Received: 6 February 2023 | Revised: 3 April 2023 | Accepted: 5 April 2023

DOI: 10.1002/ajim.23482

COMMENTARY

AMERICAN JOURNAL OF INDUSTRIAL MEDICINE WILEY

Overexertion and heat stress in the fire service: a new conceptual framework

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Abstract

From the year 2000, the United States Fire Administration (USFA) has been recording all line-of-duty deaths in the fire service. Stress or overexertion caused 1096 out of 2598 total line-of-duty deaths in the United States from 2000 to 2021. Those deaths due to stress or overexertion were further classified as myocardial infarction (90%), cerebrovascular accident (6.8%), other (2.6%), and heat exhaustion (0.6%). Environmental heat exposure is a concern in firefighting, as firefighters work in extreme conditions, such as high ambient temperatures, while wearing protective clothing. Heat stress is not only hazardous to the cardiovascular system, but may accentuate muscle fatigue and overexertion. In addition, overexertion itself is related to increased incidence of musculoskeletal injuries, usually to the lower extremities. Further, there is a strong physiological mechanistic link to suggest that the increased occupational heat exposure and thermoregulatory strain firefighters experience may be a stressor that increases the risk of injuries. This commentary hopes to show the need for further research on the effects of occupational exposures and physiological strain in the fire service.

KEYWORDS

cardiovascular health, exhaustion, firefighter, line-of-duty death, occupational health

1 | INTRODUCTION

Firefighting is a dangerous occupation with a non-negligible risk of line-of-duty death. The Centers for Disease Control and Prevention (CDC) and United States Fire Administration (USFA) maintains a database on the incidence of chronic illnesses and line-of-duty deaths across the United States. Several works suggest that workers in the fire service are plagued by chronic health conditions (e.g., cardiovascular disease, metabolic disorders, obesity, and cancer).[1,2] Additionally, firefighters often exhibit poor cardiovascular health[2,3] which is likely a reason why cardiac-related deaths are the leading cause of line-of-duty fatalities since the National Fire Protection Association (NFPA) began analyzing firefighter deaths in 1977.[1]

Line-of-duty deaths in the fire service occur during many tasks and may have several causes. However, there may be other physiological determinants whose interactions have yet to be fully explored. It is important to note that older firefighters are more likely to die from cardiovascular incidents than their younger counterparts. For instance, in 2020, about 2/3 of firefighter deaths over the age of 45 arose from a cardiac event.[1] It may be speculated, however, that environmental factors (i.e., heat exposure) during critical and essential job-related tasks may indirectly contribute to line-of-duty deaths that occur off the fire-ground. The purpose of this editorial review is to describe the role of overexertion-related events on mortality risk while not on the fire-scene, incorporating CDC and USFA data on nature and causes of deaths, and activities at the time of death. A secondary aim is to attempt to elucidate the impact of overexertion and heat exposure on musculoskeletal injuries in the fire service. We aim to describe a hypothetical framework that may support future investigations of larger magnitude to further explain the impact of environmental events on firefighter mortality risk.

2 | CURRENT FIRE SERVICE STATISTICS

From 2000 to 2021, the USFA has collected information on all line-of-duty deaths in the U.S. fire service.[4] Each death was categorized to suggest factors leading to the fatality (i.e., nature, cause, role). Stress or overexertion caused 1,096 out of 2,598 total line-of-duty deaths in the United States from 2000 to 2021.[4] Those deaths due to stress or overexertion were further classified as arising from myocardial infarction (90%), cerebrovascular accident (6.8%), other (2.6%), and heat exhaustion (0.6%). The utility of historical trends to describe the health of the contemporary firefighter may be considered by reviewing recent years' mortality data in more detail. For instance, in 2020, there were a total of 62 line-of-duty deaths with the cause of 34 categorized as stress or overexertion.[1] In line with historical trends, myocardial infarctions were the most common classification of stress or overexertion line-of-duty deaths for 2020. Line-of-duty deaths in 2021 are omitted in the present work as many causes of death may be due to COVID-19 exposure. In 2022, 96 firefighter line-of-duty deaths occurred,[4] of which approximately 32 deaths arose from stress or overexertion.[4] While this proportion of line-of-duty deaths due to stress or overexertion is smaller than previous years, it still remained the leading cause of death for firefighters in 2022.[1] Collectively, these data suggest a continuing pattern of sudden cardiac deaths as a result of stress or overexertion.

