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Psychophysiological Responses of Firefighters to Emergencies: A Review

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Abstract: Firefighters perform strenuous muscular works in hazardous environments and chaotic conditions, under time pressure and psychological stress. Various studies have shown high values of oxygen uptake, heart rate, blood lactate concentrations and salivary cortisol and A-Amylase in laboratory test, in real-life and simulated interventions of firefighters. These high values have been attributed to the combined effect of the metabolically active muscle, thermoregulatory strain and fatigue resulting from the protective gear and a self-contained breathing apparatus in addition to further supplementary overweight (i.e., lifting weights, rescuing victims). In order to protect health and safety of firefighters and victims during emergencies, high levels of cardiovascular endurance and strength in firefighters are strongly recommended. In fact, high levels of physical fitness showed to increase firefighters' work ability, safety and decreased risk of injury.

Keywords: Anxiety, cardiovascular diseases, heart rate, hormonal responses, self-contained breathing apparatus, thermal strain.

INTRODUCTION

Considerable information in the literature [1-5] has shown the work of the firefighters as the civilian employment with the highest variability of exposure to physical stress and risks. During the emergencies, the firefighters have to filter a large number of sensory stimuli (i.e., people in need, environmental events, movements of colleagues) that turn into specific reactions and actions. These actions and reactions occur in multiple forms characterized by several variables: space-time, duration, breaks, nature of the emergency (i.e. fire in an apartment or car accident), and biomechanics movement (i.e. running or climbing stairs).

Various studies [1, 5-17] documented that the combination of physical activity, unpredictable conditions, warm clothing and/or exposure to external heat sources causes an increased physiological and psychological stress. In addition, firefighters wear protective clothing (PC) and self-contained breathing apparatus (SCBA), which are heavy, thick, multilayered and bulky (i.e., 23 kg). This overload can have adverse effects upon gait (-25% of walk velocity), metabolic and thermoregulatory efficiency (+20% strain), tolerance time to work (-22% to low and -75% to high intensity), fatigue and the risk of injury [4, 18-23].

Cady *et al.* [24] have shown that high levels of physical efficiency can help the firefighters to carry out tasks (i.e., the lifting and carrying of the fire hose, transport equipment up and down the stairs, entering with force or transport in safety of victims) and are related to a decreased risk trauma.

Although physical stress and the workload of a real emergencies are difficult to measure, several authors have claimed that the firefighting causes a heart rate (HR) close to the maximum values [5, 12, 16, 17] with decrease in the stroke volume [12], and increase in the core temperature [5, 11, 12], in the levels of blood lactate [10, 16, 17] and psychological stress [3, 5, 11, 12]. For this reason, it is recognized [25, 26] that firefighters must possess the physiological characteristics that enable them to respond to the emergencies. Study of Hammer *et al.* [27] emphasizes the need of a higher priority for firefighter fitness programs in order to best ensure the safety of firefighters and the public.

The aim of this review was to (a) examine evidence on the physical demands and the actual workload of firefighting, (b) identify the relative importance of the various contributing factors, and (c) make recommendations on physical programs and future research in this area.

A set of relevance criteria was developed a priori. The criteria required to be included were the job requirements and their implications in terms of physical, physiological and psychological aspects.

A search filter and electronic search strategy were developed in collaboration with a librarian with extensive experience in conducting systematic reviews. The search filter used a series of firefighter related keywords to extract potentially relevant articles from electronic databases: Medline, Psycinfo, Current Contents, Sportdiscus. All

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databases were searched for all languages and age groups and from the earliest records available. Duplicates between databases were identified and removed to create a master list.

RISK FACTORS

Several studies [1, 2, 28] have shown that environmental and physical stress met by the firefighters can determine occupational hazards ranging from lesions to death. The high incidence of musculoskeletal and circulatory trauma [29-31] and premature death [32], has been attributed to the considerable physical and mental commitments [1, 4], overexertion and strain [33] imposed after completion of rescue operations. These traumatic events, often associated with subjective perception of physical and mental fatigue with repercussions on the private life [34], may be due to poor or even missing physical training.

