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# Examination of Strenuous Activity Preceding Cardiac Death during Firefighting Duties

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**Abstract:** Sudden cardiac death accounts for approximately 45% of duty-related fatalities among United States firefighters. Strenuous physical exertion is recognized as a trigger of sudden cardiac events. This study describes the duration of strenuous physical exertion on-scene preceding a fatal cardiac event by situation encountered during firefighting duties. Data provided by the National Institute for Occupational Safety and Health Fire Fighter Fatality Investigation and Prevention Program for duty-related firefighter fatalities over a 9-year period were analyzed. Among the 235 fatalities investigated, 45% had a cause of death that was cardiac in origin. Time (mean ± SD) spent on-scene in strenuous work was 30 ± 26 min, 14 ± 15 min, and 47 ± 52 min for fire, non-fire emergency, and training situations, respectively. Across all emergency operations and training, 31% of fatalities occurred among firefighters who performed ≤10 min of strenuous work, whereas 13% of fatalities occurred among those who performed >60 min. Study findings indicate that there is considerable variability in the duration of strenuous work preceding fatal cardiac events during firefighting duties. Notably, a high percentage of fatal cardiac events occurred after a relatively brief period of strenuous work, suggesting that the performance of any strenuous work, even that of short duration, may be sufficient to provoke a cardiac event in a firefighter with underlying cardiac disease.

**Keywords:** firefighting; sudden cardiac event; strenuous work

## 1. Introduction

Since the National Fire Protection Association (NFPA) began tracking on-duty firefighter fatalities more than 30 years ago, sudden cardiac death (SCD) has consistently accounted for the largest share of duty-related firefighter deaths annually, averaging 43% over the last decade [1]. Among public safety workers, this statistic is conspicuously high compared with values of 7% and 11% for duty-related deaths attributable to similar causes for police officers [2] and emergency medical services workers [3], respectively. Despite the high prevalence of SCD among firefighters while on the job, cohort mortality studies and national data have not consistently shown that firefighters experience a greater risk of death due to heart disease than the general population [4–8]. Still, unforeseen incapacitation of an on-duty firefighter due to a sudden cardiac event could adversely affect the safety of the victim, fellow first responders, and the public; therefore, understanding factors that contribute to duty-related cardiac events is essential.

Research clearly shows that specific firefighting duties, namely fire suppression, alarm response, and training, are associated with an increased risk of death due to cardiac-related causes [9–12]. The greatest risk of cardiac death occurs during or shortly after fire suppression, when the odds are 10–130 times greater than during fire station duties [9–12]. Heavy physical exertion, particularly among individuals unaccustomed to such activity, has been implicated as a trigger of sudden cardiac events in the general population [13–16]. Research has established that firefighting is strenuous work, with studies reporting that firefighting tasks require an energy expenditure of 6–13 metabolic

equivalents (METs) [17–19]. Other research has reported that firefighting places considerable strain on the cardiovascular system, including maximal or near maximal heart rate [20–22], decreased plasma volume [23] and stroke volume [20,21], diminished diastolic function [20], impaired endothelial function [24,25], and an enhanced coagulatory state [25,26]. These physiological changes may cause myocardial ischemia, plaque disruption, and/or thrombotic occlusion, leading to a cardiac event in individuals with underlying disease. Consequently, researchers have proposed that the strenuous nature of firefighting work alone, or coupled with other physiologic stressors common to firefighting, such as heat stress, dehydration, elevated sympathetic nervous system activation, or exposure to fireground contaminants may precipitate cardiac death in susceptible firefighters [27–29].

Although there is considerable epidemiological evidence for the triggering of a cardiac event by strenuous physical exertion [13–16], no studies have characterized the physical work performed by firefighters prior to the onset of a fatal cardiac event. Therefore, the purpose of this study was to describe the duration of strenuous physical exertion on-scene preceding a fatal cardiac event by situation encountered during firefighting duties for incidents that occurred 9 January 2008–10 February 2017, and were investigated by the National Institute for Occupational Safety and Health (NIOSH) Fire Fighter Fatality Investigation and Prevention Program (FFFIPP).

## 2. Materials and Methods

This study analyzed data provided by the NIOSH FFFIPP, which conducts independent investigations of selected firefighter line-of-duty deaths as part of a firefighter safety initiative. The decision to investigate is reached using a prioritization guideline based on leading risks to firefighters, fire service stakeholder input, and the availability of resources. Since the program's inception in 1998, approximately 30% of firefighter fatalities have been investigated. The data analyzed were from the NIOSH Core Component Form, which is completed by a NIOSH fatality investigator who performs a site visit, reviews department records, and interviews department personnel. The form allows the investigator to systematically collect information about the fire department, incident, victim, and contributing factors. Data from the form were entered into a dataset by NIOSH and shared with investigators. Data analyzed in this study included fatalities with incident dates between 9 January 2008, and 10 February 2017.

When performing an investigation, NIOSH investigators completed forms that categorized the nature of a fatality as medical, which included coronary heart disease, cardiac conduction problems, heart valve abnormality, cardiomyopathy, aortic aneurysm, hyperthermia, or "other medical" issue; or as non-medical, which included internal trauma, asphyxiation, burns, crush injury, "other non-medical", or unknown. For this study, coronary heart disease, cardiac conduction problems, heart valve abnormality, cardiomyopathy, and "other medical" that was determined to be cardiac-related based on additional details in the dataset were classified as having a medical cause of death that was cardiac in origin. In the event of a questionable value in the dataset, the completed NIOSH investigation report posted on the NIOSH website was reviewed, and the value from the report was used.

