extreme situations may be severe enough to cause collapse.

According to Zylberstein (15) the average physical load on a fireman during simulated fire fighting under highly realistic conditions is equivalent to an oxygen uptake of 1.9 l/min. His results were based on measurements of pulmonary ventilation in fire fighters wearing a smoke mask and performing given tasks in a building on fire. Individual heart rate measurements disclosed that some phases of the work were exceptionally demanding and in-

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duced maximal or near-maximal heart rates. The average heart rate and body temperature disclosed that the subjects wearing smoke masks were exposed to considerable additional loading because of the heat. Thus, average heart rates were around 30 beats/min higher during fire fighting than under the corresponding work load at room temperature. The conclusion was that fire fighting in a smoke mask could not be recommended for more than 20–25 min.

Lemon & Hermiston (9) measured the energy cost of four selected fire fighting tasks. They concluded that even when the obvious external stresses (heat, emotional stress, etc) present at an actual fire are eliminated, fire fighting consists of heavy physical work corresponding to 60–80 % of maximal oxygen uptake.

In view of the severe demands on fire fighters, annual medical checkups, including a bicycle ergometer test with electrocardiography (ECG) were recommended by Zylberstein (15). A maximal aerobic power of at least 2.8–3.0 l/min was considered necessary in order to guarantee an adequate safety margin in work situations where severe heat development and brief but extremely heavy phases occur. Since the requirements of bicycle ergometer exercise at an intensity of 200 W is roughly equivalent to an oxygen uptake of 2.8–3.0 l/min, it was recommended that a fireman working in a smoke mask should be able to perform exercise at this work load (15).

Since these recommendations were issued in 1973, medical checkups, including exercise tests, have been introduced for firemen in most Swedish towns. The

results for full-time and part-time firemen in Helsingborg were reported by Wadstein & Hofvendahl (14) in 1975, and they demonstrated that many part-time and even some full-time firemen failed to satisfy the established criteria for physical work capacity.

Firemen in the Stockholm Fire Service have performed exercise tests with ECG since 1974 at the Work Physiology Unit, Department of Occupational Health of the National Board of Occupational Safety and Health. The present report is a tabulation of the results of these examinations; it also presents comparisons with other groups of firemen and other groups of men. On the basis of results from the exercise tests and the measurements during simulated fire fighting (15) future measures to reduce occupational risks for fire fighters are also discussed.

Subject group

From 1974 to 1978, 477 employees of the Stockholm Fire Service were examined. All had been trained for fire fighting in a SCCALBA and performed this work when required. The majority were firemen, but a small group of supervisors, leading firemen, and fire engineers (a total of 35 leading firemen and fire engineers) was also included. Ten employees had not been examined because of long illness, and five because they refused to participate. There were 386 employees on 30 June 1978, but a larger number was actually examined because of staff turnover in the Service during the period.

Table 1 shows that the average height

Table 1. Age, anthropometric data and resting blood pressure. Mean values $\pm$ standard deviations are given (only mean values for age).

Age (a)	Number	Height (cm)	Weight (kg)	Resting blood pressure (mm Hg)	
				Systolic	Diastolic
20–29 26	128	181 $\pm$ 7	76.7 $\pm$ 8.3	128 $\pm$ 12	76 $\pm$ 9
30–39 33	146	179 $\pm$ 6	78.2 $\pm$ 8.2	127 $\pm$ 11	76 $\pm$ 8
40–49 45	54	178 $\pm$ 5	77.3 $\pm$ 6.6	138 $\pm$ 17	83 $\pm$ 8
50–59 53	89	178 $\pm$ 6	82.2 $\pm$ 11.7	140 $\pm$ 17	86 $\pm$ 10

Fig 1. Average heart rate during bicycle ergometer exercise. The two regression lines show the relationship between heart rate and intensity of work for two male age groups in the Rebus study (7). (Open triangles = 20- to 29-year-olds, open squares = 30- to 39-year-olds, filled triangles = 40- to 49-year-olds, filled squares = 50-year-olds and older)

Fig 2. Systolic and diastolic blood pressure at rest and during exercise on a bicycle ergometer. Systolic blood pressure in the 50-59 and the 40-49 age groups was significantly higher ($p < 0.001$) than in the 20-29 and 30-39 age groups during exercise. The differences in diastolic blood pressure between these groups were also significant ($p < 0.01$ or $p < 0.001$). (Open triangles = 20- to 29-year-olds, open squares = 30- to 39-year-olds, filled triangles = 40- to 49-year-olds, filled squares = 50-year-olds and older)

of the youngest fire fighters (20-29 a) was greater than that of firemen in the two eldest groups ($p < 0.01$ or < 0.001), whereas the oldest firemen were significantly heavier than the others ($p < 0.001$). The oldest firemen were therefore relatively overweight when compared to the other groups. As expected, a higher systolic and diastolic resting blood pressure was found in the oldest age groups ($p < 0.001$).

