

Cardiovascular Stress, Energy Expenditure and Subjective Perceived Ratings of Fire Fighters During Typical Fire Suppression and Rescue Tasks

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The study determined physiological and psychophysical responses to fire fighters' typical activities. Self-reported assessment of the most demanding fire fighting/rescue tasks were collected with a questionnaire. Then 19 voluntary fire fighters performed 3 simulated fire fighting/rescue tasks in protective clothing. Heart rate (HR), blood pressure and energy expenditure were measured; the rating of perceived exertion (RPE) was assessed with the Borg scale. The questionnaires showed that carrying out victims, fire suppression and resuscitation were classified as heavy load; climbing stairs with a hose as moderate load. According to RPE the subjects considered their effort during ladder climbing fairly light and only somewhat harder during stair climbing and carrying out injured people. The study demonstrated that typical fire fighting/rescue tasks were associated with high energy expenditure and imposed considerable cardiovascular stress. The Borg scale appeared not suitable for assessing perceived exertion in fire fighters during simulated tasks.

fire fighters' tasks rating perceived exertion cardiovascular stress energy expenditure

1. INTRODUCTION

Fire fighters perform their typical occupational activities in very difficult, unpredictable emergency conditions. The wide variety of tasks performed by fire fighters ranges from rescuing victims of automobile accidents or fighting structural fires to neutralizing toxic substances. These tasks differ greatly in physical effort, metabolic and physiological cost required to perform them, and in the magnitude of cardiovascular stress. This stress is caused by physical effort and thermal load as

well as by prolonged anxiety [1]. Cardiovascular stress is increased by the use of impermeable clothing, which protects fire fighters from harmful environmental conditions but constitutes an additional load and disturbs heat dissipation.

Researchers have long been interested in estimating the physiological load of fire fighters during emergency conditions. Although it is possible to monitor physiological parameters continuously by using portable data recorders, it is still difficult to estimate physiological load placed on fire fighters during a real-life emergency,

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mainly because of very strenuous environmental conditions (heat, humidity), protective clothing and fire fighters' activities which may disturb data collection.

A few studies have discussed cardiovascular stress parameters of fire fighters during real emergencies [1, 2] but considerably more studies have been performed in fire fighters during their work in simulated conditions. However, the validity of such simulations regarding the type of tasks and the results obtained under such conditions raises doubts.

Heart rate (*HR*) is a reliable parameter for estimating the intensity of effort during field studies. Monitoring *HR* is convenient because the measuring device is portable and cost is low. *HR* response in fire suppression tasks under simulated conditions has been found to be comparable with the sparse studies performed in real-life emergencies [2, 3, 4].

Borg's rating of perceived exertion (RPE) scale is commonly used in evaluating subjective strain experienced during dynamic exercise. Perceived exertion ratings integrate many signals elicited from the peripheral working muscles and joints, from the cardiovascular and respiratory systems and from the central nervous system [5]. What is most important is that RPE is a very useful instrument that is easy to perform, requires minimal instrumentation and does not interrupt work. The RPE scale is also often used in clinical exercise tests for diagnostic purposes, in rehabilitation to monitor the intensity of exercise or during occupational work to estimate physical load [6, 7].

The aim of the present investigation was to determine physiological and psychophysical responses to typical activities of fire fighters. For this purpose self-reported assessment of the heaviness of the most demanding fire fighting/rescue tasks and some related data were collected with a questionnaire. In the second part of the study, a field study, physiological responses and perceived exertion were examined in voluntary fire fighters who performed three simulated most typical fire fighting/rescue tasks in their protective clothing.

2. METHODS AND PROCEDURE

In the first stage of the study a questionnaire prepared in collaboration with representatives of fire fighters was sent to 150 randomly chosen fire fighters. All of them were members of municipal squads in Warsaw, involved in fire fighting and rescue operations in the city. They were asked to fill in the questionnaire during their shifts, immediately after fire fighting/rescue tasks. The following information was collected with the questionnaire: age, weight, height, duration of service, general state of health, medicines taken, smoking habit, additional occupational activities and recreational activity in free time. Moreover, the fire fighters were asked to list the most typical fire fighting tasks and to characterize them according to their duration and physical load using a 6–20-point RPE scale [5].