Incident information recorded in the dataset included the type of situation encountered (e.g., structure fire, motor vehicle accident (MVA)), the time spent on-scene or at training prior to the onset of symptoms, and the time spent performing strenuous work prior to the onset of symptoms. For cardiac training-related deaths, training was classified as physical fitness, firefighting-live fire, or firefighting-other than live fire (e.g., apparatus, maze, ice rescue, departmental physical ability training, or fitness testing) based on data in the NIOSH fatality investigation report. Time spent on-scene prior to the cardiac event or symptom onset was used to identify the incident stage as defined by the United States Fire Administration (USFA): initial attack (first 10 min), continuing operations (11–60 min), or extended operations (>60 min).

For fatalities with a cardiac cause of death and symptoms that occurred when the firefighter was engaged in fireground activities at a structure fire, the NIOSH fatality investigation report was used to categorize the firefighter's assignment as firefighter, driver/operator, company officer, or chief officer.

Firefighter status recorded in the dataset was collapsed into two groups: career (union and nonunion) and volunteer (volunteer, paid call, other, unknown). Age was calculated by subtracting the date of birth from the date of the event when age was not recorded in the dataset.

Data from the USFA [30] were downloaded from an online fatality database, and data for the same period covered by the NIOSH dataset were extracted. The nature of fatal injury and type of duty from the USFA dataset were used to determine proportions of all U.S. duty-related firefighter fatalities that were investigated by NIOSH. Categories for nature of fatal injury and for situation encountered for the USFA and NIOSH data were similar but not identical; therefore, USFA categories were grouped to closely match the NIOSH categories. USFA fatalities with a nature of fatal injury reported as heart attack, cerebrovascular accident, heat exhaustion, or other/unknown with cause of death listed as stress/overexertion or exposure were considered to be a medical fatality, and the remaining fatalities were considered to be non-medical in nature. USFA types of duty reported as after, other on-duty, and returning were grouped to correspond with the NIOSH nonemergency/not applicable category of type of situation encountered.

Data were analyzed using IBM SPSS Statistics for Windows (Version 25, IBM Analytics, Armonk, NY, USA). Descriptive statistics were used to describe NIOSH-investigated deaths by type of fatality and situation encountered and to describe the time and strenuous work on-scene immediately prior to a fatal cardiac event. For strenuous work, the accuracy of one reported value of 592 min, the entire time spent on-scene during a wildland fire, was considered suspect and excluded from the analysis. Continuous variables are presented as mean ± SD. The chi-square test was used to assess whether the nature of fatality, origin of death (medical-related fatalities only), or type of situation encountered (cardiac deaths only) was associated with NIOSH's decision to investigate. Following a significant chi-square test, pairwise comparisons of column proportions were used to identify the type of situations that differed. Statistical significance was set at $p < 0.05$.

## 3. Results

Table 1 presents the duty-related fatalities reported by the USFA and investigated by NIOSH over the study period 9 January 2008–10 February 2017, defined by the incident dates in the NIOSH dataset. NIOSH investigated 235 of the 868 fatalities (27.1%) reported by the USFA. There was no significant association between the nature of fatality (medical versus non-medical, $p = 0.339$) or the origin of medical-related death (cardiac versus noncardiac, $p = 0.309$) and the decision to investigate by NIOSH. NIOSH investigated 25.8% (124 of 481) of all USFA duty-related fatalities attributed to medical events and 25.1% (107 of 427) of reported cardiac deaths. The nature of the fatality was medical-related in 55.4% (481 of 868) of the USFA fatalities and 52.8% of the fatalities investigated by NIOSH. Fatalities attributed to cardiac-related events accounted for 88.8% (427 of 481) and 86.3% of medical-related deaths in the USFA and NIOSH datasets, respectively, and 49.2% (427 of 868) and 45.5% (107 of 235) of all deaths in the respective datasets.

There was a significant association between the type of situation encountered and whether NIOSH investigated the fatality ($p < 0.001$; Table 1). NIOSH was more likely to investigate USFA-reported cardiac fatalities that occurred during fire- or training-related situations and less likely to investigate those that occurred during the response or nonemergency/non-training ($p < 0.05$). NIOSH investigated 50.7% (36 of 71) of USFA reported cardiac fatalities that occurred at fires, 42.9% (21 of 49) of those that occurred during training, and 8.3% (3 of 36) that occurred during the response.

Table 2 shows that 124 of the 235 fatalities investigated by NIOSH were due to medical causes, with the largest share attributed to coronary heart disease (CHD; 76.6% (95 of 124)). Three fatalities in the "other medical" category were cardiac in nature, bringing the number of cardiac deaths to 107. Mean age of the 107 firefighters who succumbed to a cardiac-related death was 49 ± 9 years and 106 of the firefighters were men. At the time of the fatal event, 52.3% were career firefighters. Years of experience as a firefighter were 21 ± 9 for career only (n = 46), 17 ± 13 for volunteer only (n = 38), and

16 ± 11 as career and 10 ± 13 as volunteer for those with both career and volunteer experience (n = 20), which may have coincided.

