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Review

The Impact of Firefighter Physical Fitness on Job Performance: A Review of the Factors That Influence Fire Suppression Safety and Success

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Abstract: Purpose: The objective of this review was to analyze the physiological impact of fire suppression on the human body. Design: The literature review included studies focused on workload requirements for common firefighting tasks, effect of health status on the firefighting profession, and attempts to establish a minimum physiological workload capacity for successful performance of firefighting. Findings: The existing literature provides evidence of the high degree of physiological stress that firefighters are under during fire suppression tasks and the great degree of maximal physical capacity that firefighting often requires. Firefighters often operate close to maximal aerobic capacity while performing tasks common to the profession. This is especially true due to the added physiological stress placed on the human body while wearing personal protective equipment during firefighting. Conclusions: Future investigations are necessary to further explore markers of physiological stress during firefighting and the impact that it may have on the ability to withstand the development of disease as well as fire suppression safety. Using completion time of fire suppression tasks as a criterion of success may be an important consideration in addition to the physiological requirements of the occupation when assessing the appropriateness of an individual to be a firefighter. An important future consideration is the effect that fire suppression activities may have on reaction time in critical situations in which life-and-death decisions must be made.

Keywords: firefighting; occupational ergonomics; tactical performance; applied physiology

1. Introduction

Based on data received by the National Fire Protection Association (NFPA) from responses to the 2016 National Fire Experience Survey, Haynes and Molis [1] reported that an estimated 62,085 firefighter injuries occurred in the year, 2016, alone, with 39.2% of these injuries occurring on the fire ground. The leading cause of fire ground injuries in the 2016 NFPA survey was overexertion or strain (27.1%) while another leading cause of injury was due to falls, jumps, or slips (21.0%) [1]. The wearing of protective turnout gear and personal protective equipment (PPE) can pose a substantial challenge in addition to the tasks necessary for firefighting. Turnout gear has been shown to substantially increase the experience of a heat load in addition to the typical increases in muscular strain and decreased freedom of movement [2,3]. The inability to lose body heat through evaporation due to the necessary protective layers of the turnout gear decreasing water vapor permeability can increase the risk for thermoregulatory dangers [4].

The physiological requirements for tasks commonly performed by firefighters has been studied by a number of authors. Firefighters commonly must bend down or stoop while walking or even crawl to stay below the smoke that rises to the ceiling or to avoid debris above their heads [5]. The act of altering posture from upright walking to stoop-walking requires a marked increase in energy expenditure (EE) [6]. The metabolic cost of stoop-walking increases as the posture is further stooped or bent over [6]. Search and victim rescue is considered one of the most demanding and physiologically stressful tasks that a firefighter may need to conduct in a firefighting scenario [7]. It has been reported that the average heart rate (HR) exhibited during this activity can be around 153 beats per minute (bpm) with a core temperature increase of about 1.3 °C [7]. A more recent study evaluated the physiological response of firefighters to crawling while wearing full turnout gear and equipment during a similar search and victim rescue task [5]. This group reported that the participants during this task were on average at about 88% of their maximum HR (HR_{max}) [5]. The mean difference between the standing HR and the crawling HR was 97 bpm, illustrating the physiological workload placed on the body by crawling [5]. These same authors reported that the duration of the crawling search and rescue exercise lasted between 14.4–21.0 min and that of the 25 firefighters that were tested, five completely exhausted the oxygen contained in the tank of their self-contained breathing apparatus (SCBA) and 16 had drained their SCBA tank to below 25% remaining, exhibiting a critically low level [5]. Therefore, 84% of the firefighters had depleted their SCBA tank of oxygen to a critical level within the length of time that it took to complete the search and rescue exercise that was meant to mimic an actual firefighting scenario [5]. This is compounded by the fact that the wearing of the SCBA has been shown to reduce performance capacity by as much as 20% at maximal workloads [8,9].

