

Firefighter Fitness: Improving Performance and Preventing Injuries and Fatalities

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Abstract

Firefighting is dangerous work. Each year, approximately 80,000 firefighters are injured and about 100 firefighters lose their lives in the line of duty. Firefighters face multiple dangers in the course of their work; they encounter toxic fumes, dangerous products of combustion, high radiant heat loads, and a chaotic work environment. Despite the myriad dangers, the leading cause of line-of-duty death among firefighters is sudden cardiac event, accounting for approximately 45% of duty deaths. Firefighting requires high levels of aerobic fitness, anaerobic capacity, and muscular strength and endurance; however, data suggest that many firefighters do not possess high aerobic or anaerobic capacity. Furthermore, many firefighters are overweight and have one or more modifiable risk factors for cardiovascular disease. The safety of the public and the health and safety of firefighters would be enhanced if firefighters followed well-designed fitness programs to improve overall health and fitness.

Introduction

Firefighters perform strenuous work in hostile, chaotic, and unpredictable conditions. Thus, firefighting is widely recognized as dangerous work. In 2009, there were 1.35 million fires in the United States, resulting in 3,010 civilian deaths, 17,050 civilian injuries, and an estimated total property loss of \$12.5 billion (25). There are approximately 1.2 million firefighters in more than 30,000 departments providing local communities with protection from fire and other hazards. Roughly 29% of the U.S. Fire Service is made up of career, paid firefighters, while the remaining 71% are volunteer firefighters (25).

Firefighters are a unique occupational group, and they face multiple dangers in the course of their work; firefighters encounter toxic fumes, dangerous products of

combustion, high radiant heat loads, and a chaotic work environment. In addition to hazards encountered at the scene of a fire, firefighters also perform rescues, extrications, emergency medical system (EMS) calls, and respond to natural disasters and hazardous materials spills. Attesting to the dangerous nature of the job, approximately 80,000 firefighters are injured on the job each year. More than 40% of the injuries occur on the fireground, despite the fact that firefighters spend a very small percentage of their time engaged in fire suppression activities. When expressed relative to the type of call they are responding to, approximately 23 to 25 firefighters are injured per 1,000 fires,

whereas only 0.6 to 0.7 injuries occur per 1,000 non-fire emergencies (24).

Firefighting also results in approximately 5.7 firefighter fatalities per 100,000 structure fires (13). A retrospective study, performed between 1995 and 2004, revealed that 1,006 firefighters had died in the line of duty during that period. Approximately 45% of those fatalities were the result of cardiovascular events. While most people recognize that firefighting is dangerous, many believe that fire or the products of combustion account for most of the fatalities in the Fire Service. As seen in Figure 1, the percentage of fatalities attributed to sudden cardiac events far outnumbered the deaths due to burn or asphyxiation on a consistent basis.

Physical Demands of Firefighting

Firefighting involves a unique set of stressors (Fig. 2). Firefighters perform strenuous muscular work; they must climb stairs and ladders, carry and use heavy tools, often above their head or in awkward positions, and they may be called upon to perform difficult rescue operations. Firefighters work in dangerous environments; they encounter extreme temperatures, toxic smoke (including carbon monoxide and hydrogen cyanide), and chaotic conditions that include loud noise and low visibility. Further, this work must be done with time urgency and is often performed under the psychological stress of knowing that civilians are

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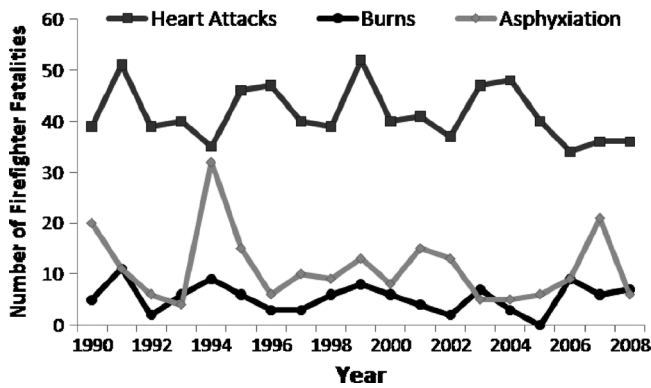