**Table 1.** Duty-related firefighter fatalities for incidents occurring 9 January 2008–10 February 2017, reported by the United States Fire Administration (USFA) and investigated by the National Institute for Occupational Safety and Health (NIOSH).

| Category | Variable | Reported by the USFA | Investigated by NIOSH | | $X^2$ ($p$ Value) |
|---|---|---|---|---|---|
| | | | No | Yes | |
| | | N | N (%) | N (%) | |
| **Fatality** | Duty-related firefighter fatality | 868 | 633 | 235 | |
| **Nature of Fatality** | Non-medical cause of death | 387 | 276 (43.6) | 111 (47.2) | 0.915 (0.339) |
| | Medical cause of death [a] | 481 | 357 (56.4) | 124 (52.8) | |
| **Origin of Death** [a] | Noncardiac | 54 | 37 (10.4) | 17 (13.7) | 1.034 (0.309) |
| | Cardiac [b] | 427 | 320 (89.6) | 107 (86.3) | |
| **Type of Situation Encountered** [b] | Fire | 71 | 35 (10.9) | 36 (33.6) * | 47.611 (<0.001) |
| | Non-fire emergency ops | 36 | 28 (8.8) | 8 (7.5) | |
| | Training | 49 | 28 (8.8) | 21 (19.6) * | |
| | Responding | 36 | 33 (10.3) | 3 (2.8) * | |
| | Nonemergency/Nontrain [c] | 235 | 196 (61.3) | 39 (36.4) * | |

Ops, operations; nontrain, non-training. [a] NIOSH: medical; USFA: heart attack, cerebrovascular accident, heat exhaustion, or other/unknown with cause of death listed as stress/overexertion or exposure. [b] NIOSH: cardiac-related; USFA: heart attack. [c] NIOSH: false alarm, other, unknown/not applicable, and undefined; USFA: returning, other on-duty, and after. * $p < 0.05$ for No/Yes comparison.

**Table 2.** Duty-related firefighter fatalities investigated by NIOSH by nature of fatal illness/injury for incidents that occurred 9 January 2008–10 February 2017 (N = 235).

| Nature of Fatal Injury/Illness | N | Percentage |
|---|---|---|
| Medical | 124 | 52.8 |
| Coronary heart disease | 95 | 40.4 |
| Cardiac conduction problem | 1 | 0.4 |
| Heart valve abnormality | 2 | 0.9 |
| Cardiomyopathy | 6 | 2.6 |
| Aortic aneurysm | 2 | 0.9 |
| Hyperthermia | 5 | 2.1 |
| Other medical | 13 | 5.5 |
| Non-medical | 109 | 46.4 |
| Internal trauma | 27 | 11.5 |
| Asphyxiation | 26 | 11.1 |
| Burns | 14 | 6.0 |
| Crushed | 16 | 6.8 |
| Other non-medical | 26 | 11.1 |
| Unknown | 2 | 0.9 |

The distribution of cardiac-related fatalities by type of situation encountered is presented in Table 3. Nearly 35% (36 of 107) of fatalities investigated were associated with fires, where 69.4% (25 of 36) were structure fires. Fatalities that occurred during non-fire emergency operations and training accounted for 7.5% and 19.6% of investigations, respectively. The nonemergency/non-training category included fatalities that occurred at the fire station and other nonemergency duties and accounted for a large share of situations (36.4%).

**Table 3.** Type of situation encountered among cardiac-related fatalities investigated by NIOSH for incidents that occurred 9 January 2008–10 February 2017 (N = 107).

| Type of Situation Encountered | N | Percentage |
|---|---|---|
| Fire | 36 | 33.6 |
| Structure | 25 | 23.4 |
| Wildland | 9 | 8.4 |
| Outdoor | 2 | 1.9 |
| Non-fire emergency operations | 8 | 7.5 |
| Motor vehicle accident | 3 | 2.8 |
| Emergency medical services | 5 | 4.7 |
| Training | 21 | 19.6 |
| Physical fitness | 5 | 4.7 |
| Firefighting-live fire | 4 | 3.7 |
| Firefighting-other than live fire | 12 | 11.2 |
| Responding | 3 | 2.8 |
| Nonemergency/Non-training | 39 | 36.4 |
| False alarm | 2 | 1.9 |
| Other | 3 | 2.8 |
| Unknown/Not applicable | 33 | 30.8 |
| Undefined | 1 | 0.9 |

During emergency situations (fire and non-fire emergencies; Figure 1), the fatal cardiac event or symptom onset occurred during the initial attack (first 10 min) in 9 firefighters (~20%), during continuing operations (11–60 min) in 26 firefighters (~60%), and during extended operations in 9 firefighters (~20%). As shown in Figure 1, the nine fatal events that struck during extended operations occurred during structure or wildland fires.