For a five-year period [35], 368 on-duty U.S. firefighters died during emergencies: 39% of heart attacks, and 61% of other causes (i.e., burns, asphyxiation and motor vehicle related trauma). Each year, coronary heart disease (CHD) is the leading cause (90%) of the death in firefighters with 45% during firefighters' activities [36, 37]. Karter and Molis [33] claimed that for every fatal on-duty heart disease event, there are an estimated 17 nonfatal events in the U.S. fire service.

Recent studies [2, 38, 39] estimated that firefighters spent 1% to 5% of their time on fire activities, yet 32% of deaths occurred from CHD-related events during that time. Fernhall *et al.* [40] examining standard echocardiographic measures of cardiac size and performance in response to a 3 h firefighting training exercise have shown significant cardiovascular changes.

The high level of cardiovascular diseases (CVD) and mortality in the firefighters depends on the interaction of several factors such as sympathetic activation [3, 16], physical workload [41-43], heat [5,11,44], dehydration [11, 12, 22], inadequate physical activity [45, 46], dietary habits [47-50], shift work [47, 51-53], smoke exposure [54, 55], noise [56] and psychological stress [12-14, 57, 58].

A study of Baur *et al.* [59] on the association between CVD factors and cardiorespiratory fitness in 968 firefighters showed that higher metabolic equivalents categories were significantly associated with lower diastolic blood pressure, body fat, triglycerides, low-density lipoprotein cholesterol and total/high-density cholesterol ratio, and higher high-density lipoprotein.

CARDIOCIRCULATORY STRAIN

Among the different parameters studied, the maximum oxygen uptake (VO_{2max}) is the variable most frequently taken into consideration. In this sense, there are recommendations that require minimum values VO_{2max}> 33 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, with preferably >45 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, to successfully complete a rescue protocol standard [1, 13, 41, 42, 60]. The single analysis of firefighters' activities showed that: climbing stairs with PC+SCBA for 5 minutes required an average VO_2 of 39.0 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ [61], lifting and moving the hose required a VO_2 of 23.4-25.7 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, while the control of a flexible tube a VO_2 of 30.9 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (approximately 75 and 98 % of VO_{2max}) and to transport the equipment on the stairs a VO_2 of 36.6-44.0 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ [62]. Various studies [6, 62, 63] have determined that immersion in the smoke (search and rescue) is the most challenging task faced by the firefighters. Perroni *et al.* [17] by analyzing simulated emergencies (i.e., child rescue; 250 m run; search and rescue; 250 m run) of 20 Italian firefighters have shown that VO_2 consumption of the search and rescue was 56 ± 6% compared to the total energy requirement of a simulated emergencies and was 67 ± 16% compared to VO_{2max} evaluated in laboratory.

The HR has been analyzed in response to a real emergency [14, 64, 65], to the sound of the alarm [66], to various activities of the firefighters [1] and to the use of SCBA [67, 68]. Several authors [9, 10, 14, 67, 69] have reported an HR, variable from 150 to 190 $b{\cdot}min^{-1}$, attributable to environmental stress, work stress, and high psychological stress. In particular, in response to the distress call the HR rapidly increases with range from 84% to 100% of the individual maximum heart rate (HR_{max}), equivalent to 63-97% of VO_{2max} [14]. HR increases during very hard work carried out for a shorter period of 15 min [9-11], and for a longer period [70], and remains high during the recovery phase [16, 17]. Indeed, Perroni *et al.* [17] showed that the values of HR and VO_2 increased during the simulated emergencies and they remained elevated after 30 min of rest (HR: 108 ± 15 beats min^{-1}; VO_2: 8.86 ± 2.67 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) with respect to basal values (HR: 66 ± 8 beat min^{-1}; VO_2: 4.57 ± 1.07 ml kg^{-1} min^{-1}. After short (352 ± 42 s) simulated rescue of hospital patients, Von Heinburg *et al.* [71] have shown high values of HR (96 ± 5% of HR_{max}), perceived effort (8.9 ± 1.0), blood lactate concentrations (13 ± 3 $mmol{\cdot}L^{-1}$), and consumption of oxygen (3.9 ± 0.5 $L{\cdot}min^{-1}$) in firefighters.