Figure 1: Firefighter casualty statistics from 1990 to 2008. Based on data from The National Fire Protection Association (NFPA).

in imminent danger. Additionally, firefighters must perform their work while wearing personal protective equipment (PPE), equipment that is necessary to protect the firefighter but that also imposes a considerable physiological burden because of its weight, insulative properties, and restrictiveness. The unique set of stressors that are encountered during firefighting results in substantial physiological strain, particularly to the thermoregulatory and cardiovascular systems.

Physiological Strain of Firefighting

Considering the work that is done and the environment in which it is performed, firefighting is among the most arduous work that humans undertake. Not surprisingly then, firefighting affects every system of the body. Figure 3 summarizes some of the major effects of firefighting on the body.

While firefighting results in significant physiological strain affecting nearly every system of the body, statistically the greatest risks to the firefighter come from the cardiovascular and thermal strain associated with firefighting. Strenuous firefighting activities lead to near maximal heart rates (HR) that can remain elevated for extended periods of time (1,38). Stroke volume decreases following strenuous firefighting activity (38). Firefighting may result in high blood pressures

that quickly drop below resting values following cessation of work (21).

Firefighting is associated with profuse sweating and hence a decrease in plasma volume. A 15% reduction in plasma volume has been reported after 18 min of strenuous firefighting drills (38). The decrease in plasma volume contributes to the reduction in stroke volume noted above and leads to hemoconcentration. Hemoconcentration causes a change in blood electrolytes and increases blood viscosity (39). Platelet number increases (more than can be explained by hemoconcentration) and platelet aggregability increases following firefighting activity (41).

Given that firefighters wear heavy, insulative PPE that often weighs in excess of 22 kg and are called upon to perform strenuous muscular work in very hot environments, it is no surprise that firefighting leads to thermal strain. Challenges to the thermoregulatory system include elevated core temperature (hyperthermia) and dehydration. Hyperthermia and dehydration are very serious problems in the Fire Service because these twin challenges can hasten the onset of fatigue and limit work time, add to cardiovascular strain, lead to fatal heat illnesses (including heat stroke), impair cognitive function, and increase the risk of injury.

Core temperature increases rapidly but does not reach drastically high levels during short-term firefighting. Periods of 18 to 20 min of firefighting have been reported to cause an average increase in body temperature of 1.5 to 2.5°F (21,40). Prolonged firefighting or repeated evolutions of training would cause greater elevations in body temperature. Firefighting, like other strenuous activity, leads to fatigue. The fatigue may be due to neural, metabolic, or muscular factors and is likely hastened by work in the heat. Fatigue can impair the firefighting mission and may increase susceptibility to injury.

Performance Requirements

Firefighting requires high levels of aerobic fitness, anaerobic capacity, and muscular strength and endurance. Additionally, given the detrimental effects of excess body fat, firefighters also should possess an appropriate body composition. Several studies have attempted to quantify the aerobic

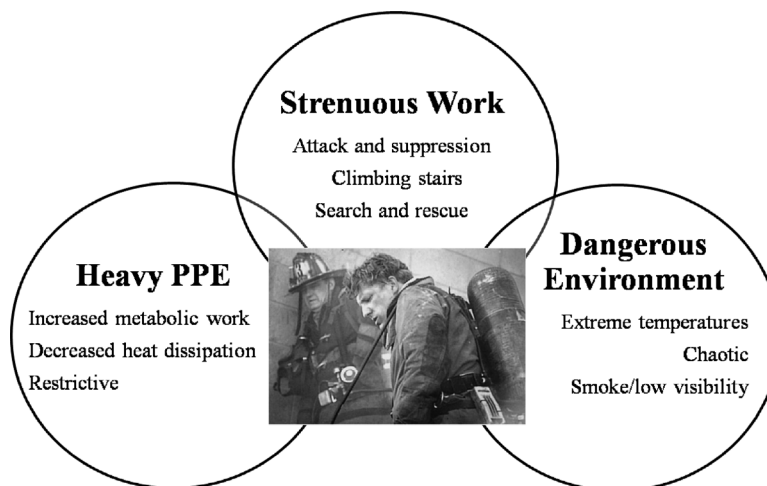


Figure 2: Unique job stressors. Stressors associated with firefighting include strenuous muscular work, heavy personal protective equipment (PPE), and a hot and dangerous environment.