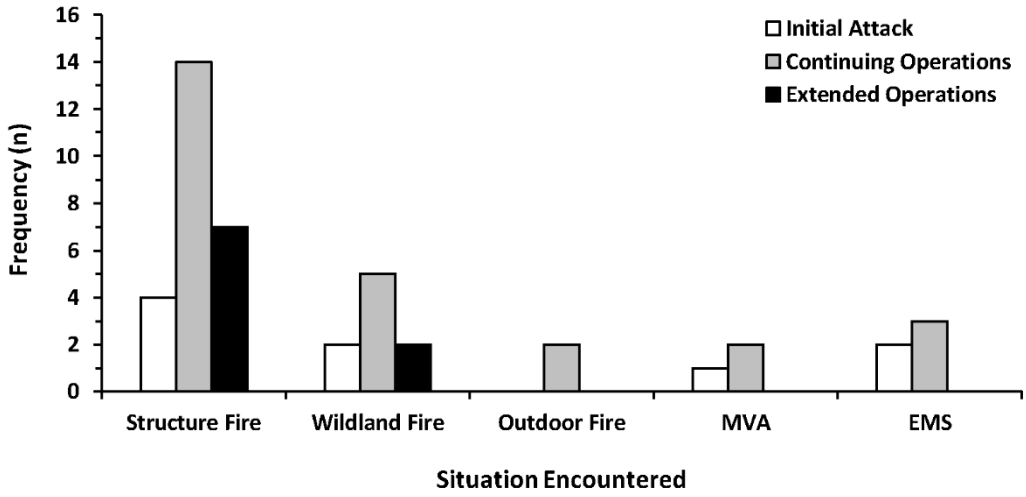


**Figure 1.** Frequency of fatal cardiac events by emergency situation encountered and incident stage among cardiac fatalities investigated by NIOSH for incidents that occurred 9 January 2008–10 February 2017 (N = 44). MVA, motor vehicle accident; EMS, emergency medical services. Initial Attack, first 10 min on-scene; Continuing Operations, 11–60 min on-scene; Extended Operations, >60 min on-scene.

The time spent on-scene and the time engaged in the performance of strenuous work prior to the onset of symptoms for the cardiac event are summarized in Table 4. On average, firefighters who died of cardiac-related causes during a situation that involved a fire spent 55 ± 96 min on-scene and 30 ± 26 min performing strenuous activity. Mean time spent by firefighters in strenuous work was similar for structure and wildland fires. Mean time spent performing strenuous work was approximately 15 min less during non-fire emergency operations (14 ± 15 min) than during emergency situations involving

fires. During training, nearly 50 min, on average, was spent in strenuous activity before symptom onset. Three cardiac fatalities occurred during the response, and firefighters did not reach the scene; therefore, no times were reported for on-scene or strenuous work.

**Table 4.** Time (mean ± SD) spent on-scene and performing strenuous work prior to the onset of symptoms by type of situation encountered among cardiac fatalities investigated by NIOSH for incidents that occurred 9 January 2008–10 February 2017 (N = 92).

| Type of Situation Encountered | On-Scene (min) | Strenuous Work (min) |
|---|---|---|
| Fire (n = 36; n = 35) | 55 ± 96 | 30 ± 26 |
| Structure (n = 25) | 42 ± 28 | 30 ± 25 |
| Wildland (n = 9; n = 8) | 99 ± 187 | 35 ± 31 |
| Outdoor (n = 2) | 14 ± 4 | 10 ± 9 |
| Non-fire emergency operations (n = 8) | 27 ± 21 | 14 ± 15 |
| Motor vehicle accident (n = 3) | 27 ± 22 | 19 ± 27 |
| Emergency medical services (n = 5) | 27 ± 23 | 11 ± 2 |
| Training (n = 21) | 149 ± 144 | 47 ± 52 |
| Physical fitness (n = 5) | 36 ± 19 | 36 ± 19 |
| Firefighting-live fire (n = 4) | 304 ± 192 | 77 ± 91 |
| Firefighting-other than live fire (n = 12) | 145 ± 115 | 42 ± 46 |
| Responding (n = 3) | - | - |
| Nonemergency/Non-training (n = 18; n = 24) | 68 ± 109 | 34 ± 35 |
| False alarm (n = 2) | 20 ± 6 | 20 ± 6 |
| Other (n = 2) | 103 ± 124 | 28 ± 18 |
| Unknown/Not applicable (n = 13; n = 19) | 73 ± 122 | 37 ± 38 |
| Undefined (n = 1) | 27 | 20 |

Note: The "n" reported is the same for On-scene and Strenuous Work for all situations other than Fire, Wildland, Nonemergency/Non-training and Unknown/Not applicable, where the value for On-scene is followed by the value for Strenuous Work.

The distributions of time engaged in the performance of strenuous work for emergency operations and training are shown in Figure 2. The sample size is small for some situations, but situations were not collapsed to avoid masking the effects of differences in the type of work performed and the environment on the duration of strenuous work. The figure reveals considerable variability for most situations encountered. As shown in Figure 2, 31% (20 of 64) of fatal cardiac events that manifested during emergency operations or training occurred among firefighters who had performed ≤10 min of strenuous work, as opposed to 13% (8 of 64) of fatal cardiac events that occurred after >60 min of strenuous work. When grouped by type of situation, the proportion of fatalities that occurred among firefighters who completed ≤10 min of strenuous work was 29% during fires, 63% during non-fire emergencies, and 24% during training. Firefighters reportedly performed no strenuous work during two fire-related incidents and one training situation. Only four firefighters engaged in >60 min of strenuous work during fires, and four engaged in >60 min of strenuous work during training.