The field study consisted in selected physiological parameters being measured during three typical fire fighting/rescue tasks in 19 voluntary fire fighters. All subjects were members of three Warsaw squads. Their mean age was 29.2 (± 6.4 , 22–47) years, height 177.5 (164–192) cm, BMI (Body Mass Index) 27.0 (± 5.9 , 22.7–32.2) kg/m². All subjects were in good health, which was confirmed by periodic medical examinations. Pulmonary function tests revealed no marked impairments. None of the fire fighters was taking any medications, and 10 of them smoked cigarettes.

The field studies were performed in a residential building located near the station, in springtime, in the morning at the ambient temperature of approximately 12 °C. All the subjects wore special, certificated gear which consisted of impermeable and inflammable protective clothing and a self-contained breathing apparatus (SCBA). Cotton T-shirts and shorts were worn under the protective clothing. Such gear is routinely used in real-life emergencies. The total weight of gear with an air bottle and a hose was approximately 32 kg.

The tasks performed by the subjects were chosen out of seven fire fighting/rescue tasks evaluated by the fire fighters in the questionnaire studies performed earlier. They were (a) climbing a 20-m ladder, sloped at 70°, (b) climbing stairs

to the 5th floor with a hose (the hose weighed 7 kg), (c) rescuing a victim from the 5th floor by two fire fighters.

HR was measured continuously with a Sport-Tester PE 3000 (Polar Electro OY, Finland); blood pressure was measured before and immediately after cessation of the task with an electronic device; energy expenditure was measured on the basis of a pulmonary ventilation measurement [8] using a WE-meter device (CB Elektronics, Poland). Energy expenditure was calculated from the Datta–Ramanathan equation with some correction (empirically calculated exclusively for this equipment). RPE was recorded immediately after the tasks with the 6–20 point Borg scale [5].

The values of the parameters determined during the tasks were compared with the reference values obtained before the exercise, in the standing position in the protecting clothing.

The results of the HR measurements during the task were also compared with (a) individual maximal heart rate (HR_{max}) predicted by subtracting the age of the person from 200 beats/min, according to Standard No. EN ISO 8996:2005 [9], (b) the limit value of HR (HR_{limit}) at the workplace was predicted using the following formula: $HR_{limit} = 185 - 0.65 A$, where A is the person’s age, according to Standard No. EN ISO 9886:2005 [10].

The protocol of the study was approved by the Ethics Committee at the Medical University in Warsaw.

Statistical analysis of the results was made with the Shapiro–Wilk test to check the distribution of data and with Student’s t test for related data.

3. RESULTS

3.1. Questionnaire Studies

We obtained 113 correctly filled up questionnaires (75% of the sample).

The mean age of the fire fighters who participated in this part of the study was 33.3 (23–45) years, their mean experience was 9 (0.8–20) years. All of them worked in a system of shifts consisting of 24 hrs of duty followed by 48 hrs off. Fifty-two percent were nonsmokers, but 32% had smoked in the past. Four fire fighters had some health problems: 2 had hypertension, one neurosis and one duodenitis; however, they took medication regularly. Only 38% of the subjects had normal body weight (BMI < 25), 59% were overweight (BMI > 25) and 13% were obese (BMI > 30%). Fifty-seven percent of the fire fighters exercised in their free time; most often it was jogging, cycling and swimming. Almost 48% of the fire fighters had additional occupational duties during their time off. According to the questionnaire the number of rescue operations during the shift varied, but they usually took part in one to six. The duration of those operations ranged from 30 to 240 min ($M = 85$ min) and depended on its type (from small to big fires).