Climbing stairs or rungs on a ladder is a common task for firefighters. O'Connell, Thomas, Cady, and Karwasky [10] reported that when firefighters completed a stepping exercise at 60 steps/min for 5 min to simulate climbing stairs while wearing full turnout uniform and equipment weighing 39.3 kg led to substantial increases in both heart rate (HR) and oxygen consumption (VO_2). HR reached an average of 95% of the maximum during this workload and VO_2 reached 80% of the maximum [10]. Additionally, McClellan and Selkirk [4] recommended not using HR as an index of heat strain for firefighters due to the typical fall in HR seen during recovery despite a rise in core temperature. With the average age of the firefighters in the study being 34 years old, this exercise HR would correspond to performing at approximately 82% of the HR_{max}; making this a vigorous-intensity exercise [7,11].

More recent work has reported an average rise of 1.9 °C over a 3 h firefighting period that continued to rise with each work cycle, despite intermittent breaks of at least 30 min [12]. Horn et al. [12] reported the average rise in core temperature to be between 0.036–0.048 °C per minute of firefighting activity. The elevated HR response combined with the rise in core temperature places a considerable challenge on the body, especially considering the additional equipment and clothing that is typically required during firefighting. An encouraging development is that Coca et al. [2] has reported that the newer prototype firefighter turnout gear, which has additional protective capabilities for chemical and biological hazards, did not decrease the overall functional capability compared to what was considered the standard turnout gear. However, this research group did state that participants wearing this new gear did seem to be less comfortable compared to the more traditional gear [2]. Coca et al. [3] recommend that a comprehensive evaluation of PPE is needed in order to maximize firefighter protective capabilities without compromising performance ability. Louhevaara et al. [9] recommended that due to the necessity of wearing the SCBA and turnout clothing (total weight typically at least 25 kg) for proper safety while firefighting and the effect that it has on physical performance, the firefighting profession should only employ healthy individuals who are in sufficient physical shape.

2. Effect of Health Status on Firefighting

With the research reporting that carrying added weight leads to an increased cardiovascular and metabolic load, it would make sense that carrying additional unnecessary weight could lead to added physiological stress as well. Excess body fat not only has an effect on decreasing exercise efficiency, but also limits mobility and the capacity to dissipate heat [13]. Additionally, with an abnormally elevated blood pressure being an important risk factor for heart disease and related cardiovascular issues, a firefighter should aim to maintain a normal resting blood pressure without requiring medical control [13]. Therefore, it is likely that as the blood pressure climbs during exercise, the level of elevation will be within normal limits. Kales, Polyhronopoulos, Aldrich, Leilao, and Christiani [14] conducted medical evaluations on 333 firefighters and found that the mean body mass index (BMI) was 28.9 kg/m^2 (placing them in the overweight category). They reported that 51% of the firefighters that they evaluated fell in the overweight category (BMI $\geq$ 25.0 kg/m^2), 34% fell into the obese category (BMI $\geq$ 30.0 kg/m^2), and 2% were considered morbidly obese (BMI $\geq$ 40.0 kg/m^2) [14]. Taking these values together, based on the Kales et al. [14] data set, 87% of firefighters were considered either overweight or obese. This data has been supported by similar work, which used the BMI as a means for healthcare preventative screening among professional firefighters [15]. Of the 218 firefighters assessed, the mean BMI was 28.8 kg/m^2 and 48% were considered overweight, 29.8% were considered obese, and 2.3% were considered morbidly obese [15]. Poston et al. [16] reported similar findings in that 79.5% of 478 career firefighters and 78.4% of 199 volunteer firefighters were overweight or obese. In regards to obesity status, 33.5% of career firefighters were considered obese and 43.2% of volunteer firefighters were considered obese [16]. Munir et al. [17] reported that 53% of a sample of 1,232 firefighters were classified as overweight and 13% were classified as obese. Additionally, significant inverse relationships have been reported in firefighters between BMI and blood pressure, aerobic capacity, and total cholesterol [15]. These results demonstrate the potentially high prevalence of overweight and obesity in the firefighting profession [14–17].