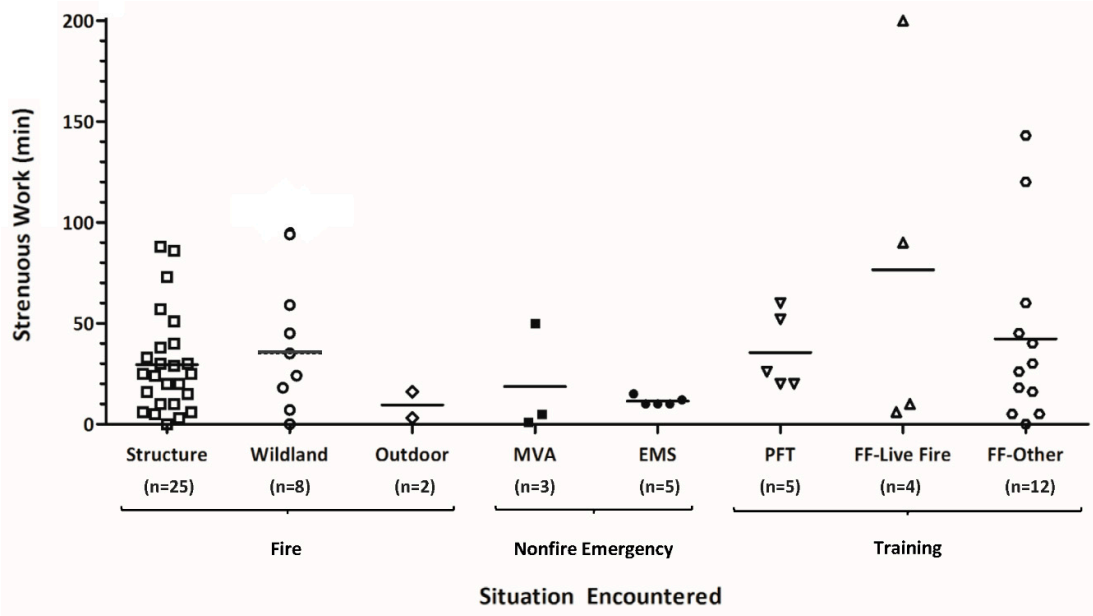


**Figure 2.** Distribution of time (min) spent performing strenuous work on-scene prior to the onset of symptoms by situation encountered among cardiac fatalities investigated by NIOSH for incidents that occurred 9 January 2008–10 February 2017 (N = 64). MVA, motor vehicle accident; EMS, emergency medical services; PFT, physical fitness training; FF, firefighting. Solid lines represent the mean.

Figure 3 shows by assignment the distribution of time spent performing strenuous work on-scene prior to the onset of symptoms at structure fires for cardiac fatalities. Only one fatality involved a driver/operator, and he had spent 5 min performing strenuous work on-scene. Four members were chief officers, and two had worked strenuously for ≥30 min assisting with fire attack. Mean time spent in strenuous work was 28 ± 22 min, 35 ± 32 min, and 25 ± 24 min for firefighters, company officers, and chief officers, respectively.

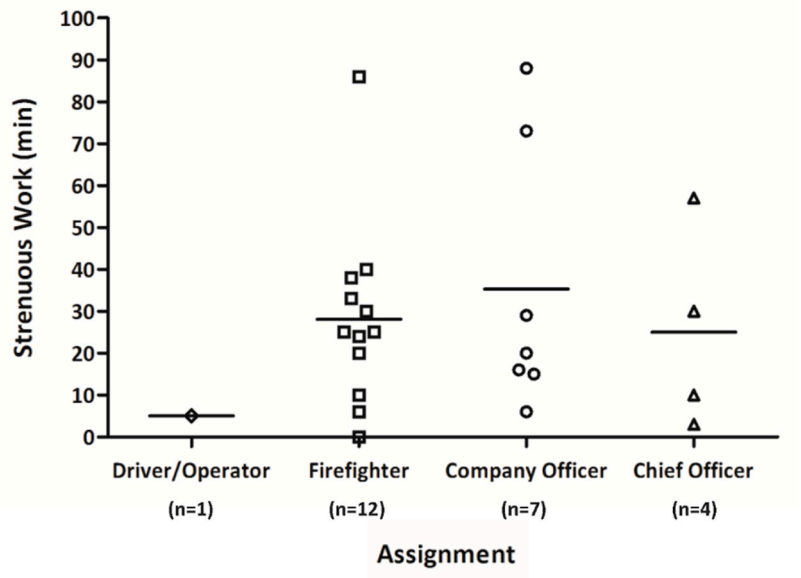


**Figure 3.** Distribution of time (min) spent performing strenuous work on-scene prior to the onset of symptoms at structure fires by assignment among cardiac fatalities investigated by NIOSH for incidents that occurred 9 January 2008–10 February 2017 (N = 24). Note, no assignment was made for one pending investigation.

## 4. Discussion

This study provides the most complete characterization to date of the work performed by firefighters prior to the onset of a duty-related fatal cardiac event over a 9-year period (January 2008 to February 2017) using data from the NIOSH FFFIPP. The study's primary finding was that the time spent performing strenuous work prior to the manifestation of cardiac symptoms varied considerably by type of situation encountered and within a given situation. Notably, 31% of cardiac fatalities that occurred during emergency operations or training involved firefighters who had performed ≤10 min or strenuous work, including a few firefighters who had not performed any strenuous work. Alternatively, only 14% of cardiac fatalities occurred among firefighters who had performed >60 min of strenuous work during extended operations.

Study findings support researchers' proposals that physical work should be examined as a potential trigger of cardiovascular events in susceptible firefighters [27–29]. This conclusion by itself was not unexpected based on epidemiological research [13–16,31]; however, study results also revealed considerable variability in the duration of strenuous work performed prior to the fatal event. During structure fires, 28% of firefighters performed ≤10 min of strenuous work, whereas 12% performed >60 min. Although several authors have proposed that the combination of heavy muscular work, heat stress, and dehydration may account for the increased risk of a sudden cardiac event during fire suppression [7,28], this study found that a high percentage of fatal cardiac events occurred after a relatively brief period of strenuous work, when heat stress and dehydration would likely not be contributory factors. The performance of any strenuous work, even that of short duration, may be sufficient to provoke a cardiac event in a susceptible firefighter with underlying cardiac disease.