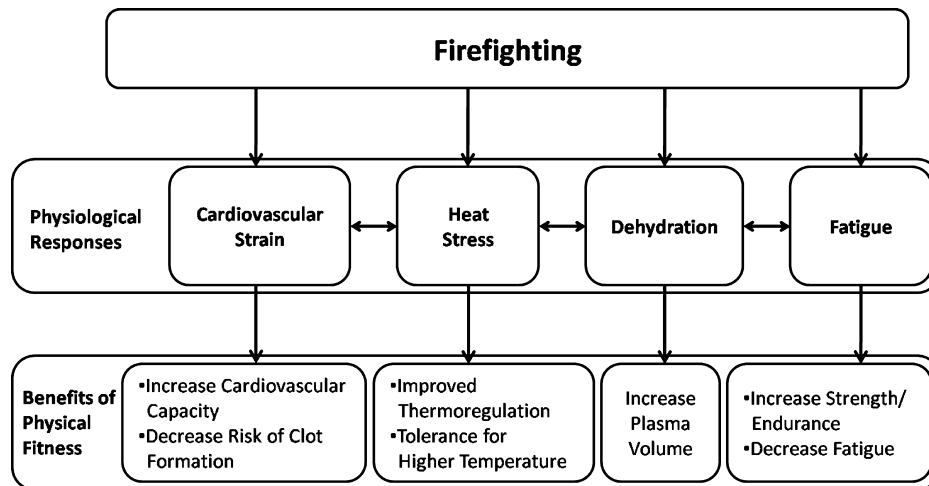


Figure 3: Primary physiological responses to firefighting and the benefits of physical fitness. Firefighting results in considerable physiological strain. A well-designed fitness program provides multiple benefits and helps prepare the firefighter for the demands of firefighting.

requirements of firefighting. A limitation to all of these studies is that they “simulate” firefighting activity. Further, the work that must be performed varies greatly based on the work assignment (*e.g.*, officer, venting, advancing a charged hose line, performing a rescue). Studies have reported the estimated oxygen consumption associated with firefighting to range between 33.6 and 49.0 mL·kg⁻¹·min⁻¹ (17,26,28,44). Sothmann and colleagues (1990) devised a simulated set of firefighting drills that took approximately 9 min to complete (44). The participants had an average $\dot{V}O_{2max}$ of 39.9 mL·kg⁻¹·min⁻¹ and worked at approximately 76% of their $\dot{V}O_{2max}$ to complete the simulated drills (44). To validate a minimum $\dot{V}O_{2max}$ requirement, the researchers recruited another group of firefighters ($\dot{V}O_{2max}$ range 26–51 mL·kg⁻¹·min⁻¹) and had them perform the fire-suppression drills. Seven of 10 firefighters with a $\dot{V}O_{2max}$ of 33.5 to 41.0 mL·kg⁻¹·min⁻¹ were able to successfully complete the drills within the allotted time. All participants with a $\dot{V}O_{2max}$ greater than 41 mL·kg⁻¹·min⁻¹ were able to complete the fire-suppression activities within the acceptable timeframe. Based on research findings, the National Fire Protection Association (NFPA) Standard on Occupational Medical Programs for Fire Departments recommends that firefighters have a minimal aerobic capacity of 42 mL·kg⁻¹·min⁻¹ (metabolic equivalent of task score, 12) (31).