Rodrıguez-Marroyoa *et al.* [72] analyzed the HR of firefighters during real wildfire suppression according to the type of attack performed (direct, indirect or mixed). They found significantly higher HR in direct and mixed versus indirect attacks and demonstrated that wildfire firefighting depends on the tactics chosen for performing the task.

In addition to physiological overload of the emergencies, firefighters wear PC+SCBA and use heavy equipment (i.e., ladders, fire hose lines, etc.). Indeed, Smith *et al.* [10] have shown high levels HR wearing PC while Manning and Griggs [73] observed a rapid increase in HR up to 70-80% of maximum values during the first minute wearing PC+SCBA.

Baker *et al.* [67] have compared the cardiorespiratory and thermal responses of two intensities of treadmill exercise (12 min) in firefighters wearing PC and sports ensemble (SE). At $7km{\cdot}h^{-1}$, VO_2 was significantly higher in PC (36.1 - 39.9 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) than in SE and represented 74% VO_{2max}, while Bruce-Low *et al.* [68] have shown an increase of 39.8% wearing PC. Several authors [74-77] suggest that PC+SCBA used by the firefighters would negatively affect VO_{2max}. In particular, Perroni *et al.* [77] by evaluating the VO_{2max} of firefighter recruits with step test performed with and without PC+SCBA, have shown that wearing the PC+SCBA about 10% of firefighter recruits had failed to complete the step test.

Various authors [1, 14, 78] have shown that good levels of aerobic power are useful to carry out fire fighting activities in relation to the use of PC+SCBA. Comparing PC with only shorts and a T-shirt, previous studies have shown a reduction of 25% of maximum power [79] and an increase of VO_2 (11%) running on treadmill to 7 $km \cdot hr^{-1}$ [67], while comparing PC with an outerwear, have reported a 50% increase of the metabolic load [70]. Faff and Tutak [80] have shown that when the environmental temperature is increased from 20 °C to 39 °C (humidity of 70%), HR increases significantly with PC and fatigue manifests itself much faster. In this direction, various authors [5, 17] have stated that it is not possible to exclude that the progressive increase in HR is determined by changes in temperature regulators imposed by PC. A study by Eglin *et al.* [64] on a group of instructor firefighters showed increased levels of HR and internal temperature during exercise. The same authors hypothesized that these increments were attributed to dehydration, reduced heat tolerance and physical performance.

Given the nature of their duties, a physiological age-related decline could be expected during the occupational period of firefighters. Baur *et al.* [59] have investigated the effect of increasing age on cardiorespiratory fitness in career of firefighters as well as the modifying effects of physical activity and adiposity. They found that cardiorespiratory fitness decline was greatly attenuated among leaner firefighters who reported more physical activity.

Cross-sectional studies on firefighters have shown a constant decrease in age-related [24], an annual decrease of 0.30 to 0.80 $ml \cdot kg^{-1} \cdot min^{-1}$ in relative aerobic capacity between the age groups of 19 to 29 years and 50 to 59 years [81], 0.60 to 0.70 $ml \cdot kg^{-1} \cdot min^{-1}$ between the age groups of 30 to 34 years and 50 to 54 years [82], a decrease in VO_{2max} values of 10 $ml \cdot kg^{-1} \cdot min^{-1}$ after 20 years [83], and a 45% reduction in VO_{2max} of the firefighters of 20 and 60 years [84]. Punakallio *et al.* [85] have studied aerobic capacity and predictors as exercise, smoking, and drinking habits in 78 male Finnish firefighters (aged 30 to 44 yrs) at 3- and 13-year follow-ups. They found that the average annual change in absolute ($L \cdot min^{-1}$) and weight-related ($ml \cdot kg^{-1} \cdot min^{-1}$) aerobic capacity was −1.12% and −1.33%. Exercising at least 4 to 5 times a week was the best protective factor, and regular smoking and more than 15 units of alcohol a week were risk factors for decline in aerobic capacity.

In this direction, the admission and retention of English firefighter recruits, are subject to a limit of maximum aerobic power of 42 $ml \cdot kg^{-1} \cdot min^{-1}$ and require additional training for those who fail to reach that value [26]. Wynn and Hawdon [86] wanted to determine whether a reduction in, or elimination of, a defined cardiorespiratory standard for firefighter was influenced by a number of occupational and health-related outcomes. The results of this study showed that the removal of a defined standard cardio is associated with adverse effects on health and employment outcomes.