Methods

Examinations were performed on work-days, although never following fire fighting. During 10 min of supine rest an ECG was recorded. Blood pressure was measured indirectly on the right arm with a cuff and an aneroid manometer. An exercise test was then performed at exercise intensities of 600, 900 and 1,200 kpm/min (prior to 15 September 1977) or 100, 150 and 200 W (after 15 September 1977). The test was performed for 6 min at each intensity and with no interval between intensities. Blood pressure was measured after 3 min and heart rate recorded after 2, 4, 5 and 6 min at each intensity. Prior to 15 September 1977 a mechanically braked bicycle ergometer (Monark) was

Fig 3. Number of firemen who completed (open part) and failed to complete (shaded part) the exercise test in the different age groups.

Fig 4. Reasons for interruption of the exercise test in different age groups. The exercise test was prematurely terminated because of fatigue, electrocardiographic changes, hypertension or joint pain.

employed and thereafter an electrically braked bicycle ergometer (Siemens-Elma). The pedaling rate (50 rpm) was regulated with a metronome and a tachometer, respectively. Room temperature ranged from 18 to 20°C.

The ECG was recorded with an ink-jet recorder (Mingograf 61, Siemens-Elma), with the subject at supine rest, every fifth minute of each intensity, immediately after, 1 and 3 min after, and often even 10 min after exercise. Prior to 1 January 1977 I, II, III, aVR, aVL and aVF extremity leads plus CR_{1, 2, 4, 5, 7} and V_{1, 2, 4, 5, 7} precordial leads were employed; CH_{1, 2, 4, 5, 7} were employed during and immediately after exercise. After 1 January 1977 unipolar V₁₋₆ precordial leads were used before and after exercise, whereas recordings during and immediately after exercise were made with CH₁₋₆. The ECG recordings were classified by the author according to the modified Minnesota Code (13). For the QRS amplitudes, either the modified code or the original code by Blackburn et al (5) was employed, depending on whether the recording had been made with CR or V leads.

Exercise tests were not performed on firemen with infectious diseases, symptoms or ECG findings indicative of some acute myocardial process, and/or blood pressure exceeding 200/100. However, after a delay of a few weeks, it was possible to perform exercise tests for all subjects who had had initial contraindications.

An exercise test was interrupted prematurely on the following indications:

1. Subjective discomfort: exhaustion (ie, maximal loading), chest pain or severe joint or leg pain.

2. Objective findings: blood pressure exceeding 250/120, S-T segment depression (more than 1.5 mm, Minnesota code 4.1) or ventricular premature beats appearing with increasing frequency as the work load increased (Minnesota code 10.1—3).

Results

Exercise tests

There were no differences in heart rate between the different age groups during exercise (fig 1). The increase in blood pressure during exercise was equally great in all the age groups, but the two older groups were always on a higher level (fig 2).

For 47 or the 417 firemen (11%) who performed the exercise tests, the test had to be interrupted before the sixth minute at 200 W (fig 3). Most of them (30) were over 50 a of age. Hence only 66% of the firemen in this group complied with the established criteria. In 31 cases the exercise was stopped because of fatigue, ie, demands exceeded maximal performance capacity (fig 4). In five cases the test was stopped because of knee or hip pain or elevated blood pressure. Eleven of the exercise tests had to be interrupted because of ECG changes during exercise (see the section on exercise electrocardiograms). Fig 4 shows that tests were aborted typically because of poor physical work capacity in firemen under 50 and because of pathological ECGs or blood pressure responses in older firemen. Chest pain in conjunction with exercise did not occur in a single case.

Maximal aerobic power (1) was calculated in order to facilitate comparison of the physical work capacity of the firemen

Fig 5. Calculated maximal aerobic power (l/min) of firemen. Mean values (circles) ± 2 SD are given. The solid line and the shaded area from 25 to 60 a represent the corresponding values for industrial workers (3) and the crosses represent values for men in the Rebus study (7).