Mittleman et al. [18] described the triggers of experiencing a myocardial infarction (MI) and established the frequency by which they occur following strenuous physical labor. It has since been well established that performing strenuous physical work often precedes, or even initiates, the experiencing of an MI [18]. Cady, Thomas, and Karwasky [19] conducted physical work capacity, strength, and flexbility evaluations and reported that firefighters who are considered unfit by this battery of testing are 2.6 times more likely to suffer a myocardial infarction (MI) than firefighters who are considered fit. Washburn, LeBlanc, and Fahy [20] reported that the number one cause of death of firefighters is the experience of a MI. Davis and Gallagher [5] noted the near maximal HR that can be experienced while conducting tasks relative to firefighting while wearing full turnout gear and therefore could potentially be associated with an increased risk of experiencing a cardiovascular event, such as an MI. Calavalle et al. [21] reported that the main factors that influence the performance of a firefighting simulating stair-climbing test are the ability to carry a heavy load (22.8% of total variance), effect of excessive body fat (19.6% of total variance), age (19.3% of total variance), and fitness level (16.4% of total variance). This implies that while fitness levels are important to the performance of tasks related to firefighting, the carrying of a load (which is common in firefighting) and potential excesses of body mass are the most important variables to consider [21]. This supports previous findings by Perroni et al. [22] that even firefighters who are considered experts in their field can experience a severe physiological challenge based on unpredictable environmental conditions, especially if they lack an adequate level of fitness. Combining these results together, performing heavy physical labor while wearing full turnout gear can elicit near maximal HRs that for a person who is considered overweight or obese, can substantially increase the likelihood of experiencing a cardiac event [5,20,21].

Recent evidence has indicated that even in fit and active adults, reaction time can be significantly hindered and perceived exertion is significantly higher when wearing a 75 lb weighted vest to simulate the wearing of PPE while performing a simulated firefighting task [23]. Morris et al. [23] exhibited evidence that just the added mass alone of the simulated PPE significantly hampered reaction time. If reaction time is hindered, decision making may be delayed, potentially leading to an increase in the risk of injury to the firefighter or another individual as a potential emergency victim. Combining the findings of Morris et al. [23] with previous findings by Perroni et al. [22], even firefighters who are considered experts in their field can experience a great degree of physiological stress, especially if they lack an adequate level of fitness. For the firefighter who is overweight or obese, carrying extra fat mass (as well as this fat mass trapping a substantial amount of extra heat) can potentially lead to the increased likelihood of experiencing a cardiac event [13,21,24].

3. Markers of Physiological Stress during Firefighting

Firefighting can be one of the most physiologically stressful professions, not only due to the threat of fire and smoke to the firefighter, but also for the task at hand of protecting and/or retrieving a potential victim as a first responder to an emergency. The risk of thermal stress experienced by a firefighter's body is increased by the potential trapping of body heat by the protective turnout gear in addition to any heat gained by the body from the surrounding environment [5]. The inability to lose the increasing amount of trapped body heat leads to peripheral vasodilation in an attempt to decrease the level of thermal strain placed on the body, potentially leading to increased cardiovascular demands, which may lead to firefighters having an increased likelihood of experiencing a cardiovascular event or heat illness/emergency [5,20,25]. McLellan and Selkirk [4] noted the recovery times needed for firefighters wearing protective turnout gear and various methods that can be employed to lead to a more expedient loss of stored body heat. In this study, a heat stress level and recommended response flowchart used by firefighting commanding officers of the Ontario, Canada Fire Department to their firefighters was included [4]. Based on their findings, recovery from a bout of fire suppression can be greatly improved by replacing uniform pants worn under PPE with shorts, increasing fluid replacement of up to 65% of fluid lost through sweat, and employing active cooling methods through arm and hand cold water immersion [4]. In a recent study, Morris et al. [26] reported that a simulated fire stair climb while wearing athletic attire (shorts and t-shirt) along with a weighted vest to simulate PPE was enough to substantially elevate the physiological strain index (PSI) above what would be expected solely due to the exercise alone. PSI is calculated based on a previously published equation [27] and uses measurements of HR and core temperature to gauge the degree of physiological stress that an individual is experiencing on a 0–10 scale (0 representing no physiological stress and 10 representing severe physiological stress). The participants in the study experienced a "moderate" degree of physiological strain even while wearing clothing that allowed heat to escape naturally [26]. This study did not have their participants wear full turnout gear, so a future study should evaluate to what degree the wearing of full turnout gear that is well established to trap heat can lead to further elevations in the degree of physiological strain.