THERMOREGULATORY ASPECTS

Various studies [10, 87] have shown that working in a hot environment generates greater physiological and psychological stress compared to a thermo-neutral environment. Exposure to heat during firefighting varies in severity, duration and irregular intensity. The duration of exposure to heat is often determined by the SCBA and is usually limited to about 20 min. Eglin and Tipton [88] have documented how the firefighting instructors were exposed to heat for 40 min during training exercises while Ruby *et al.* [89] have shown that the duration of fire suppression ranged from 12 to 18 hours. In addition, the firefighters' environment may have extreme and dangerous temperatures, varying between 67 °C and 190 °C but can reach more than 200 °C [9-11, 64, 90]. The study of Angerer *et al.* [69] wanted to determine cardiocirculatory and thermal strain during fire suppression in firefighters and compare it with the strain during medical and performance evaluations. During the fire suppression, body core temperature increased by 0.9 ± 0.5 °C and blood parameters changed accordingly. In this direction, laboratory studies [67, 91-95], simulated activities [42, 68] and actual emergencies [14, 64, 65] showed thermal increase due to heat radiated by the fire, physical activity and use of PC+SCBA. It is observable an increased internal temperature (1.5 °C) when subjects wearing PC+SCBA [44] in temperate environment.

In relation to clothing, Taylor [96] recorded temperatures of flashover of 91°C (internal coat), 59 °C (outer sleeve), 54 °C (inner sleeve) and 42 °C (chest) during simulated activities. In this study, the authors have shown that the clothes in contact with the skin provide an important layer of insulation. Previously, White and Hodous [97] and White *et al.* [98] had studied the effects of different sets protective of firefighters and they explained that fatigue occurred more quickly, both at low intensity and in high intensity test, when the subjects wore the PC+SCBA. PC+SCBA have caused a high degree of stress characterized by fatigue that occurred after 25 min of working at low intensity, and after 4 min of high intensity work. Carter *et al.* [44] have shown that a period of firefighting exposure greater than 10 min without adequate rest and cooling may lead to a significant accumulation of heat stress and fatigue during further firefighting activity, irrespective of physical prowess.

Various studies [68, 93, 99, 100] have shown that the PC+SCBA does not favor thermoregulation, increases skin and internal temperature and decreases the rate of heat transfer due to the limited permeability to water vapor. Furthermore, the increase in the rate of sweating causes dehydration [101, 102] and reduction of the heat dissipation from the body [103, 104]. Taylor *et al.* [105] have investigated the overall impact upon performance during a maximal, job-related obstacle course trial and an incremental treadmill test to exhaustion (with and without protective equipment). The PC reduced exercise tolerance by 56% on a treadmill, with the oxygen consumption reserve being 31% lower while for the obstacle course, performance declined by 27%.

Research on thermoregulation in the firefighters and other professions that use PC has shown a continuous increase of rectal temperature during recovery in contrast with the decrease in HR [10, 106]. These events increase the threat of heat stress. To improve the regulation of body temperature, some authors [107, 108] have previously assumed the greater effectiveness of a PC that presents lower thermal protection. Carter *et al.* [44] have shown that an appropriate recovery can be achieved by removing the

PC+SCBA and placing itself in front of a fan. Gonzalez *et al.* [109] showed a 10% decrease in the thermal resistance of the PC of the firefighters, replacing long pants with shorts. Various studies [110, 111] have supported the decision to replace the uniform of the firefighters of New York City with shorts and T-shirt. In particular, Malley *et al.* [110] performed an exhaustion exercise on treadmill (15-20 min) in room temperature and showed that the use of shorts would make negligible the negative effect on the increase in internal temperature. The study of Chou *et al.* [112] examined the influence of wearing trousers or shorts under firefighting PC with phase change materials (PCMs) on physiological/subjective responses of firefighters. The results suggest that performance was improved while wearing shorts under PC with PCMs, although no significant difference in reducing thermal stress while wearing shorts instead of trousers was revealed.

