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## Duty-related risk of sudden cardiac death among young US firefighters

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### Abstract

**Background**—Little is known regarding duty-related risks for sudden cardiac death (SCD) among young firefighters.

**Aims**—To investigate duty-related SCD among US firefighters aged 45 or younger.

**Methods**—We collected data on duty-related SCD from the US Fire Administration (USFA) and the US National Institute for Occupational Safety and Health (NIOSH). Two physicians independently reviewed each record. The proportions of time spent by firefighters performing specific duties were estimated from a municipal department, 17 large metropolitan departments and a national database. We estimated the duty-specific relative risks (RRs) and 95% confidence intervals (95% CI) of SCD relative to non-emergency duties based on the observed deaths and the expected average proportions of time per duty.

**Results**—The USFA recorded 205 age-eligible on-duty SCDs between 1996 and 2012; 86 (42%) of these deaths and one additional SCD were investigated by NIOSH (total  $n = 206$ ). NIOSH was more likely ( $P < 0.001$ ) to report on SCD associated with physical training (69% of cases were investigated) and fire suppression (57%). Compared with non-emergency duties, the risk of SCD was increased for fire suppression (RR 22.1, 95% CI 14.8–32.9), alarm response (RR 2.6, 95% CI 1.5–4.6), alarm return (RR 4.1, 95% CI 2.7–6.2) and physical training (RR 4.8, 95% CI 3.2–7.2). RRs for SCD were higher among firefighters with a pre-existing history of a cardiac condition. All 16 SCDs associated with alarm response occurred among volunteer firefighters.

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Conflicts of interest

S.N.K. and D.L.S. report serving as paid expert witnesses, independent medical examiners or both in cases involving firefighters. No other potential conflict of interest relevant to this article was reported.

**Conclusions**—The performance of strenuous emergency duties is strongly associated with an increased risk of SCD among young firefighters, particularly among those with a history of cardiovascular disease.

### Keywords

Firefighters; longitudinal study; occupational disease; occupational exposure; sudden cardiac death

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## Introduction

Despite the high risk of trauma during fires and other emergency activities, sudden cardiac death (SCD) is the leading cause of on-duty death among the 1 100 000 firefighters in the USA [1,2]. An increased incidence of SCD among firefighters has been documented during certain emergency and strenuous duties, which can trigger SCD among individuals affected by underlying coronary heart disease (CHD) and/or left ventricular hypertrophy (LVH) [3–6]. It is unknown whether these findings, mainly observed among middle-aged firefighters with CHD, also apply to younger firefighters. SCD among young and apparently healthy subjects is often associated with a structural cardiac abnormality, rather than CHD [7]. Nevertheless, a recent study of US firefighters aged 45 or younger found a major role for traditional cardiovascular risk factors (obesity, cigarette smoking and hypertension) in conveying an increased risk of SCD through the development of CHD and LVH/ cardiomegaly [8].

Since little is known about the occupational determinants of on-duty SCD among younger firefighters, we investigated the duty-related risks of SCD among firefighters aged < 45 using data from two US national databases maintained by the US Fire Administration (USFA) and the National Institute for Occupational Safety and Health (NIOSH).

## Methods

We collected death records from USFA and NIOSH. The USFA maintains a systematic database of all deaths associated with firefighting in the USA since 1981 [9]. Each record includes name, age, rank, classification (e.g. volunteer, career), dates of incident and death, location, cause and nature of death, duty (type, specific activity, emergency context) and a description of the event (systematically available from 1993). The NIOSH program investigates firefighter line-of-duty deaths for prevention purposes, analysing all putative determinants of the events [10]. The NIOSH database is neither representative nor comprehensive [3,6,8], but all reports comprehensively describe the event and, whenever relevant, contain a summary of the pre-morbid clinical history and findings of the post-mortem examination. From 1994, the USFA has recommended performing an autopsy for all fatalities possibly associated with firefighting [11]. However, the final decision to undertake a necropsy is at the discretion of local coroners.

The protocol for data extraction from the two databases has been described elsewhere [6,8]. Briefly, for this study, we collected all fatality reports published between 1996 and 2012 from both databases. Two physicians independently examined each summary report for

possible inclusion and data extraction. The senior physician investigator (S.N.K.) resolved any disagreements.