In addition to cataloging the cause of line-of-duty deaths, the USFA also reports the activity at the time of death.[4] These data suggest line-of-duty deaths from stress or overexertion occurred the most frequently during the following activities: fire suppression tasks (31.8%), other/unknown (29.3%), not on the scene (15.4%), in-station duties (7.1%), fitness activity (4.7%), command (4.2%), personal vehicle driving/riding (3.4%), and emergency medical services (1.6%).[4] Further, although fire suppression tasks are associated with the single highest proportion of line-of-duty deaths; 36.4% of deaths occurred not fighting fires (not at scene/in-station, support/command, EMS) and 29.3% of deaths were deemed as having unknown or other causes.[4] Although fire suppression related tasks are often thought to be more dangerous, the data suggest that other job-related tasks were more often associated with cardiac-related deaths.

3 | ROLE OF ENVIRONMENTAL HEAT EXPOSURE AND STRENUOUS WORK IN FIREFIGHTERS

Environmental heat exposure is one of the biggest concerns in occupational settings, and firefighting is no exception.[5] Firefighting mandates physically demanding work in extreme conditions, such as high ambient temperatures.[6] Also, layered protective clothing (e.g., bunker gear over station attire) is often employed during firefighting tasks which may elevate heat storage and thermal strain and thus increase physiological strain and decrease firefighters' work capacity.[7] The combined effect of internally-generated heat during strenuous exercise and external heat sources can lead to high thermal strain.[8] Consequently, physiological and thermoregulatory strain are major health and performance concerns for firefighters and potentially contributory to the stress or overexertion that are the main causes of line-of-duty death.

The combination of high heat stress and physical exertion is a cause of sudden cardiac events in firefighters.[9,10] Hyperthermia, dehydration, inflammation, and cardiovascular strain all play roles in these incidents.[11,12] Additionally, prolonged firefighting has a negative effect on vascular function, contributing to increased arterial stiffness and wave reflection.[13,14] Exposure to extreme heat and physical exertion during firefighter simulation also has been shown to increase thrombogenicity, decrease vascular function, and cause myocardial injury in healthy firefighters.[15] These results indicate the pathways between firefighter work and cardiovascular mortality, including that arising from acute myocardial infarction.[15–17]

Strenuous physical activities in extreme environments can lead to dehydration, which also contributes to cardiovascular and thermoregulatory strain. Hypotension and cardiovascular strain are often observed in firefighters due to heat exposure and increase body fluid loss.[18] Dehydration can lead to elevated whole-body viscosity, which can be a risk to the cardiovascular health of firefighters.[19] Aggressive fluid replacement is suggested following firefighting work.[6]

Heat stress is not only a hazard to the cardiovascular system, but can play a role in muscle fatigue and overexertion.[20,21] Physiological and thermoregulatory strain induced by overexertion during firefighting work can also lead to performance decrements and musculoskeletal injuries. Combining the effects of exercise and heat impairs firefighter-specific functional balance and increases the likelihood of slips, trips, and falls, which lead to musculoskeletal injuries.[20,21] Additionally, elevated core temperature and heat stress could cause greater fatigue and lower cognitive function in some firefighters.[22] Mitigating physiological and thermoregulatory strain is critical to prevent overexertion and musculoskeletal injury which represent the leading cause of lost-time duty in firefighters[20,21]

4 | MUSCULOSKELETAL INJURIES AND OVEREXERTION

As stated above, firefighters frequently suffer from overexertion resulting from excess physical demand and strain on the body while on duty.[23,24] Previous work in the fire service has shown overexertion is related to increased incidence of musculoskeletal injuries, such as strains and sprains, usually to the lower extremities.[25,26] High obesity prevalence is seen in firefighters[27,28] and a majority have low aerobic capacity,[29] which may collectively place them at a greater risk for musculoskeletal injuries due to mobility and functional performance decrements.[27,30,31] In addition to the aforementioned factors, half of the United States career firefighters are between 30 and 49 years old; it is well understood that increasing age is associated with reduced strength, power, aerobic capacity, and fatigue resistance.[32,33] Recent works have highlighted that firefighters over the age of 40 years have an increased risk of musculoskeletal injuries and

overexertion, while firefighters older than 60 years have an increased risk of experiencing overexertion.[23] From 1998 to 2020, the number of firefighters that are 50 to 59 years old has increased by 49%, while those 60 years and older have doubled.[34]