Collins [28] notes that the ability to identify alterations in autonomic nervous system activity may allow for a quantification of stress exposure and the potential effect of multiple ongoing stressors to potentially determine the underlying risk factors for stress-related diseases or conditions, as well as leads to methods for monitoring on-the-job stress. Smith, Petruzzello, Chludzinski, Reed, and Woods [29] studied the physiological and psychological stress response to a live firefighting emergency by measuring plasma levels of adrenocorticotropic hormone (ACTH), cortisol, and levels of leukocytosis and lymphocytes. Levels of ACTH and cortisol may be elevated in response to a stressor and these elevations may be tied to a suppression of the immune system, potentially leading to an increased susceptibility to infection [29,30]. Smith et al. [29] reported that in response to a live firefighting emergency, firefighters displayed elevated levels of plasma ACTH and cortisol that remained elevated above normal levels for 90 min after ceasing firefighting. Relatedly, there was shown to be a significant amount of leukocytosis as well as a decreased amount of lymphocytes measured immediately after firefighting that continued in the 90 min following firefighting [29]. Walker et al. [24] reported similar findings in a firefighting simulation exercise in a heat chamber. Results showed that increases in immune system markers {leukocytes, interleukin-6 (IL-6), tumor necrosis factor alpha (TNF-α)} occurred simultaneously with each increase in core temperature [24]. In addition, the platelet number exhibited an increase in response to increased core temperature as well, potentially increasing the likelihood of a cardiac event occurring when a firefighter performs repeated fire suppression tasks without allowing proper heat dissipation [24].

Smith et al. [29] also assessed the psychological stress level and the firefighters studied reported a decreased perception of energy, which was found to have a relationship to the elevation in stress hormones in that those who had the highest level of cortisol in their blood also reported their feelings of energy to be the lowest [29]. These findings are potentially rather complex in that the changes that were noted differed based on the timing of measurement as well as the inability for the firefighters to return to the baseline level of perception of energy after the 90 min of recovery [29]. These findings also support the importance of work-rest cycling for firefighters [29]. Of important practical consideration, this substantial physiological and psychological disturbance experienced by the firefighters suggests that the potential depression in immune system function also experienced by the firefighters could potentially create a substantial occupational hazard in that given that firefighters are often the first responder to many types of emergencies, this period of increased susceptibility to infectious diseases could lead to victims who have the capability to transmit a disease, thus transmitting that disease to the firefighter [29].

4. Using Completion Time as a Criterion of Success

In addition to setting a minimal physiological threshold to be achieved for consideration for safety or success in fire suppression, a number of researchers have also used time to completion of a simulated job performance assessment as a measure of successful performance [31–33]. Sothmann et al. [33] described the phenomenon of flashover as the point that spontaneous combustion occurs when increases in temperature and flammable gases are trapped within a contained environment. Considering that any other definition of success related to the destruction of property or potential deaths is difficult to quantify as an acceptable amount, using time as a measure of success could be a more easily definable and measurable variable [33]. Dreger and Petersen [31] reported that a strong relationship existed between predicting the average time to completion for a firefighter job simulation task with the VO_2 required of the task (34.1 mL/kg/min). The need to complete a live firefighting response in a reasonable amount of time is more likely to be completed quicker by those with a higher aerobic capacity or fitness level than those who are considered less fit [33]. Louhevaara et al. [32] made a similar recommendation that those who are able to complete a fire suppression task in a more reasonable amount of time are more likely to maintain their physiological efficiency and safety during the emergency response.