We applied the following inclusion criteria:

1. age at death 45 years;
2. cause of death SCD;
3. (a) SCD within 24 hours of last fire service duty or (b) sudden cardiac event within 24 hours of last duty followed by permanent loss of consciousness until death;
4. death occurred between 1 January 1996 and 31 December 2012;
5. medical history and/or autopsy report available (NIOSH database only).

Based on the duty performed at the time of the onset of the symptoms, we grouped SCD events into one of six categories [3,4,12]:

1. fire station tasks and non-emergency duties (administrative and fire station tasks, fire prevention, inspection, maintenance, meetings and classroom activities);
2. non-fire emergencies (emergency medical services (EMS) rescues and other non-fire operations);
3. physical training (physical fitness tests, fitness activities, simulated or live fire, rescue emergency and search drills);
4. alarm return (all events occurred upon returning from an emergency);
5. alarm response (all events after an emergency dispatch and prior to reaching the emergency scene);
6. fire suppression (including all operational activities on the fireground).

For the SCD cases reported both from USFA and NIOSH, we crosschecked blindly the classification of the duties in the two databases. For non-concordant cases, we relied on the more comprehensive information provided by the NIOSH reports. We classified volunteer, paid on-call and part-time firefighters together as 'volunteers' and full-time firefighters working in career fire departments as 'career' firefighters. We evaluated pre-existing cardiovascular conditions based on the NIOSH reports. We did not extend this analysis to the USFA database due to the lack of information on preexisting medical conditions. We included the following when present: CHD (pre-morbid myocardial infarction, angioplasty, stent placement, positive calcium score or positive exercise tolerance test); valvular abnormalities/ diseases; pre-morbid self-reported history of chest pain or shortness of breath or a previous history of an abnormal electrocardiogram (as reported by NIOSH investigators based on clinical records). Since the NIOSH database does not seek to be comprehensive (the deaths investigated are identified through an algorithm designed to address prevention priorities [13]), we conducted a secondary analysis to assess how the selection process might bias the study of relative risks (RR) associated with specific duties. We used three independent estimates to approximate the proportional time that an average firefighter

spends in each duty (Table 1). These estimates have been previously described in detail [3,4].

We performed statistical analyses using Stata 12.1 SE (Stata Corp., College Station, TX). We defined a two-sided  $P$  value  $\leq 0.05$  as statistically significant. We compared continuous variables, expressed as median and interquartile range (IQR), using the Mann-Whitney  $U$ -test. We used Cohen's  $\kappa$  to study agreement on duty at time of death between the two databases. Assuming independence between duties and the risk of SCD, we calculated the expected deaths based on the relative time per duty. We estimated the duty-specific RR and the associated 95% confidence intervals (95% CIs) of SCD by fitting Poisson regression models including observed counts as the dependent variable and the logarithm of the proportion of time per duty as the offset. As this study involved only deceased subjects, it was exempt from institutional review board review, which by US Federal law classifies research on deceased subjects as exempt non-human subjects investigation [14]. All data were extracted from freely available electronic databases maintained in the public domain by US Federal agencies. To preserve the anonymity of the study population, our final database did not include any personal identifiers and we only presented aggregated data.

## Results

Figure 1 presents the process for identifying on-duty SCDs among firefighters aged 45 or younger. The USFA database included 205 SCDs occurring between 1996 and 2012 among firefighters aged 45 or younger and meeting the study's inclusion criteria. The NIOSH investigated 86 of these deaths (42%) and one case from 2012 that was not yet included in the USFA database at the time of data extraction, bringing the total number of unique SCDs to 206. All deaths classified as SCD according to the USFA records were confirmed by the more informative NIOSH reports. Among the 86 deaths included in both data sets, the agreement between the two databases on the duty at the time of the death was extremely robust (Cohen's  $\kappa$  0.90, 95% CI 0.82–0.97). Among cases investigated by NIOSH, we observed similar distributions of hypertension, heart mass and past cardiovascular history by duty performed at the time of the death (Supplementary Table 1, available as Supplementary data at *Occupational Medicine* Online). Victims dying during physical training tended to be younger and less frequently smokers. Firefighters dying during fire station and other non-emergency duties or EMS and other non-fire emergencies tended to have a lower body mass index.