Firefighters also must have a high anaerobic capacity to perform certain job tasks. Strenuous firefighting relies on anaerobic energy sources (in addition to aerobic sources) and high lactate values (6–13 mmol) have been reported following demanding firefighting simulations (2,17,26).

Muscular strength and endurance also are important to meet the physical demands placed on firefighters. Muscular strength and endurance are necessary for forcible entry, advancing the fire hose, chopping tasks, and victim rescues. Sothmann and colleagues (2004) have sought to validate minimally acceptable standards for muscular strength and endurance necessary to successfully perform firefighting tasks (43). Participants completed a simulated set of firefighting tasks and a battery of tests of physical abilities. The

researchers found that physical ability tests (hose drag/high rise pack carry, arm lift, and muscle endurance) combined to significantly predict performance time on the simulated firefighting tasks. Rhea and colleagues (2004) investigated the relationship between several fitness scores and job performance (assessed by performance time on a simulated hose pull, dummy drag, stair climb, and hose hoist) (34). These authors reported high correlations between measures of muscular strength, muscle endurance, anaerobic performance, and performance times.

Fitness Profile of U.S. Firefighters

Given the heterogeneous nature of the U.S. Fire Service, it is difficult to get an accurate, generalizable assessment of the “typical” firefighter. Firefighter fitness profiles are likely to vary greatly depending upon region of the country, career or volunteer status, the age of the firefighter, and the hiring, medical, and fitness policies of the department.

Aerobic Capacity

Despite the physically demanding aspects of the job, several studies have reported that firefighters do not possess above-average aerobic capacity. Again, caution must be used when interpreting the literature because many articles report fitness values on a small number of firefighters, from a single department or small group of departments. Furthermore, many of the aerobic fitness values reported in the literature are based on submaximal exercise tests. In general, reported aerobic fitness values for firefighters range from 35 to 56 mL·kg⁻¹·min⁻¹ (9,35,37,49). An early study that randomly sampled 150 firefighters from a large metropolitan city found that aerobic capacity significantly decreased from the 20- to 25-yr-old group (47.7 mL·kg⁻¹·min⁻¹) to the 30- to 35-yr-old group (37.9 mL·kg⁻¹·min⁻¹) and from the 35-yr-old group to the 40- to 45-yr-old group (31.5 mL·kg⁻¹·min⁻¹). In each case, however, the firefighters’ aerobic capacity was similar to that predicted for sedentary individuals (37). In contrast, Davis and colleagues (2002) studied a small municipal fire department on the West Coast and found that firefighters in the 20- to 29-yr age

group had an aerobic capacity of $55.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and that the oldest group, 50–59 yr, had an oxygen uptake of $40.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (9). In every decade-group, the firefighters' aerobic capacity was higher than age-predicted values (9). While it is tempting to hope that the improvements in aerobic capacity cited in the more recent study reflect positive changes relative to fitness patterns among the Fire Service, other evidence suggests that firefighters possess modest aerobic capacity (7,9,49). A study of over 100 recruit firefighters in a metropolitan fire department found that recruit firefighters entered the fire service with an aerobic capacity of $35 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (9). Encouragingly, the study went on to document a 28% increase in aerobic capacity following a 16-wk fitness program.

Muscular Strength and Endurance

In general, firefighters have high levels of muscular strength and endurance (2,9,29,34,35,43). Muscular strength and endurance are necessary to perform common firefighting activities, such as carrying ladders, advancing charged hose lines, and using heavy equipment. Firefighters rely on upper- and lower-body strength to perform their jobs. Further, core muscular strength also may serve to reduce the incidence of injuries (48). The high level of strength reported in the fire service also may reflect cultural values within the Fire Service.