Fig 6. Calculated maximal aerobic power (ml/kg $\times$ min) of firemen. Mean values (circles) ± 2 SD are given. Mean values for industrial workers (solid lines from 25 to 60 a) and the Rebus population (crosses) (7) are also shown.

with other groups of men (fig 5—6). Since the work of firemen is performed standing and walking, ie, while supporting body weight, maximal aerobic power per kilogram of body weight provides additional information on the ability to satisfy occupational requirements. A mean value, based on two or three submaximal exercise intensities, was calculated for each fireman. As expected capacity declined with increasing age ($p < 0.001$ for any comparison between age groups).

Resting electrocardiograms

Table 2 contains a tabulation of the most important resting ECG codes. Q waves were found only in a few cases, most of

whom were young firemen with insignificant changes and with no other indications of myocardial disease. Left axis deviation was found in a few cases, except among the oldest firemen, who displayed a relatively high prevalence (9 %).

Only a few firemen displayed S-T segment depressions or T wave changes. However, there was a relatively high prevalence of prolonged conduction time (Minnesota code 6.3). Arrhythmias, like atrial fibrillation, flutter or nodal rhythms, were not found, and ventricular premature beats were found in only a few cases.

Exercise electrocardiograms

In conjunction with exercise, S-T segment depressions of the type seen in coronary insufficiency (code 4.1—4) were found to a slight extent in young firemen (2—3 %) and to a somewhat greater degree (8—9 %) in older firemen (table 3). The prevalence of T wave changes was also low.

Discussion

The results showed that the physical work capacity of firemen declines with age, a finding in accordance with the results of previous studies of men (1, 3, 7, 8). However, the decline with age appears to be greater in fire fighters than in, eg, industrial workers (fig 5 & 6). After the age of 50 industrial workers had even higher values for maximum oxygen uptake per kilogram of body weight than the fire fighters. On the other hand, the firemen had, as expected, a considerably greater aerobic capacity (around 35 % higher maximal oxygen

Table 2. Electrocardiographic (ECG) changes at rest. Total number of firemen with a given ECG diagnosis and the prevalence as percentage are stated. The ECG classification is stated in parentheses according to the modified Minnesota code.

ECG change	Age group (a)							
	20—29		30—39		40—49		50—59	
	Number	%	Number	%	Number	%	Number	%
Q wave (1.3)	3	2	4	3	0	0	1	1
QRS axis deviation								
Left (2.1)	2	2	0	0	1	2	8	9
Right (2.2—3)	6	5	7	5	0	0	2	2
High amplitude R waves								
Left (3.1, 3.3)	10	8	19	13	1	2	3	3
Right (3.2)	1	1	1	1	0	0	0	0
S-T depressions								
> 0.5 mm (4.1—4)	1	1	0	0	0	0	1	1
< 0.5 mm (4.5)	0	0	1	1	0	0	1	1
Junction depression (4.6—7)	1	1	0	0	1	2	0	0
T waves (5.1—3)	1	1	0	0	0	0	1	1
A-V conduction defects (6.3)	5	4	4	3	1	2	5	6
Ventricular conduction defects								
Left bundle branch block (7.1)	0	0	0	0	0	0	1	1
Right bundle branch block (7.2)	0	0	0	0	0	0	1	1
Ectopic beats								
Ventricular (10.1—2)	0	0	0	0	0	0	0	0
Ventricular (10.3—5)	1	1	0	0	0	0	1	1

Table 3. Electrocardiographic (ECG) changes in conjunction with exercise. Number of subjects with a given ECG diagnosis and the prevalence as percentage are given. The results during and immediately after exercise and the results 1—10 min after exercise are shown. The ECG classification is stated in parentheses according to the modified Minnesota Code.

ECG change	Age group (a)							
	20—29		30—39		40—49		50—59	
	Number	%	Number	%	Number	%	Number	%
S-T depressions								
> 0.5 mm (4.1—4)								
During exercise	3	2	5	3	1	2	7	8
After exercise	0		2	1	3	6	8	9
< 0.5 mm (4.5)								
During exercise	1	1	0	0	0	0	0	0
After exercise	0	0	2	2	0	0	0	0
Junction depression (4.6—7)								
During exercise	23	18	38	26	18	33	34	38
After exercise	11	1	13	9	8	15	12	14
T waves (5.1—3)								
During exercise	0	0	1	1	0	0	0	0
After exercise	1	1	2	1	0	0	0	0
Ectopic beats								
Ventricular (10.1—3)								
During exercise	0	0	0	0	1	2	4	5
After exercise	0	0	0	0	0	0	1	1
Ventricular (10.4—5)								
During exercise	3	2	5	3	2	4	8	9
After exercise	2	2	2	1	0	0	10	11