5 | MUSCULOSKELETAL INJURIES AND HEAT

Previous studies have revealed associations between heat exposure and increased incidence of musculoskeletal injuries.[35] There may be physiological and occupational-specific mechanisms that increase injury risk in the fire service. Elevated core temperature causes declines in voluntary activation[36] and impairs the contractile properties of muscle,[37] leading to declines in muscle function including rapid strength, isometric peak torque, and isotonic peak power. Aspects of muscle function have been shown to critically influence performance in firefighters.[30,38] As the most common mechanism of injury in career firefighters are slips, trips, and falls, factors which reduce balance in firefighters remain of concern. Career firefighters with lower rapid strength have demonstrated poorer performance on a functional balance assessment.[30] A separate report suggested that faster stair climb time was associated with greater isometric peak torque and isotonic peak power of the leg extensors in career firefighters.[38] Furthermore, as described above, dehydration is common on firegrounds. The loss of body fluid from exercise has been clearly linked to the impairment of muscle function[39] and is associated with poor balance metrics.[40] While a previous review paper demonstrated a clear association between an increased risk of falls in dehydrated older adults,[41] there remains a surprising gap in the literature investigating the relationship between (de)hydration and fall risk in firefighters, other first responders, or those in similar occupations. Future studies are encouraged to quantify the magnitude of the effect of dehydration on risk of slips, trips, or falls in firefighters.

6 | FUTURE DIRECTIONS

The current work aims to create a foundation that may support future investigations into the impact of heat exposure and overexertion on firefighter mortality risk. The USFA data outlined in the current work provides initial summaries of numerous variables, including incident, firefighter age, rank and classification, incident date, date of death, cause of death, nature of death, activity at the time of death, emergency, duty, property type, and memorial fund information. Though data on environmental conditions at the incident are not available, future studies could address the impact of environmental conditions on firefighter mortality-risk. In addition, the current data set does not list firefighter sex; however, data suggest that females may have diminished capacity to dissipate heat relative to males[42]; suggesting future work may be needed to better understand the influence of sex on heat effects in firefighters. Lastly, there is evidence for an age-effect on the ability to dissipate heat that may affect firefighters' physiological responses to managing heat[43–45] and which may be a direction for future work.

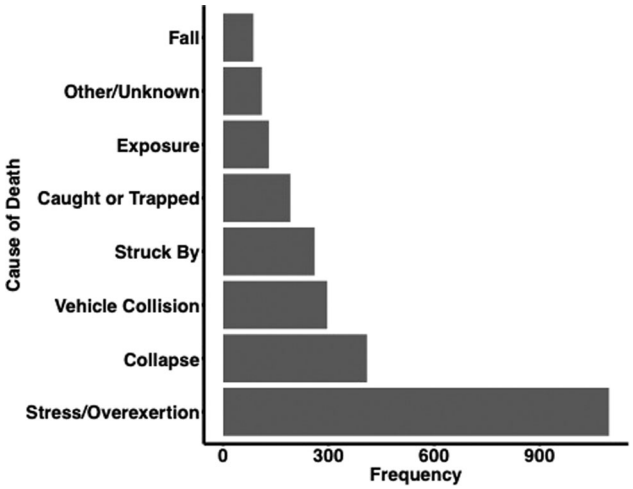

FIGURE 1 Causes of death for all line-of-duty deaths from years 2000 to 2021.

7 | CONCLUSION

Firefighting as an occupation suffers from an increased incidence of both fatal and nonfatal injuries relative to other common occupations.[4] Within firefighting, the largest proportion of fatal injuries are usually cardiovascular-related, while nonfatal mechanisms of injury are often linked to physical hazards for the musculoskeletal system. While speculative, there is a strong physiological mechanistic link to suggest that the increased occupational heat exposure and thermoregulatory strain firefighters experience on the job may be a unique stressor that increases risk for fatal and nonfatal injury alike. This report underscores the need for further research on the impacts of occupational exposures and their physiological repercussions on those working in the fire service Figure 1.

AUTHOR CONTRIBUTIONS

Ms. Wohlgemuth, Dr. Sekiguichi, and Dr. Mota designed the work, acquisition, analyzed data for the work, drafted the work, revised the work critically, gave final approval of the version for publication, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

ETHICS APPROVAL AND INFORMED CONSENT

There was no ethics review and approval and/or no informed consent. Consent was not required or relevant for this work because the data are public. Record provided from the United States Fire Administration. No names or personal identifying data are included in the work.

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