In Table 2, we show the proportion of SCD reported by the USFA and also investigated by NIOSH as a function of the duty associated with the fatalities. NIOSH was more likely to investigate SCD associated with physical training (69%) and fire suppression (57%) compared with 42% of overall SCD ( $P < 0.001$ ). Career firefighters' deaths were investigated in 55% of cases, while only 31% of deaths occurring among volunteers were studied ( $P < 0.05$ ). The age distribution of the cases investigated by NIOSH (median 39, IQR 34–43 years) and of those that were not investigated (median 40, IQR 36–43) did not differ significantly.

In Table 3, we present the RRs for duty-related SCD risk based on USFA data. We observed the highest risks for fire suppression duties regardless of the exposure assessment assumptions. However, the choice of the estimates influenced the magnitude of the RR point estimates. Physical training and alarm return were also associated with increased risks of SCD. Evidence was more limited for alarm response and limited to volunteer firefighters. We did not find an increased risk for SCD for EMS and other non-fire emergencies in any of the three exposure assessment scenarios.

In Supplementary Table 2, available as Supplementary data at *Occupational Medicine* Online, we present the RR for duty-related SCD risk based on NIOSH data. The patterns of RRs were similar but higher for physical training and fire suppression than using USFA data.

In Table 4, we stratify the duty-related risk of SCD according firefighters' job status, that is career or volunteer. The risk estimates were similar with the exception of alarm response, which was markedly elevated among volunteers, while we observed no such deaths among career firefighters.

Among SCDs investigated by NIOSH, 38% (95% CI 28–49%) had a history of any cardiovascular condition; and as many as 21% of SCD cases (95% CI 13–31%) had a pre-morbid history of CHD or CHD equivalent. In Table 5, we stratify the duty-related risk of SCD according to firefighters' pre-morbid cardiovascular history using NIOSH cases. The RRs associated with fire suppression, alarm return and response, and physical training were consistently higher among firefighters with a history of cardiovascular diseases or conditions.

## Discussion

Our study provides definitive evidence that performing strenuous emergency duties is a risk factor for SCD among young firefighters. We demonstrate that the duty-specific risks of SCD were higher among subjects with a pre-morbid history of cardiovascular conditions. Both of these findings are consistent with previous studies of exclusively CHD-related SCD among mostly older firefighters [3,4]. We are the first to report that alarm response is associated with an increased risk of SCD only among volunteer firefighters.

The main strength of our study is the use of an internal comparison group; indeed, we estimated the expected death counts based on fire service data. We believe that the three sets of duty-time estimates cover all plausible exposure scenarios [3,4]. Despite the variations in the magnitude of the RRs, the analysis conducted using different assumptions consistently identified increased risks of SCD for physical training, alarm return and fire suppression. Our analysis, based on expected deaths, eliminate the healthy worker effect, which hampered the study of cardiovascular disease among emergency workers in many previous investigations [15].

Our study does have limitations. Although the USFA provides a comprehensive database of deaths among US firefighters, it presents only limited medical information. However, we found that the identification of SCD was highly reliable: all 86 cases also analysed by NIOSH were confirmed as SCD by the more detailed clinical and autopsy reports. Another

limitation of our study is the potential for misclassification of the last duty as the USFA database presents only a brief summary of the event. However, we found almost perfect agreement between the duties assessed using the USFA records and those based on NIOSH reports. Because the NIOSH investigations present detailed descriptions of the circumstances of deaths and of underlying medical causes, we believe that exposure misclassification and case ascertainment bias are not major concerns. The NIOSH criteria for investigation are likely to bias the estimates of the duty-related RRs based on NIOSH reports. Thus, it is not surprising that the RR associated with physical training and fire suppression were higher in this sub-selection of cases.

Information on personal cardiovascular risk factors was not available in the USFA database. However, personal risk factors are not confounders in our analysis. Indeed, we did not compare different populations, but the risk of SCD as a proportion of time spent in each duty. It is reasonable to assume that personal risk factors (such as obesity, hypertension and diabetes) are stable within the same subject over multiple work shifts, while job-related psycho-physiological stressors vary across work shifts. Tobacco smoking, an exogenous trigger of cardiovascular events, might bias our estimates towards the null hypothesis. Indeed smoking is much more frequent during downtime on routine duties and unlikely to occur in the heat of performing emergency/ strenuous tasks.