An important consideration for why using time to completion of a simulated firefighting workload would be important can be directly related to the finding by Turner et al. [34] that for every 9.2% increase in ventilatory equivalent during simulated firefighting, it would result in a decrease of an estimated 3–4 min in service time for an SCBA cylinder with a 45 min capacity. While this certainly highlights the importance of workload intensity to the firefighting tasks, it also underlines the importance of completing a firefighting task in an efficient amount of time due to the limitation of the capacity of the SCBA tank [5,34]. Considering that the core temperature tends to rise on average about 0.048 °C per minute, firefighters could also see their core temperature climb to dangerous levels within 60 min of firefighting activity [12].

5. The Support for the Establishment of a Minimum Physiological Workload Capacity for Fire Fighting Safety and Performance

A number of studies have evaluated the physiological requirements of differing firefighting tasks in an attempt to better understand the minimal threshold workload that should be able to be cleared by an experienced firefighter [5,9,10,21,32,33,35,36]. These studies are summarized and presented in Table 1. In addition, there has been a concerted effort to attempt to establish a minimum required physiological workload achievement of both new and existing firefighters. The aim has been to assess the necessary minimally required physical performance ability of new and existing firefighters in an attempt to ensure safety as it pertains to the ability of the firefighter to be able to complete the task as safely as possible [12,21,31–33,35–41]. These studies are summarized and presented in Table 2.

Table 1. Physiological cost of firefighting tasks.

Study	Sample Size	Findings and Descriptions of Firefighter Sample
Louhevaara et al. [9]	9 (9 M, 0 F)	Protective clothing and SCBA increased physiological workload requirement of 2.1–2.8 L/min (54–75% of VO_2 max) during simulated firefighter tasks.
O'Connell et al. [10]	17 (17 M, 0 F)	Aerobic consumption (VO_2) of 39.0 mL/kg/min (11.1 METs) was reported to be the minimal threshold necessary for a person to successfully complete a fire suppression simulation task. This value (39.0 mL/kg/min) corresponded to 97% of the sample's average VO_2 max.
Sothmann et al. [33]	136 (136 M, 0 F)	Completing simulated firefighting task while wearing protective gear required VO_2 of 30.5 ± 5.6 mL/kg/min (76% of average VO_2 max) (8.7 METs).
Gledhill & Jamnik [35]	8 (8 M, 0 F)	90% of firefighting operations evaluated required a $VO_2 \geq 23$ mL/kg/min (corresponded to 50–85% of VO_2 max) (6.6 METs). The most physiologically demanding firefighting tasks required a mean VO_2 of 41.5 mL/kg/min (range of 36.6–44.0 mL/kg/min) (average 11.9 METs, range of 10.5–12.6 METs) led to a peak blood lactate concentration of 6–13.2 mMol/L.
Sothmann et al. [40]	10 (10 M, 0 F)	Predicted VO_2 of 25.6 ± 8.7 mL/kg/min (7.3 ± 2.5 METs) (63 ± 14% of sample's VO_2 max or MET max of 11.6 METs) during fire suppression emergencies.
Holmer & Gavhed [36]	15 (15 M, 0 F)	Mean VO_2 during simulated firefighting tasks (which lasted ≈ 22 min) was 2.75 ± 0.291 L/min (Average HR response was 168 ± 12 bpm). Most physically demanding simulated firefighting task required an average VO_2 of 3.55 ± 0.271 L/min (Average HR response was 179 ± 13 bpm).
Calavalle et al. [21]	35 (35 M, 0 F)	Reported that simulated job performance assessment led to an average HR reserve (HRR) percentage of 82.5 ± 9.9% of HRR.

MET = metabolic equivalent (1 MET = 3.5 mL/kg/min).