uptake per kilogram of body weight) and lower heart rates during exercise than a group of men selected at random and tested in another Swedish study (6, 7) (fig 1, 5, 6). The firemen had a greater standard deviation in calculated maximal aerobic power than industrial workers. Hence some firemen, even before the age of 40, had a calculated maximal aerobic power lower than the established criterion of 2.8 l, whereas approximately 30 % of the firemen in the 40—49 age group and approximately 60 % of the 50—59 age group failed to reach this value. Most of the firemen were still able to complete exercise at an intensity of 200 W (equivalent to oxygen demands of 2.8 l/min)

probably because they utilized anaerobic energy sources at that load. Thus exercise at 200 W for 6 min can usually be performed with a maximal oxygen uptake of about 2.6 l/min or more. The fast heart rates at 200 W, corresponding to the calculated maximum heart rate in the oldest groups, also lend support to this assumption.

As mentioned in the introduction, the physical work capacity of firemen in many Swedish towns has been tested during the past few years, but only the results from Helsingborg (14) have been published to date. On the basis of these results, work capacity, expressed as maximal aerobic power, was calculated (table 4). The ca-

Table 4. Maximal aerobic power of full-time and part-time firemen. The values were calculated on the basis of submaximal exercise tests, except for the groups from the United States and Canada, for whom maximum values were measured. The values from Canada and Helsingborg are approximate and were calculated from Lemon & Hermiston (8) and Wadstein & Hofvendahl (14). The mean values $\pm$ 1 SD for maximal oxygen uptake ($\dot{V}O_2$ max), calculated in l/min and in ml/min $\times$ kg of body weight are given along with the number of subjects.

Firemen	Age group			
	20—29 a	30—39 a	40—49 a	50—59 a
Stockholm (full-time)				
Number	128	145	52	74
$\dot{V}O_2$ max				
l/min	3.67 $\pm$ 0.74	3.39 $\pm$ 0.69	2.91 $\pm$ 0.55	2.54 $\pm$ 0.51
ml/min $\times$ kg body weight	48.0 $\pm$ 8.9	43.5 $\pm$ 8.0	37.8 $\pm$ 7.4	31.5 $\pm$ 7.2
Märsta, Järfälla & Sollentuna (full-time)				
Number	26	40	12	
$\dot{V}O_2$ max				
l/min	3.69 $\pm$ 0.68	3.28 $\pm$ 0.67	3.16 $\pm$ 0.63	
ml/min $\times$ kg body weight	49.2 $\pm$ 8.5	42.9 $\pm$ 8.1	40.0 $\pm$ 9.8	
Helsingborg (full-time)				
Number	14	29	15	6
$\dot{V}O_2$ max				
l/min	3.6	3.2	2.9	2.4
ml/min $\times$ kg body weight	51	46	41	34
California, USA (full-time)				
Number	11	21	12	
$\dot{V}O_2$ max				
l/min	3.52	3.19	2.84	
Canada (full-time)				
Number	15	15	15	
$\dot{V}O_2$ max				
l/min	3.5	3.4	2.7	
ml/min $\times$ kg body weight	43 $\pm$ 4	40 $\pm$ 6	32 $\pm$ 7	
Helsingborg (part-time)				
Number	5	14	14	9
$\dot{V}O_2$ max				
l/min	3.5	2.9	2.4	2.2
ml/min $\times$ kg body weight	50	39	32	30

capacity of firemen in some of Stockholm's nearby towns, as tested at the National Board of Occupational Safety and Health, is also presented, as well as values for Canadian (8) and Californian (A Kasch, personal communication) firemen. Differences in physical work capacity between full-time firemen from different towns were slight, and a decline in capacity with increasing age was noted in all groups. The part-time firemen from Helsingborg differed from the full-time groups by displaying a much lower capacity. Only 20 % of the part-time firemen were able to manage the 200-W load.

The total age-induced decline in calculated maximal aerobic power was approximately 0.8 l/min, ie, from 3.7 l/min in the 20–29 age group to 2.9 l/min in the 40–49 age group. The decline up to retirement age (currently 60) was about 1.3 l/min. Thus, a fireman capable of displaying 2.8 l/min at the age of 50 would have to have a capacity that was at least 0.8 l/min higher when he was hired, which usually occurs when he is 20 to 25 a old. This oxygen uptake level corresponds to the demands of bicycle ergometer exercise at an intensity of 250 W (ie, approximately 3.5 l/min). Therefore, a work capacity equivalent to this intensity should be demanded at the preemployment examination.