The subjects listed the most frequent and strenuous tasks performed during fire fighting/rescue tasks. Among them were recognizing a situation (searching a building), climbing a ladder, climbing stairs with a hose, carrying injured people out of burning buildings, carrying out dangerous elements, resuscitating and suppressing a fire.

TABLE 1. Duration of Task and the Rating of Perceived Effort (RPE) of Tasks Evaluated by Fire Fighters in Questionnaire Studies as Most Typical in Fire Suppression and Rescue Tasks ($N = 113$)

Task	Duration (min)		RPE	
	<i>M</i>	Range	<i>M</i> (<i>SD</i>)	Range
Recognizing a situation/searching a building	5.2	1–15	12.1 (2.3)	6–18
Climbing a ladder	5.4	5–30	13.1 (2.1)	8–19
Climbing stairs with a hose	8.0	1–25	15.1 (2.5)	6–19
Rescuing a victim	6.4	1–20	15.5 (2.1)	10–19
Suppressing a fire	60.0	3–180	15.2 (2.2)	10–19
Removing dangerous elements	57.0	10–180	16.2 (1.9)	12–19
Resuscitating	17.3	2–60	15.2 (2.3)	10–19

Table 1 presents those tasks and their duration with the RPE scale. According to the RPE scale the most exhaustive tasks were carrying out dangerous elements, carrying out injured people, suppressing a fire, resuscitating and climbing stairs with a hose. All those tasks were treated as heavy effort. Tasks such as recognizing a situation and climbing a ladder were considered as moderate effort.

3.2. Field Studies

Table 2 presents individual values of subjects' HR responses to three different tasks with means (SD) for 19 fire fighters.

During ladder-climbing mean HR_{max} for the whole group was 159.4 beats/min, which was 93.4% of the mean individual HR_{max} and 95.8% of the established HR_{limit} . In two cases the limit of predicted HR_{max} and in five cases HR_{limit} were exceeded.

During stair-climbing with a hose mean HR_{max} was 164.4 beats/min. It was 96.8% of mean HR_{max} and 98.7% of the mean value of HR_{limit} . HR_{max} and HR_{limit} were exceeded in five cases each.

TABLE 2. Heart Rate (HR) Response to Three Simulated Tasks Carried Out by Fire Fighters Expressed as Maximal HR (HR_{max}) During Task, Percentage of Individual HR_{max} [10] and Percentage of HR Limit ($\%HR_{limit}$) [9] Values During Work

Initials	Task										
	Individual		Climbing a Ladder			Climbing Stairs With a Hose			Rescuing a Victim		
			HR_{max} During Task	% Individual HR_{max}	% HR_{limit}	HR_{max} During Task	% Individual HR_{max}	% HR_{limit}	HR_{max} During Task	% Individual HR_{max}	% HR_{limit}
M.Z.	176	169.4	140	79.5	82.6	150	85.2	88.5	176	100.0	103.9
N.T.	176	169.4	162	92.0	95.6	173	98.3	102.1	133	75.6	78.5
K.D.	164	161.6	160	97.6	99.0	170	103.7	105.2	180	109.8	111.4
K.B.	176	169.4	161	91.5	95.0	171	97.2	100.9	160	90.9	94.5
Sz.J.	167	163.6	168	100.6	102.7	160	95.8	97.8	144	86.2	88.0
S.Z.	178	170.7	173	97.2	101.3	160	98.9	93.7	194	109.0	113.6
D.G.	167	163.6	160	95.8	97.8	165	98.8	100.9	168	100.6	102.7
M.M.	153	154.5	150	98.0	97.1	159	103.9	102.9	169	110.5	109.4
G.M.	175	168.8	172	98.3	101.9	178	101.7	105.5	171	97.7	101.3
Sz.C.	177	170.1	161	91.0	94.7	173	97.7	101.7	175	98.9	102.9
B.A.	171	166.2	168	98.2	101.1	171	100.0	102.9	162	94.7	97.5
O.Z.	176	169.4	142	80.7	83.8	165	93.8	97.4	165	93.8	97.4
M.Z.	178	170.7	157	88.2	92.0	166	93.3	97.2	166	93.3	97.2
L.M.	171	166.2	142	83.0	85.4	161	94.2	96.9	133	77.8	80.0
W.D.	166	162.9	160	96.4	98.2	146	88.0	89.6	145	87.3	89.0
W.K.	163	170.0	161	98.8	94.7	166	101.8	97.6	164	100.6	96.5
D.M.	167	163.6	152	91.0	92.9	162	97.0	99.0	165	98.8	100.9
Ž.K.	174	168.1	160	92.0	95.2	167	96.0	99.3	181	104.0	107.7
Ch.P.	171	166.2	180	105.3	108.3	161	94.2	96.9	168	98.2	101.1
<i>M</i>	170.8	166.5	159.4	93.4	95.8	164.4	96.8	98.7	164.2	96.2	98.6
<i>SD</i>	6.5	4.1	10.7	6.9	6.6	7.8	4.8	4.6	15.9	9.6	9.6
Min	178	170.7	180	105.3	108.3	178	103.9	105.5	194	110.5	113.6
Max	153	154.5	140	79.5	82.6	146	85.2	88.5	133	75.6	78.5