Table 2. Recommendations for establishment of a minimum threshold of physiological performance for firefighters.

Study	Sample Size	Recommendations for Physical Performance Ability of Firefighters
Davis & Gallagher [5]	14 (14 M, 0 F)	Mean HR experienced during simulated firefighting crawling task was on average 174 ± 12.6 bpm (corresponding to 80.0 ± 0.1% of HRR).
Lemon & Hermiston [38]	45 (45 M, 0 F)	Noted decline in strength with age. Professional firefighters (especially those over 40) should develop and maintain a certain level of fitness.
Kilbom [37]	417 (417 M, 0 F)	Firefighters should be able to perform exercise on a cycle ergometer at an intensity of 200 W for 6 min (equivalent of ≈ 2.8 L/min) before being allowed to participate in fire suppression emergencies in a SCBA. Firefighters >50 years old should not be permitted to perform any fire suppression activity necessitating the use of an SCBA.Criteria at pre-employment should be more stringently tied to overall workload capacity.
Louhevaara et al. [9]	9 (9 M, 0F)	Use of protective clothing and SCBA suitable only for fit individuals with a healthy cardiovascular system.
Sothmann et al. [33]	136 (136 M, 0 F)	Sensitivity of use of 33.5 mL/kg/min (9.6 METs) value for successful completion of simulated firefighting task (determination of true "unsuccessful performances"): 67%. Specificity of use of 33.5 mL/kg/min (9.6 METs) value for successful completion of simulated firefighting task (determination of true "successful performances"): 83%. VO_2 max of 39.5 mL/kg/min (11.3 METs) was considered the minimal threshold that enabled most of the firefighters to effectively complete the simulated firefighting table with a successful time.
Gledhill & Jamnik [35]	8 (8 M, 0 F)	Recommended a minimum VO_2 max for firefighters of 45 mL/kg/min (12.9 METs).
Sothmann et al. [40]	10 (10 M, 0 F)	Support previous recommendations for a minimum VO_2 max for firefighters ranging from 33.5–42.0 mL/kg/min (9.6–12.0 METs).

Table 2. *Cont.*

Study	Sample Size	Recommendations for Physical Performance Ability of Firefighters
Louhevaara et al. [32]	59 (59 M, 0 F)	Firefighting simulation drill successfully completed for those firefighters possessing a VO_2 max ≥ 40 mL/kg/min (11.4 METs).
Williford et al. [41]	91 (91 M, 0 F)	Successful completion of a simulated job performance assessment of firefighting tasks reported significant correlations with total grip strength, fat-free weight, height, pull-ups completed, push-ups completed, 1.5 mile run time, sit-ups completed, body weight, and body fat percentage. Best multiple predictor of successful completion of simulated job performance was 1.5 mile run time, fat-free weight, and pull-ups completed (explaining 53% of the total variance).
Rhea et al. [39]	20 (17 M, 3 F)	Simulated job performance assessment reported significant correlations with total fitness, muscular strength measures (bench and hand grip), muscular endurance measures (bent-over row, bench press, shoulder press, bicep curl, and squat), and 400-m sprint time.
Dreger & Petersen [31]	53 (30 M, 23 F)	Simulated job performance assessment associated with an 8-min completion standard required a VO_2 of 34.1 ± 4.0 mL/kg/min (9.7 ± 1.1 METs).
Holmer & Gavhed [36]	15 (15 M, 0 F)	Recommended that those performing a firefighting workload of at least 475 W/h for 15–20 min have a minimum VO_2 of 2.45 L/min. Recommended that those performing a firefighting workload of at least 600 W/h for <5 min have a minimum VO_2 of 3.10 L/min.
Calavalle et al. [21]	35 (35 M, 0 F)	Simulated job performance assessment reported four significant predictors of performance success: Capacity to carry extra load, and the effect of body fat, age, and overall fitness level.

MET = metabolic equivalent (1 MET = 3.5 mL/kg/min).