Additionally, despite engaging in only a short period of strenuous work (≤10 min), six firefighters were on-scene during continued (11–60 min) or extended emergency operations (>60 min). The noisy, emotionally charged, immediately dangerous to life or health environment on the fireground causes sympathetic activity to increase or remain elevated, which may have contributed to triggering the fatal cardiac event. Research indicates that sympathetic activation may provoke the development of dangerous ventricular arrhythmias and SCD, especially in individuals with cardiac disease [32,33].

The 5- to 14-fold increased risk of cardiac death during alarm response reported in prior studies suggests that sympathetic activation alone may trigger a sudden cardiac event in a vulnerable firefighter [9,10,12]. The finding of no strenuous work among three cardiac fatalities in this study is consistent with this supposition. Approximately 3% of the cardiac deaths NIOSH investigated were associated with the alarm response, but national data from this study and prior studies [10,12] show that 8%–13% of cardiac deaths occur during this type of duty, which is not considered physically demanding.

NIOSH investigated 43% of all USFA-reported cardiac-related training deaths over the study period. The deaths of five firefighters during physical fitness training, during which the effects of physical exertion were essentially isolated from other potential triggers of cardiac death that could act in concert during emergencies or firefighting training/drills, is consistent with research showing that cardiac death can be triggered by strenuous physical work alone. The longer duration of strenuous work during firefighting training than physical fitness training for some fatalities may be more reflective of differences in relative intensity of the work or differences in underlying cardiac pathologies than added stressors during firefighting training.

Previous studies have not found an increased risk of cardiac death during non-fire emergency duties, but approximately 9% of cardiac-related deaths occur during this type of duty [10,12]. In this study, the duration of strenuous work for emergency medical services (EMS) calls was tightly clustered around 11 min, whereas the duration for MVA ranged from 1 min to 50 min. The narrower range for EMS calls might be expected, as strenuous work is primarily limited to gaining access to the patient and transferring the patient to the emergency vehicle for transport.

In addition to examining strenuous work during different firefighting situations, the work performed during structure fires was explored in further detail. Heart rate responses have been reported to be highly task dependent during actual emergencies [34]. Additionally, despite many

studies that have documented near maximal heart rates among most firefighters during live fire training [20,22,35,36], Romet and Frim [37] reported that heart rate responses were influenced by the type of work performed and the environmental stressors (interior versus exterior work) during live fire training. In their study, heart rates differed by 30–40 beats per min between the least and most demanding assignments. More recently, Horn et al. [38] also showed that core temperature responses varied by assignment, with overhaul and ventilation operations resulting in the highest core temperatures. In this study, the assignments of driver/operator and chief officer were not expected to require much strenuous work, although individuals in these assignments are likely to experience psychological stress and are frequently exposed to environmental pollutants. Whether the inclusion of only one driver among the 25 deaths was related to the physical demands of the assignment being lower than those of firefighter and company officer, or to the NIOSH selection process for investigating a fatality, or to the lower proportion of driver/operators among members is unclear. A fire chief often assumes the role of incident commander, but two chiefs in this study assisted with fire attack and performed ≥30 min of strenuous work.

Strenuous work is inherent to the job of firefighting; therefore, it is important to recognize that the absolute risk of SCD during any single episode of vigorous exertion has been reported to be very low (1 SCD per 1.51 million episodes of exertion) [13]. In addition, and paradoxically, an effective way to counter the triggering role of strenuous physical exertion may be through regular strenuous physical exertion, albeit as part of a prudent fitness program following medical clearance. Studies have demonstrated that habitual strenuous physical exertion has a protective effect against the transiently increased risk of cardiac death with strenuous physical exertion [13,31,39]. Albert et al. [13] reported a relative risk of SCD of 10.9 in the period during and 30 min after exertion among men who regularly (≥5 times per week) engaged in vigorous exertion (≥6 METs) compared with a relative risk of 74.1 among men who rarely (<1 time per week) exercised at a vigorous intensity.

*Strengths and Limitations*

The main strength of this study is that the NIOSH fatality investigations provided a detailed description of the environment and activities preceding the duty-related fatal event. Reliance solely on data obtained from the NIOSH FFFIPP investigation is also a limitation because not all firefighter duty-related fatalities were investigated. Additionally, year-to-year differences in the prioritization guidelines used by NIOSH may have affected the number and type of fatalities investigated annually. Aggregate data showed that during the study period, the proportions of fatalities investigated by NIOSH that were due to medical (52.8%) and cardiac-related (45.5%) causes were similar to the proportion of medical and cardiac fatalities identified through national data (55.4% and 49.2%, respectively), but this might not hold true for other time periods. Over the study period, inclusion of a higher proportion of emergency- and training-related cardiac deaths among NIOSH investigations compared with national data increased the sample size for situations that were likely to elicit strenuous work. The quantification of strenuous work was a subjective measure based on the judgment of the NIOSH investigator, which is a limitation. However, a limited number of investigators conducted investigations, and ratings were likely consistent for each investigator. This study used categories established by NIOSH to report strenuous work, but it should be noted that firefighters perform strenuous work at times that may not have been captured in this analysis, such as upon the return from an incident. Although not a limitation per se, associations among strenuous work and factors such as age, firefighter status, ambient conditions, and prior calls were not considered, primarily due to the small sample sizes for most situations. These factors could be considered in future research to quantify the risk of cardiac death associated with strenuous work during firefighting.