Obesity

There is considerable evidence of a high prevalence of obesity among U.S. firefighters (7,12,16,42,46,50). Clark and colleagues (2002) investigated the body mass index (BMI) and health status of a group of municipal firefighters and reported that 80% of the firefighters were overweight or obese and that there was a significant increase in systolic blood pressure, diastolic blood pressure, cholesterol, and triglycerides as firefighters increased in fatness category (7). Conversely, $\dot{V}O_{2\text{max}}$ and METS decreased with increasing fatness (7). A study involving a large group of career firefighters ($N = 332$) found that at baseline testing, 53% of firefighters were overweight (BMI between 25 and 29.9), with an additional 35% classified as obese (BMI ≥ 30). Additionally, obese firefighters were more likely to have hypertension and low levels of high-density lipoprotein-cholesterol (42). A study of more than 100 career and volunteer firefighters with no known history of cardiovascular disease, stationed throughout Illinois, found an average BMI of 28.1 and that 75% of the participants had a BMI greater than 25 (12). Furthermore, Fahs and colleagues (2009) reported that increased BMI was associated with increased arterial stiffness (12). In addition to the high prevalence of overweight and obesity in the Fire Service, there is evidence that firefighters are getting heavier over time. Soteriades *et al.* (2005) found that over a 5-yr follow-up period, the prevalence of obesity increased from 35% to 40%, and the proportion of firefighters with extreme obesity increased fourfold (from 0.6% to 2.4%) (42).

Cardiovascular Risk

Most studies that have compared the overall cardiovascular mortality of firefighters with the general public have found that firefighters do not have an increased risk

for cardiovascular death, except in instances where the careers of firefighters included significant time on the job before the use of respiratory protection (11). Studies in Boston, Connecticut, New Jersey, San Francisco, Seattle, Edmonton/Calgary and Florida all have found no association between cardiovascular mortality and occupation (3,10,14,18,27,30,36,47). Similarly, a recent review found that firefighters have similar risk profiles for obesity, hypertension, and hyperlipidemia compared with the general population (11).

Mismatch Between Fitness Demands and Fitness Profiles

Given that so much of a firefighter's time is sedentary, perhaps it is not surprising that they do not differ from the general population in fitness, obesity, or other cardiovascular risk factors. However, considering that their work is punctuated by periods of intense activity, these risk profiles may explain why sudden cardiac events are the leading cause of line-of-duty deaths among firefighters; essentially, there is a mismatch between the fitness and health requirements of strenuous firefighting and the current fitness profile of the U.S. Fire Service.

Fitness Recommendations

Current standards recommend that firefighters participate in a fitness program (22,32), but it is the responsibility of each individual department to determine whether to institute a fitness program. The NFPA 1583 Standard recommends a program that is positive, nonpunitive, and does not set fitness standards. Of the 440 firefighter fatalities investigated by the National Institute of Occupational Safety and Health (NIOSH) during the period from 1995 to 2004 (44% of fatalities during that period; 440 of 1,006), 39% of the departments offered a voluntary fitness program, but only 8% had mandatory participation (33).

Cardiovascular events are by far the leading cause of line-of-duty deaths among firefighters. Additionally, cardiac events are disproportionately related to fire suppression activities, with firefighters having a 10- to 100-fold increased risk of experiencing a fatal cardiac event after fire suppression versus normal duties at the station (23). Thus firefighters should have a high level of cardiovascular fitness in order to improve performance and decrease the risk of on-the-job fatalities associated with strenuous activity. Additionally, nearly 80,000 firefighters are injured each year, with a large percentage of these injuries occurring during fireground operations. Clearly, fitness has an important role to play in preparing firefighters for the strenuous activity they encounter during firefighting activity. Appropriate fitness programs can enhance overall health, improve performance, and lessen the risk of firefighter injury or fatality. Firefighters and the public they serve will benefit from more fitness programming in the Fire Service.

Fitness Prescription for Firefighter Health and Safety

Firefighting is strenuous physical work and places considerable strain on the body. In order to meet the unique physical demands of firefighting and to perform firefighting in a safe manner, firefighters must be physically fit. Like soldiers and elite athletes, firefighters should be physically

prepared to meet the unique physical challenges they face. Figure 3 depicts the direct ways in which a fitness program can mitigate against the physiological strain of firefighting.