As already noted, only 66 % of the firemen over 50 a of age could complete the exercise test. These failures were due to poor work capacity, ECG changes during exercise, and increases in blood pressure. None of the firemen examined with ECG displayed any cardiac symptoms during the exercise tests. However, during work in hot environments with a SCCALBA, circulatory loading may briefly be even greater than in the exercise test. Therefore there is every reason to regard seriously ECG changes during the exercise test. Even men with a normal ECG run the risk of developing coronary insufficiency after the age of 50. Another reason why elderly firemen should be considered at higher risk is impaired orthostatic tolerance with increasing age. The risk of orthostatic insufficiency and fainting is especially great after heavy manual labor under hot conditions. To summarize, work in hot environments after the age of 50

must be regarded as presenting increased risks because of the danger of physical exhaustion, orthostatic responses, and cardiac complications.

Only few firemen under the age of 50 were forced to stop the exercise test because of poor physical work capacity, and ECG changes caused interruption of the test in only one case. Even young firemen should be given regular medical checkups, including exercise tests, but, since they are usually able to complete the test, intervals between checkups can be made relatively long. Moreover simple bicycle ergometer tests at lower work loads are performed each year at most Swedish fire stations. It is suggested that an exercise test, including an ECG, should be made every fifth year up to the age of 40 and every second year from the age of 40 to 50.

The possibility that firemen run an elevated risk of contracting cardiovascular and pulmonary disease has been discussed by some authors. According to Mastromatteo (10), firemen display increased mortality from cardiovascular disease, and according to Barnard (4, 8) the prevalence of pathological exercise ECGs is somewhat elevated, even though ischemic heart disease (IHD) risk factors are found with a low prevalence. Thus Barnard reported a 10 % prevalence of pathological S-T depressions (> 1 mm) during or after exercise; the corresponding figure for the Stockholm group was 7.8 % (Minnesota code 4:1–2 during or after exercise by firemen over the age of 40). In other groups of men tested with near-maximal loads, corresponding figures of 4–10 % have been reported. The prevalence of S-T depressions in firemen was lower than among forestry workers and in the Rebus population (2, 6). The differences between these studies are difficult to evaluate since testing methods, work loads, and the age composition of the subjects varied slightly. However, the Stockholm firemen did not differ greatly from comparable groups of men, and therefore no increased risk of IHD could be deduced from the exercise ECG data. In a recent mortality study of Boston firemen conducted by Musk et al (11), an increased mortality from accidents was found, whereas cardiovascular, cancer

and respiratory tract disease mortality was lower than expected. A study performed on Stockholm firemen disclosed that their total mortality was lower than for the general population (A Ahlmark and B Elfström, personal communication).

Impaired lung function, ascribed to smoke inhalation, was found in Boston firemen (12). However, firemen in the United States and Sweden are not directly comparable, since SCCALBAs are seldom used in the United States and firemen may therefore be exposed to relatively high concentrations of toxic components of smoke. This exposure is probably related to the noted effect on pulmonary function.

The results of this tabulation clearly show that almost all firemen under the age of 40 comply with the established criteria for physical work capacity. Beyond this age, an increasing number of firemen with poor physical work capacity was found. An age-induced decline in work capacity is inevitable but appears to be steeper in firemen than in other groups. The reason for this steep decline may be that preemployment requirements concerning physical work capacity were less strict 20–30 years ago. As was already noted, the situation even in the 40 to 50 age bracket can be improved if demands on physical work capacity at the time of employment are made more stringent. However, the work capacity of firemen can best be improved by rational physical training. Since the established criteria are especially severe for firemen from 40 to 50 a of age, their physical training must be conducted in a rational manner. Opportunities for simple recreational exercise are usually given during work-hours, but this is obviously not enough. Training must be performed according to modern physiological principles, preferably in the form of running; even the training of muscular strength must be included. Trained coaches are required for rational, individually tailored training. These coaches should use tests to keep a continuous check on training results.

The aforementioned recommendations can be briefly summarized as follows:

1. A firemen should be able to perform bicycle ergometer exercise at an exercise intensity of 200 W for 6 min (equivalent

to a maximal aerobic power of about 2.8 l/min) before being allowed to carry out fire fighting in a SCCALBA.

2. The criteria for work capacity should be made more stringent (exercise at 250 W for 6 min) in preemployment examinations so that there is a margin to compensate for the age-induced decline in capacity.

3. Exercise tests with ECGs should be made at intensities of 100, 150, and 200 W. The examination interval should be every fifth year up to the age of 40 and every other year thereafter.

4. Firemen over 50 should not be allowed to perform fire fighting in a SCCALBA.

5. Efficient physical training under skilled guidance should be part of the ordinary work of a fireman. Training should be carried out at least twice a week.

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