## 5. Conclusions

There was considerable variability in the duration of strenuous work reported prior to the onset of a fatal cardiac event in the duty-related firefighter fatalities investigated by NIOSH. This variability

undoubtedly reflects many factors, among them, the relative intensity of the work performed, the degree of underlying cardiovascular pathology, and mechanisms of cardiac death (i.e., myocardial infarction and cardiac arrest). Nonetheless, documenting the variability in amount of time spent in strenuous physical work adds to our understanding of the stressors that can contribute to a cardiac event and argues against a simple notion that all duty-related cardiac fatalities have a common trigger mechanism. Among firefighters with underlying cardiovascular disease, the sympathetic activation associated with the alarm response and on-scene activities may be sufficient to trigger a cardiac event. Thus, all members of a department who respond to emergencies should have appropriate medical clearance. Furthermore, it is of utmost importance that firefighters have a high level of fitness to ensure optimal job performance and to reduce the risk of cardiac death. To this end, fire departments should embrace fitness programming and health maintenance programs.

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## References

1. Fahy, R.F.; LeBlanc, P.; Molis, J.L. *Firefighter Fatalities in the United States—2017*; National Fire Protection Association: Quincy, MA, USA, 2018; p. 7.
2. Zimmerman, F.H. Cardiovascular disease and risk factors in law enforcement personnel: A comprehensive review. *Cardiol. Rev.* **2012**, *20*, 159–166. [CrossRef] [PubMed]
3. Maguire, B.J.; Hunting, K.L.; Smith, G.S.; Levick, N.R. Occupational fatalities in emergency medical services: A hidden crisis. *Ann. Emerg. Med.* **2002**, *40*, 625–632. [CrossRef] [PubMed]
4. Daniels, R.D.; Bertke, S.; Dahm, M.M.; Yiin, J.H.; Kubale, T.L.; Hales, T.R.; Baris, D.; Zahm, S.H.; Beaumont, J.J.; Waters, K.M.; et al. Exposure-response relationships for select cancer and non-cancer health outcomes in a cohort of U.S. firefighters from San Francisco, Chicago and Philadelphia (1950–2009). *Occup. Environ. Med.* **2015**, *72*, 699–706. [CrossRef] [PubMed]
5. Demers, P.A.; Heyer, N.J.; Rosenstock, L. Mortality among firefighters from three northwestern United States cities. *Occup. Environ. Med.* **1992**, *49*, 664–670. [CrossRef] [PubMed]
6. Haas, N.S.; Gochfeld, M.; Robson, M.G.; Wartenberg, D. Latent health effects in firefighters. *Int. J. Occup. Environ. Health* **2003**, *9*, 95–103. [CrossRef] [PubMed]
7. Soteriades, E.S.; Smith, D.L.; Tsismenakis, A.J.; Baur, D.M.; Kales, S.N. Cardiovascular disease in US firefighters: A systematic review. *Cardiol. Rev.* **2011**, *19*, 202–215. [CrossRef] [PubMed]
8. lefts for Disease Control and Prevention; National Institute for Occupational Safety and Health. National Occupational Mortality Surveillance (NOMS). Available online: https://www.cdc.gov/niosh/topics/noms/query.html (accessed on 24 June 2019).
9. Farioli, A.; Yang, J.; Teehan, D.; Baur, D.M.; Smith, D.L.; Kales, S.N. Duty-related risk of sudden cardiac death among young US firefighters. *Occup. Med.* **2014**, *64*, 428–435. [CrossRef] [PubMed]
10. Kales, S.N.; Soteriades, E.S.; Christophi, C.A.; Christiani, D.C. Emergency duties and deaths from heart disease among firefighters in the United States. *N. Engl. J. Med.* **2007**, *356*, 1207–1215. [CrossRef]
11. Kales, S.N.; Soteriades, E.S.; Christoudias, S.G.; Christiani, D.C. Firefighters and on-duty deaths from coronary heart disease: A case control study. *Environ. Health* **2003**, *2*, 14. [CrossRef]
12. Smith, D.L.; Haller, J.M.; Korre, M.; Sampani, K.; Porto, L.G.G.; Fehling, P.C.; Christophi, C.A.; Kales, S.N.; Porto, L.G.G. The relation of emergency duties to cardiac death among US firefighters. *Am. J. Cardiol.* **2019**, *123*, 736–741. [CrossRef]