6. Effect of Boot Type

A handful of studies have considered the potential impact that boot selection may have on physiological responses to a simulated firefighting workload. Huang, Garten, Wade, Webb, & Acevedo [42] evaluated the physiological parameters to a stair climb in firefighters while wearing a rubber firefighting boot and a leather firefighting boot. These researchers [42] reported a lack of a significance difference in cardiovascular and metabolic responses (HR, oxygen consumption, blood lactate) as well as no significant differences in leg strength parameters in response to wearing the two types of boots. However, the leather boot was reported to elicit a higher salivary cortisol value, suggesting that this type of boot may potentially lead to an increased likelihood of experiencing a higher stress response and potentially earlier onset of fatigue [42]. The rubber boot actually weighed more (approximately 0.5 kg), but did not lead to a higher experience of fatigue [42]. This perhaps suggests that a rubber boot, compared to a leather boot, may provide a more efficient footwear for firefighting [42]. The authors hypothesize that the more flexible nature of the rubber boot may allow a greater degree of flexibility and range of motion (ROM) for lower extremity movement [42]. Turner et al. [34] made a similar comparison, having participants wear full turnout clothing and PPE while carrying a hose that weighed 9.5 kg. Participants also exercised on a stair ergometer, but without carrying the hose. During the exercise on the treadmill, results showed that the 1 kg increase in boot weight for the rubber boots led to significant increases (3–10%) in cardiovascular parameters (HR and oxygen consumption) [34]. While differences on the stair ergometer were reported, they were not considered large enough to be of practical significance, supporting previous work by Huang et al. [42]. In contrast, Garner, Wade, Garten, Chander, and Acevedo [43] reported that firefighters wearing rubber boots experienced significantly greater muscular fatigue, leading to larger decreases in lower extremity peak torque compared to a leather boot. Garner et al. [43] continued by suggesting that the additional weight of the rubber boot may be the causative factor for the increased experience of muscular fatigue by the firefighters, potentially leading to a lowered ability to produce force at a time of need during an extended period of performing fire suppression.

Chiou, Turner, Zwiener, Weaver, and Haskell [44] emulated earlier work and added the additional variable of sole stiffness. Four boots were considered, with each either having a stiffer or more flexible sole. An important finding was that oxygen consumption increased with the less flexible boot sole, suggesting that the greater the boot sole flexibility, the lower the oxygen consumption [44]. Of practical significance, the increase in ventilation combined with the 1 kg increase in boot mass could result in a decrease in capacity of the SCBA tank of approximately 3 min [34,44]. The authors noted that while a mechanism for this difference was currently unknown, it could be perhaps tied to prior reporting by Cikajlo and Metjacic [45] that increases in boot sole flexibility could result in an improved gait energy efficiency, leading to a lowered oxygen consumption [44]. This will be an important area of future study to potentially confirm this hypothesis.

An important consideration in regards to boot type is the likelihood of maintaining balance while performing fire suppression. In a recent study by Chander, Garner, and Wade [46], firefighters performed multiple slip trials in which they walked across a floor, which was either covered with a slippery substance or not. The firefighters were also either informed (or not informed) of the potentially slippery floor in each specific condition [46]. Chander et al. [46] reported that leather boots provided greater stability during a slip trial compared to rubber boots. In fact, it was reported that when the firefighters wore the rubber boot that they were as much as 4.8 times as likely to slip when the slip was unexpected to occur compared to when wearing leather boots [46]. This same relationship held true even when the slip was expected by the firefighters to occur (3.6 times greater chance of a hazardous slip when wearing rubber boots) [46]. There are certainly positives and negatives to consider with each type of boot and an important area of research going forward will be to potentially develop and design a boot that can take advantage of the benefits of both types without compromising efficiency of movement or safety.