COGNITIVE STRAIN

Studies on stress, due to strenuous firefighting activities performed in a hot hostile environment, showed initial impairment in cognitive function, particularly in searching for alternative solutions and making correct decision [112, 113].

Acute stress is a state that tends to occur in situations involving novel or infrequent problems, time pressure and high uncertainty [114, 115]. Noise or a secondary task can reduce the attention allocated to the primary task. Gohm *et al.* [116] assert that affective reactions may also draw attention and influence cognitive performance. Anxiety is an uncomfortable feeling related to apprehension or worry and it is a common affective reaction to stressors in the environment.

In view of the extensive literature on the physiological aspects of the firefighters, there is limited information on stress of the psychological component related to their work activities [3, 5]. Various studies [117, 118] have shown that the responses of high state anxiety, might affect cognitive functioning resulting in poor decisions. In fact, high or low levels of activation could lead to a poor performance and a considerable likelihood of injury risk during firefighters' emergencies. In fact, Kolt and Kirkby [119] claimed that the possibility of incurring an injury is increased by high levels of anxiety and stress.

Despite Smith *et al.* [10, 12] reporting significant increases in state anxiety during simulated emergencies, no significant change in the values of state anxiety was observed by Perroni *et al.* [16]. These results could be completely different in real conditions.

Previous study of Smith [10] showed that the ratio between the tympanic temperature and anxiety in high temperature condition was not significant and that although state anxiety decreased after 10 min post- simulated firefighting task has remained significantly elevated above pre-task. Kuorinka and Korhonen [120] showed high HR as exposure at high states of anxiety during the firefighters' operation and this result was not connected to job experience or fitness status.

HORMONAL AND METABOLIC ASPECTS

The work of firefighters is characterized by irregular events during the day and night shifts. Despite the high number of studies that have been conducted on the physiological functions of firefighting, few data [3, 5] are available about the hormonal responses to firefighters' activities. Studies in the literature [121-123] have highlighted the use of salivary cortisol (sC) and salivary alpha-amylase (sA-A) as a marker of hypothalamus pituitary adrenal axis. In particular, studies have shown an increased sA-A in response to social behavior [124-126], emotions [127] and written examinations [128]. Consequently, Perroni *et al.* [16] have analyzed the values of sC and sA-A after simulated intervention. They showed higher values of sA-A in the morning of the experimental session (102.3 ± 18.7 U/ml) than resting day (sA-A = 64.2 ± 10.9) and an increase of 174% compared to pre-simulated task. The basal sC showed lower values in the morning of the experimental session (11.3 ± 1.9 nmol/l) compared to resting day (16.7 ± 2.2 nmol/l), an increase of 108.5% after 30 min post-intervention.

Ray *et al.* [3] in order to elucidate behavioral response, plasma catecholamine levels and the prevalence of neurobehavioral symptoms evaluated 62 firefighters. Compared to their colleagues not engaged in firefighting, firefighters showed higher prevalence of neurobehavioral symptoms and also a more than two-fold rise in plasma levels of epinephrine and norepinephrine indicating stimulation of sympathetic activity.

Huang *et al.* [129] examined the changes in HR, catecholamine, pro-inflammatory cytokines, and lymphocytes in 9 professional male firefighters participating in two counterbalanced exercise conditions on a cycle ergometer: (1) 37 min of cycle ergometer at 60% VO_{2max} (exercise alone condition) and (2) 37 min of cycle ergometer at 60% VO_{2max} along with 20 min of a computerized firefighting strategy and tactics decision-making challenge (firefighting strategy condition). Firefighting strategy condition elicited significantly greater HR, catecholamine, pro-inflammatory cytokines, and lymphocytes when compared to exercise alone condition. These elevations suggested that the addition of a mental challenge to physical stress can alter the hormonal and immunological responses during firefighting. Previously, Huang *et al.* [130] have examined physiological responses (HR, VO_2, expiratory ventilation, blood lactate, sC, and leg strength) to a simulated firefighter activity (stair climb) in professional firefighters wearing rubber and leather boots. Leather boots elicited significantly greater sC values and knee flexion time to peak torque. Furthermore, rubber boots (RB) revealed significantly greater ankle dorsi-flexion peak torque after stair climb. Blood lactate was positively related to knee flexion peak torque after stair climb in the RB. Wearing the RB, firefighter may increase more force production and be effective at resisting fatigue. Conversely, a study of Turner *et al.* [131] showed that there were no significant effects of boot design (leather vs. rubber) on firefighters' metabolic and respiratory variables (minute ventilation, absolute and weight -related oxygen consumption, CO_2 production, HR, and peak inspiratory and expiratory flow rates) during simulated firefighting tasks.