13. Albert, C.M.; Mittleman, M.A.; Chae, C.U.; Lee, I.-M.; Hennekens, C.H.; Manson, J.E. Triggering of sudden death from cardiac causes by vigorous exertion. *N. Engl. J. Med.* **2000**, *343*, 1355–1361. [CrossRef] [PubMed]
14. Mittleman, M.A.; Tofler, G.H.; Sherwood, J.B.; Muller, J.E.; Goldberg, R.J.; Maclure, M. Triggering of acute myocardial infarction by heavy physical exertion—protection against triggering by regular exertion. *N. Engl. J. Med.* **1993**, *329*, 1677–1683. [CrossRef] [PubMed]
15. Von Klot, S.; Mittleman, M.A.; Dockery, D.W.; Heier, M.; Meisinger, C.; Hörmann, A.; Wichmann, H.-E.; Peters, A. Intensity of physical exertion and triggering of myocardial infarction: A case-crossover study. *Eur. Heart J.* **2008**, *29*, 1881–1888. [CrossRef] [PubMed]
16. Willich, S.N.; Lewis, M.; Lowel, H.; Arntz, H.-R.; Schubert, F.; Schröder, R. Physical exertion as a trigger of acute myocardial infarction. *N. Engl. J. Med.* **1993**, *329*, 1684–1690. [CrossRef] [PubMed]
17. Gledhill, N.; Jamnik, V.K. Characterization of the physical demands of firefighting. *Can. J. Sport Sci.* **1992**, *17*, 207–213. [PubMed]
18. Lemon, P.W.; Hermiston, R.T. The human energy cost of fire fighting. *J. Occup. Med.* **1977**, *19*, 558–562. [PubMed]
19. Von Heimburg, E.D.; Rasmussen, A.K.R.; Medbø, J.I. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics* **2006**, *49*, 111–126. [CrossRef]
20. Fernhall, B.; Fahs, C.A.; Horn, G.; Rowland, T.; Smith, D. Acute effects of firefighting on cardiac performance. *Eur. J. Appl. Physiol.* **2012**, *112*, 735–741. [CrossRef]
21. Smith, D.L.; Manning, T.S.; Petruzzello, S.J. Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. *Ergonomics* **2001**, *44*, 244–254. [CrossRef]
22. Angerer, P.; Kadlez-Gebhardt, S.; Delius, M.; Raluca, P.; Nowak, D. Comparison of cardiocirculatory and thermal strain of male firefighters during fire suppression to exercise stress test and aerobic exercise testing. *Am. J. Cardiol.* **2008**, *102*, 1551–1556. [CrossRef]
23. Smith, D.L.; Petruzzello, S.J.; Goldstein, E.; Ahmad, U.; Tangella, K.; Freund, G.G.; Horn, G.P. Effect of live-fire training drills on firefighters' platelet number and function. *Prehosp. Emerg. Care* **2011**, *15*, 233–239. [CrossRef] [PubMed]
24. Ives, S.J.; Lefferts, W.K.; Wharton, M.; Fehling, P.C.; Smith, D.L. Exercise-induced heat stress disrupts the shear-dilatory relationship. *Exp. Physiol.* **2016**, *101*, 1541–1551. [CrossRef] [PubMed]
25. Hunter, A.L.; Shah, A.S.; Langrish, J.P.; Raftis, J.B.; Lucking, A.J.; Brittan, M.; Venkatasubramanian, S.; Stables, C.L.; Stelzle, D.; Marshall, J.; et al. Fire simulation and cardiovascular health in firefighters. *Circulation* **2017**, *135*, 1284–1295. [CrossRef] [PubMed]
26. Smith, D.L.; Horn, G.P.; Petruzzello, S.J.; Fahey, G.; Woods, J.; Fernhall, B. Clotting and fibrinolytic changes after firefighting activities. *Med. Sci. Sports Exerc.* **2014**, *46*, 448–454. [CrossRef] [PubMed]
27. Kales, S.N.; Smith, D.L. Firefighting and the heart: Implications for prevention. *Circulation* **2017**, *135*, 1296–1299. [CrossRef] [PubMed]
28. Smith, D.L.; Barr, D.A.; Kales, S.N. Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extreme Physiol. Med.* **2013**, *2*, 6. [CrossRef] [PubMed]
29. Smith, D.L.; Deblois, J.P.; Kales, S.N.; Horn, G.P. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc. Sport Sci. Rev.* **2016**, *44*, 90–97. [CrossRef]
30. Fire Administration. Firefighter Fatalities in the United States. Available online: https://apps.usfa.fema.gov/firefighter-fatalities (accessed on 17 January 2019).
31. Tofler, G.H.; Muller, J.E. Triggering of acute cardiovascular disease and potential preventive strategies. *Circulation* **2006**, *114*, 1863–1872. [CrossRef]
32. Podrid, P.J.; Fuchs, T.; Candinas, R. Role of the sympathetic nervous system in the genesis of ventricular arrhythmia. *Circulation* **1990**, *82*, 103–113.
33. Wolk, R. Arrhythmogenic mechanisms in left ventricular hypertrophy. *Europace* **2000**, *2*, 216–223. [CrossRef]
34. Bos, J.; Mol, E.; Visser, B.; Frings-Dresen, M.H. The physical demands upon (Dutch) fire-fighters in relation to the maximum acceptable energetic workload. *Ergonomics* **2004**, *47*, 446–460. [CrossRef] [PubMed]
35. Horn, G.P.; Blevins, S.; Fernhall, B.; Smith, D.L. Core temperature and heart rate response to repeated bouts of firefighting activities. *Ergonomics* **2013**, *56*, 1465–1473. [CrossRef] [PubMed]
36. Hostler, D.; Colburn, D.; Rittenberger, J.C.; Reis, S.E. Effect of two work-to-rest ratios on cardiovascular, thermal, and perceptual responses during fire suppression and recovery. *Prehosp. Emerg. Care* **2016**, *20*, 1–7. [CrossRef] [PubMed]

37. Romet, T.T.; Frim, J. Physiological responses to fire fighting activities. *Graefes Arch. Clin. Exp. Ophthalmol.* **1987**, *56*, 633–638. [CrossRef]
38. Horn, G.P.; Kesler, R.M.; Kerber, S.; Fent, K.W.; Schroeder, T.J.; Scott, W.S.; Fehling, P.C.; Fernhall, B.; Smith, D.L. Thermal response to firefighting activities in residential structure fires: Impact of job assignment and suppression tactic. *Ergonomics* **2018**, *61*, 404–419. [CrossRef] [PubMed]
39. Mittleman, M.A.; Mostofsky, E. Physical, Psychological and chemical triggers of acute cardiovascular events: Preventive strategies. *Circulation* **2011**, *124*, 346–354. [CrossRef]

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