TABLE 3. Blood Pressure, Energy Expenditure and Rating of Perceived Exertion (RPE) ($M \pm SD$) During Fire Suppression and Rescue Tasks in Fire Fighters ($n = 19$)

Task	Blood Pressure (mmHg)		Energy Expenditure (kJ/min)	RPE
	Systolic	Diastolic		
Reference values (standing in protective clothing)	138.2 ± 10.5	86.2 ± 7.6	4.4 ± 1.73	—
Climbing a ladder	169.3 ± 23.5	99.1 ± 14.3	54.5 ± 15.02	12.3 ± 2.8
Climbing stairs with a hose	172.3 ± 27.4	99.4 ± 13.8	55.5 ± 14.9	13.2 ± 3.1
Carrying out injured people	163.8 ± 18.5	95.4 ± 9.7	50.0 ± 15.6	13.7 ± 3.3

During rescuing a victim (carrying out injured people) mean HR_{max} was 164.2 beats/min. It was 96.2% of mean HR_{max} and 98.6% of mean HR_{limit} . HR_{max} and HR_{limit} were exceeded in 7 and 10 cases, respectively. No statistically significant differences were found in the value of HR between the three tasks applied.

In terms of strain imposed upon the fire fighters, the peak load of the task is more important than mean energy expenditure. During all three tested tasks energy demands exceeded 50 kJ/min; 54.5 kJ/min during ladder-climbing, 55.5 kJ/min during stair-climbing and 50.0 kJ/min during carrying out an injured person.

The subjects estimated their effort connected with performing the tasks as fairly light in the case of climbing a ladder (RPE = 12.3), and somewhat (moderate) hard both in climbing stairs and carrying out injured people (RPE = 13.2 and 13.7 respectively) (Table 3).

Systolic blood pressure was 169.3 (± 23.5), 172.3 (± 27.4) and 163.8 (± 18.5) mmHg, respectively during climbing ladders, climbing stairs with a hose and carrying out injured people. Diastolic blood pressure was 99.1 (± 14.3), 99.4 (± 13.8) and 95.4 (± 9.7) mmHg during climbing ladders, climbing stairs with a hose and carrying out injured people.

4. DISCUSSION

Fire fighting and rescue work is physically and psychologically demanding, with occasional high peak loads, and often severe heat exposure. According to our questionnaire study the work load of fire fighters during their shifts varies considerably depending on the number of rescue operations (1–6), their duration (30–240 min)

and the severity of the tasks. This means that sometimes the fire fighters can be relatively inactive for the greater part of the shift, but frequently they perform hard work for a long time. The data are in line with Barnard and Duncan’s [1] results obtained in 24-hr ECG recordings indicating that at times fire fighters perform work at a load close to their HR_{max} for prolonged periods. A high level of aerobic fitness is, therefore, necessary to perform this kind of work.