TRAINING PROGRAMS

Despite the literature provides some insight on the physical demands of firefighting and on the specific guideline for physical conditioning [60], there is a lack of scientific data regarding the identification of an appropriate physical training program that adequately prepares firefighters. In fact, study of Dennison *et al.* [132] demonstrated that firefighters who train regularly and possess higher fitness levels tend to perform job-specific tasks more efficiently than do untrained and lesser fit firefighters. Investigation of Swank *et al.* [133] indicated that a benefit could be derived from an intervention program for all firefighters designed to maintain or increase VO_{2max}.

Hilyer *et al.* [134] have compared the effectiveness of two in-station fitness programs. One program included strength training and aerobic training equipment at each participating fire station, whereas the other program included only calisthenics and walk/run aerobic training. Firefighters who trained in stations with equipment made statistically significant improvements in four of six fitness measures. Firefighters who trained in stations without equipment did not improve their fitness measures. They suggested that the fitness improvements made by firefighters with access to equipment might be explained by: (a) greater physiological benefits, (b) motivational influence on the quantity and quality of work accomplished during the training sessions, and (c) the availability of the equipment could have influenced the amount of time spent in training during free time.

In this direction, data from study of Abel *et al.* [135] have indicated that a circuit-based workout may produce a similar anaerobic stress as compared to performing fire suppression and rescue tasks. They purposed that firefighters should perform high-intensity cardiovascular exercises and periodize circuit-training programs by using a range of training intensities and volumes for the aerobic and anaerobic strength/power demands of firefighting. The circuits should include 5–15 functional multi-joint exercises that simulate the movement patterns used for firefighters tasks (i.e. deadlift, stair climb with hose bundles, drag a rescue mannequin). Firefighters may be instructed to perform as many repetitions as possible within a predetermined exercise time. Brief recovery periods (i.e. 20–60 seconds) should be used between exercises, such that the work-to-rest ratio is approximately 1:1. Finally, it is important that the firefighters perform a warm-up, cool-down, and flexibility training during the training session.

Furthermore, various studies [23, 136] have shown that the use of fire PC impairs balance performance. Punakallio [136] showed that the postural balance was significantly poorer in the tests with the fire PC than in the baseline tests with the sportswear. For this reason, it is also essential to provide ample balance training opportunities for firefighters with and without fire PC.

Thus further research is needed to determine the influence of training on the performance and safety of fire fighters and to develop specific firefighting conditioning programs.

CONCLUSION

From analysis of the literature, we could observe how environmental, physical and emotional stress to which the firefighters are subjected during their work activities could lead to occupational hazards, injuries and even fatal events. Cardiovascular, thermal, and psychological responses deriving from the firefighters could be due to fatigue and this could compromise the health and safety of the firefighters. It is recognized that the increase in body temperature leads to a decrease in physical and mental performance. In addition, a physiological age-related decline could be expected during the occupational period of firefighters.

For these reasons, the success of job performance may depend on the ability of the firefighter to support intense physical activity. Adequate physical fitness programs and a periodic physical fitness evaluation are necessary to ensure that physically capable personnel perform this public safety occupation. A high fitness level can be crucial to the reduction of the risks inherent to the institutional activities of the firefighters.

It is useful to propose and develop initiatives relating the suitability of all firefighters through the establishment of a working group (i.e. exercise physiologists, psychologists, doctors and administrators) for the implementation of standard procedures for fitness health of all firefighters. A regular evaluation (i.e., annually) can provide a baseline for future comparison, identification deficiencies, and assistance in establishing personalized fitness and health-related goals. An adequate financial investment focused on the assessment and increase of physical capabilities of firefighters could effectively reduce the health risks linked to emergencies.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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Declared none.

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