7. Conclusions

There is a great deal of research describing the physiological cost of fire suppression activity. Based on the previous literature, it appears that, on average, most fire suppression tasks elevate the firefighter's HR to between 80–88% of HR_{max}, with metabolic equivalent (MET) (1 MET = 3.5 mL/kg/min) values ranging from 7.3 METs up to 11.9 METs for the most physiologically demanding fire suppression tasks. While not all fire suppression tasks require an EE of 11.9 METs, it would certainly be a prudent recommendation for all firefighters who will be performing any fire suppression task expected of them be able to achieve 11.9 METs without an abnormal degree of fatigue. When taking these values together, considering the strong relationship of both HR_{max} and aerobic capacity to age, in order to substantially decrease the likelihood of a cardiovascular event during fire suppression, a firefighter (regardless of age) should aim to possess a VO_2 max of at least 46.5 mL/kg/min (13.3 METs). While this value is substantially above the current recommendations, this value should greatly increase the degree of performance success and lower the risk of a cardiovascular event. It is certainly unlikely that all firefighters will be able to achieve this level of aerobic fitness due to a multitude of factors (age, genetic potential, etc.), however, this value is being proposed as a possible threshold for performance success without abnormal fatigue or risk. This value is higher than all of the published values available and will need to be tested in order to elucidate if firefighters with this degree of aerobic fitness are able to perform at a substantially greater degree than those who have aerobic capacities below this value. The type of boot that is worn by fire fighters is an important consideration as well.

Regarding physical fitness, recommendations by the Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) (with the support of the International Association of Fire Fighters, IAFF) [47] does not recommend the use of fitness standards to be used as punitive action against fire fighters. However, they recommend the use of testing for norm-based recommendations for improvement for the health of the fire fighter as well as injury risk reduction. Based on previous research and job performance analysis, the IAFF currently recommends the following physical fitness tests be performed by fire fighter candidates: (1) Aerobic capacity employing the Gerkin protocol; (2) grip strength test; (3) push up test; (4) plank hold to failure; (5) sit-and-reach test; (6) body composition; and (7) upper and lower body strength testing using a Jackson Strength Evaluation System (Lafayette, IN) [47]. Many career fire fighting departments evaluate their fire fighters based on the WFI of the IAFF, however, it is currently unknown to what degree volunteer fire fighting departments regularly evaluate their fire fighters. Volunteer fire fighting departments often do not have the resources available to perform these important annual exams. While funding for these two departments is different, the task of fire suppression still remains the same. Future work should assess and establish means for these fire fighting departments to be able to assess and monitor the physical fitness of their members in an efficient and cost-effective fashion.

As mentioned previously, in addition to these physical fitness tests, the need to complete a live firefighting response in a reasonable amount of time is more likely to be completed quicker and more efficiently by those with a higher aerobic capacity or fitness level than those who are considered less fit. Setting a critical completion time of fire suppression simulation tasks highlights the importance of completing a firefighting task in an efficient amount of time due to the limitation of the capacity of the SCBA tank. The longer the firefighter must stay in live fire suppression, the more likely their core temperature can rise to critical and dangerous levels. As physiological monitoring equipment continues to be developed and become more cost-effective, the possibility exists that fire fighting departments could possess individual monitoring systems for their fire fighters to monitor in real time their degree of physiological stress so supervisors have a great feel for the needs of their fire fighters.

While standards have been in place for the minimum height required to manufacture fire fighting boots for the safety of the foot and lower leg, it also puts the fire fighter at a potentially increased risk of slips, trips, and falls if the boot is too stiff and unable to flex properly while a fire fighter is stepping over an obstacle. The finding by [42] that rubber boots have a lower detrimental effect on the ROM at the ankle joint will perhaps have an effect on how boots are manufactured going forward to allow for a greater degree of flexibility without sacrificing the integrity of the boot. Future investigations are necessary to further explore markers of physiological stress during firefighting and the impact that it may have on ability to withstand the development of disease as well as fire suppression safety. An important future consideration is the effect that fire suppression activities may have on reaction time in critical situations in which life-and-death decisions must be made.

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