Our data showed that only 50% of the fire fighters exercised regularly (practising different sports in their free time), although there were opportunities to exercise in all squad training programs. Gavhed and Holmér [11] reported a much better tolerance for exhausting tasks under heat stress in professional fire fighters in comparison with volunteer ones who had fewer opportunities to participate in physical training and simulated fire fighting tasks. According to other authors the activities that increase or maintain muscular strength, muscular endurance, cardiovascular fitness and decrease the percentage of body fat improve job performance [12]. Longitudinal observations demonstrated that more than half of Polish fire fighters, especially aged ones, have a physical capacity below that recommended in other countries [13]. It seems likely that the engagement of fire fighters in additional occupational activities (true for almost 48% of our study population) is conducive to their low recreational activity.

The rating of tasks according to their severity and frequency was not significantly related to the fire fighters’ age or to the size of the fire department. According to Lusa, Louhevaara and Kinnunen [14] in large departments 99% of

fire fighters specialize in certain tasks, while in medium-sized and small departments only 52 and 19%, respectively, specialize. Romet and Frim [15] concluded that frequent rotation of duties between stressful and less demanding may reduce the risk of heat stress in fire fighters.

It should be emphasized that high cardiovascular overload caused by physical effort during fire suppression tasks has an impact on the high incidence of cardiac ischemia in fire fighters. In addition, repeated exposures to high anxiety occurring already in the first minute after an alarm are also responsible for high cardiovascular stress. The state of high anxiety in real-life emergency coupled with strenuous work performed in a hot environment and in heavy protective clothing result in extremely high *HR* sustained for a long time during fire fighters' normal day on duty.

Barnard and Duncan [1] also showed that fire fighters' cardiovascular response occurred immediately after the sound of the alarm and in the fire engine, before they became engaged in any physical activity. *HR* increased rapidly by approximately 50 (12–117) beats/min. At this moment also ST-segment changes were observed in ECG. Those findings indicated a great contribution of prolonged anxiety to fire fighters' cardiovascular stress.

In our study, during simulated tasks anxiety as a factor increasing cardiovascular stress was eliminated; thus, severe physical stress was mainly caused by the combined effect of the high energy expenditure of work and the wearing of heavy protective clothing with equipment. Our results are in agreement with those reported in previous studies, which indicated that the combined effect of physical load and of carrying protective clothing with equipment constituted considerable physiological demand on fire fighters. Other authors showed that during fire suppression fire fighters attained and sustained for a long time a near-maximal *HR* [16, 17, 18]. According to Sothmann, Saupe, Raven, et al.'s [18] results obtained during fire suppression in real life, including the use of a pike pole and an axe, rescuing a victim and pulling a hose, fire fighters' mean *HR* was 157 ± 8 beats/min,

which represented $88 \pm 6\%$ of HR_{\max} individually estimated. The typical time during which such *HR* was sustained was 15 ± 7 (8–28) min. The fire fighters in that study also wore gear with SCBA while working in the vicinity of fire. Fire fighters, during typical tasks performed with various breathing equipment, exert 8–100% of their maximal load and adjust their work output to maintain that near-maximal level [17].

HR_{limit} in the working place should not exceed the maximum value of the person reduced by approximately 20 beats/min or HR_{limit} developed by the CEN-ISO groups [9, 10].

Our findings concerning *HR* in all tasks examined are similar to those reported in the aforementioned studies, performed both in simulated conditions and in real-life emergencies. *HR* exceeded often not only the recommended values for the performed work, but even maximal values predicted respectively to the subjects' age. According to the percentage of HR_{\max} and HR_{limit} rescuing a victim was the most strenuous task, which confirmed Romet and Frim's [15] data. Those authors also found that rescuing a victim and searching a building (climbing stairs) were the most strenuous fire fighting tasks associated with *HR* exceeding 150 beats/min and a rapid increase in core temperature of over 1.3 °C.