Fitness prescriptions for firefighters must meet certain criteria in order to adequately serve the U.S. Fire Service. Prescriptions need to address the unique and specific physiological demands of firefighting. This is difficult to accomplish because of the current diversity in fitness and health status of firefighters. Fitness prescriptions must recognize the unique structure and culture of volunteer and career fire departments. These prescriptions also must include individual and progressive programs to meet the individual needs of low-fit to highly-trained firefighters.

Aerobic Training

Aerobic training provides several health benefits, including improved body composition, serum lipids, glucose metabolism, and maximal aerobic capacity (20). While moderate-intensity aerobic exercise (50%–70% HR_{max}) is widely recommended for health benefits, research suggests that higher-intensity aerobic exercise training may promote weight loss and cardiovascular improvements to a greater extent (8). Given the physical demands of firefighting, and the high proportion of line-of-duty deaths attributed to cardiac events, it is essential that a training program for firefighters include endurance training.

Sprint Interval Training (SIT)

SIT is a type of high-intensity interval training (HIT) that is designed to improve endurance, increase anaerobic threshold, and improve maximal performance. This type of training has been shown to be effective at increasing aerobic capacity (6), improving endurance capacity when working at 80% of aerobic capacity (4), enhancing aerobic metabolism (19), and increasing muscle glycogen content and the maximal activity of citrate synthase (5). Given the effectiveness and efficiency of these workouts and the degree to which they mimic actual energy expenditure during an emergency, it is reasonable to include SIT in exercise prescriptions for firefighters. However, given the high intensity of the workouts and the heterogeneity of fitness levels in the Fire Service, it may be prudent to initiate exercise programs at a lower intensity and increase progressively.

Functional Training

Functional training targets movements that are necessary for activities of daily living (45). Functional training utilizes full-body, dynamic movements to increase muscular strength and endurance as well as aerobic capacity using equipment such as medicine balls, physioballs, and exercise bands to provide resistance. This type of exercise mimics the high-intensity demands of firefighting. In fact, functional training workouts have been gaining popularity among progressive Fire Departments. CrossFit workouts are now embraced by many members of the Fire Service.

Resistance Training

Resistance training increases muscle mass and function. Muscle strength and endurance routinely have been found to predict performance on simulated firefighting activities and are unquestionably important for firefighters. Additionally, resistance training is associated with a decreased risk of

all-cause mortality, the development and maintenance of lean muscle mass, and enhanced glucose metabolism (15,20). Resistance training should be part of every firefighter's fitness program. Not only will it improve work capacity, it is likely to provide protection against injuries, especially muscular strains, on the fireground.

Lifestyle Modifications

There must be a cultural change within the U.S. Fire Service in order to improve fitness and decrease injuries and cardiac events. Changes should include a fitness program designed to improve aerobic capacity, muscle strength and endurance, and functional capacity. The fitness program and a sound dietary plan also should seek to promote healthy weight for firefighters. The development of a social support system with adequate leadership and incentives should promote healthy lifestyle changes. Each individual firefighter and Fire Department must set short- and long-term goals that are realistic and measureable as well as easy to implement within the constraints of space, equipment, and other duties.

Conclusion

Firefighting is strenuous and dangerous work with a unique set of stressors. In order to meet the physical demands of firefighting, firefighters must be physically fit. Firefighters who possess high levels of cardiovascular and muscular fitness are better able to serve the public by performing their job more effectively. Fit firefighters have increased mobility, energy, and endurance, allowing them to better perform job duties efficiently and safely, and fit firefighters also are less likely to jeopardize the safety of their fellow firefighters or the public they serve.

The safety of the public and the health and safety of firefighters would be greatly enhanced if firefighters followed well-designed fitness programs to improve overall health and fitness. Exercise scientists can play an important role in enhancing firefighter's fitness, thereby improving public health and safety. Specific fitness programs that meet the needs of a broad range of individuals within the Fire Service must be developed that are tailored to the specific job requirements that firefighters face. These fitness programs should be geared toward improving health, safety, and performance. In order to be adopted, these programs must be sensitive to the diverse needs in the Fire Service.

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