Impermeable clothing inhibits to a great extent sweat evaporation, disturbing thermoregulatory mechanisms and, in consequence, increasing *HR* as well as core and skin temperature [16, 17, 20, 21]. According to Smolander et al. [22, 23] tasks performed with gas protective clothing (with a SCBA) also induced marked cardiovascular strain in subjects of the average physical condition even when the thermal strain was relatively low; the weather was very cool, it snowed and it was windy.

Independently of the influence on thermoregulatory mechanisms, wearing protective clothing and carrying SCBA induced an additional physical load which per se increases cardiovascular strain.

O'Connell, Thomas, Cady, et al. [24] and Sothmann et al. [2] emphasized that prediction of energy expenditure from *HR* is inaccurate during fire fighting. They indicated numerous factors

that could potentially alter the relation between HR and V_{O_2} in real fire fighting conditions: heat, isometric muscle contraction and upper-body work. The actual V_{O_2} during fire fighting tasks predicted from actually measured HR was significantly lower (by about 20%) than V_{O_2} which predicted from the HR/V_{O_2} relationship established during graded exercise in laboratory conditions [2, 3, 25].

There are studies that evaluated the energy expenditure of simulated fire fighting activity classifying it as heavy, varying in energy expenditure from 46.1 to 53.2 kJ/min [13]. O'Connell et al. [24] reported that the rate of energy expenditure of climbing a simulated staircase (on a stair-treadmill) in uniform and with equipment required energy expenditure of 56.6 kJ/min. In that study the uniform and the equipment (breathing apparatus and hose) weighed approximately 39 kg. Mean HR with gear was 95% of HR_{max} .

Lemon and Hermiston [26] assessed the energy expenditure of four selected, most strenuous fire fighting tasks (climbing an aerial ladder, rescuing a victim, dragging a hose and raising a ladder). The results indicated that fire fighting consists of heavy physical work, close to 60–80% $V_{O_{2max}}$, even when obvious external stress present under real fire conditions (i.e., heat and emotional stress) is eliminated. Energy expenditure calculated during these tasks was within the range of 46.0–53.2 kJ/min.

In our study energy expenditure during similar three tasks ranged from 50.0 to 55.5 kJ/min, which was comparable to other authors' results.

The RPE scale is considered reliable for predicting HR , especially at high dynamic work intensities. Moderate correlations were also found between measured and predicted (from the RPE scale) HR values for physical activities such as sweeping and carrying boxes [27]. However, in our study estimation of physical effort with the Borg scale performed during the three tasks basing on questionnaire and field studies was different. In the field study the subjects estimated all tasks as slightly less strenuous than in the questionnaire study. Thus, evaluating RPE with a questionnaire seems more appropriate for real-life emergencies.

Results of cross-sectional studies of $V_{O_{2max}}$ in the Polish working population indicate that almost 28% of men aged 20–29 have low and very low physical work capacity according to Astrand's classification [28, 29]. Fire fighters are a special occupational group in which safe performance of tasks depends on physical fitness, as seen from the results of our study.

The findings of our questionnaire study indicate that not enough attention is paid to increased fitness and physical capacity of fire fighters during their whole careers; whilst the field study demonstrated that simulated fire fighting/rescue tasks in protective clothing with breathing equipment were associated with high energy expenditure and imposed on fire fighters considerable cardiovascular strain. This is not reflected in RPE obtained with the Borg scale, suggesting the scale is not suitable for assessing perceived exertion in fire fighters during simulated tasks.

In conclusion, this study indicates that authorities responsible for the safety, health and fire fighters' work ability have to be aware of their stressful and demanding work and make more effort to enhance their abilities for this job. According to our study early detection of reduced work ability and increasing fire fighters' interest in improving their physical work capacity in their free time seem to be particularly important.

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