Our risk estimates are lower than those reported in a previous study of duty-specific risk of SCD among firefighters of all ages [4]. This finding confirms age as an effect modifier of duty-specific SCD triggering [4]. Importantly, we observed higher duty-specific risks of SCD among firefighters with a positive history of cardiovascular diseases or conditions. This finding provides further support for the suggestion that firefighters with known CHD, other clinically significant atherosclerotic endpoints and/or considerable structural heart disease should be restricted from participating in fire emergencies and certain forms of strenuous physical training [8,15]. Additionally, firefighters with cardio-respiratory symptoms or abnormal electrocardiogram findings should receive sufficient evaluation to exclude underlying disease.

EMS and other non-fire emergencies did not convey increased SCD risk in this and in previous studies [3,4]. This was also true for firefighters with pre-existing disease. Therefore, we suggest that restricted EMS duties might offer a safer alternative for carefully selected firefighters with known heart disease. All deaths related to alarm response were observed among volunteer, paid oncall or part-time firefighters. Greater sympathetic stimulation due to use of personal vehicles to reach the site of the emergency, a lesser frequency of calls or a combination of both could explain the observed difference. It is also possible that volunteers spend different proportions of time in each duty compared with career firefighters. However, we did not observe major differences for the estimates of duty-related risks other than alarm response.

Several factors could contribute to the risk of SCD observed for emergency duties. The risk of SCD increases considerably in presence of moderate or strenuous exertion [16]. Core temperatures over 38.5°C have been documented during fire ground activities[17] and working in a hot environment while wearing heavy protective clothing may result in severe



dehydration leading to volume depletion, alterations of plasma electrolyte concentrations, hyperviscosity and coagulatory changes [5,18]. Exposure to toxic substances (e.g. carbon monoxide, cyanides and particulates) could be another contributory factor during fire emergencies [15], as could psychological stress [19]. Previous studies have highlighted a substantial increase in heart rate responses immediately following an initial alarm [20,21]. Finally, shift work is associated with an increased risk of cardiac events, probably due to the disruption of circadian rhythms [22].

We previously reported that traditional cardiovascular risk factors (hypertension, obesity and cigarette smoking) are associated with SCD among young firefighters by contributing to atherosclerosis and cardiac hypertrophy [8]. These findings were based on the NIOSH database and included the 87 SCD events analysed in this study. Notably the prevalence of obesity was found to be as high as 63%, 48% of subjects had a diagnosis of hypertension, 28% of firefighters were current smokers at the time of the death and 66% of SCD occurred among firefighters with a heart weight >450 g [8]. Among the 87 SCD cases investigated by NIOSH, it was surprising to discover that when we stratified the distribution of cardiovascular risk factors by duty associated with the death we observed a lower median body mass index among subjects deceased during less stressful duties [8]. This finding could be an artefact driven by selective investigations. Unexplained deaths, for example, during resting periods among subjects assumed to have been healthy, naturally attract investigators' attention. It is not surprising that death during physical training was more common among nonsmokers and younger firefighters because these individuals probably spend more time in physical training.

Previous studies have already highlighted that the prevalence of obesity, hypertension and low aerobic capacity among US firefighter recruits is surprisingly high [23–26]. There is also growing evidence that LVH is common among active US firefighters [3,6,8]. These observations support the hypothesis that the cardiovascular strain associated with firefighting may trigger SCD in susceptible individuals with underlying heart disease (most often CHD and LVH) [5]. Prevention strategies aimed at modifying traditional risk factors might be effective in reducing the burden of SCD among young firefighters [26]. Dietary interventions may be particularly promising. A recent study of US firefighters described low compliance to a Mediterranean-like diet [27], which would probably be effective in decreasing CVD risk [28]. Interventions aimed at improving physical fitness could be effective as well, as it is known that increasing cardio-respiratory fitness has beneficial effects on cardiovascular disease risk factor profiles among firefighters [29,30].

In conclusion, our study provides evidence that performing emergency duties increases the risk of SCD among young firefighters with underlying heart disease. Less strenuous restricted EMS duties should be considered as a safer alternative for firefighters with a significant history of cardiovascular disease. Prevention strategies aimed at reducing the burden of traditional cardiovascular risk factors among young firefighters are needed [30].

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgments

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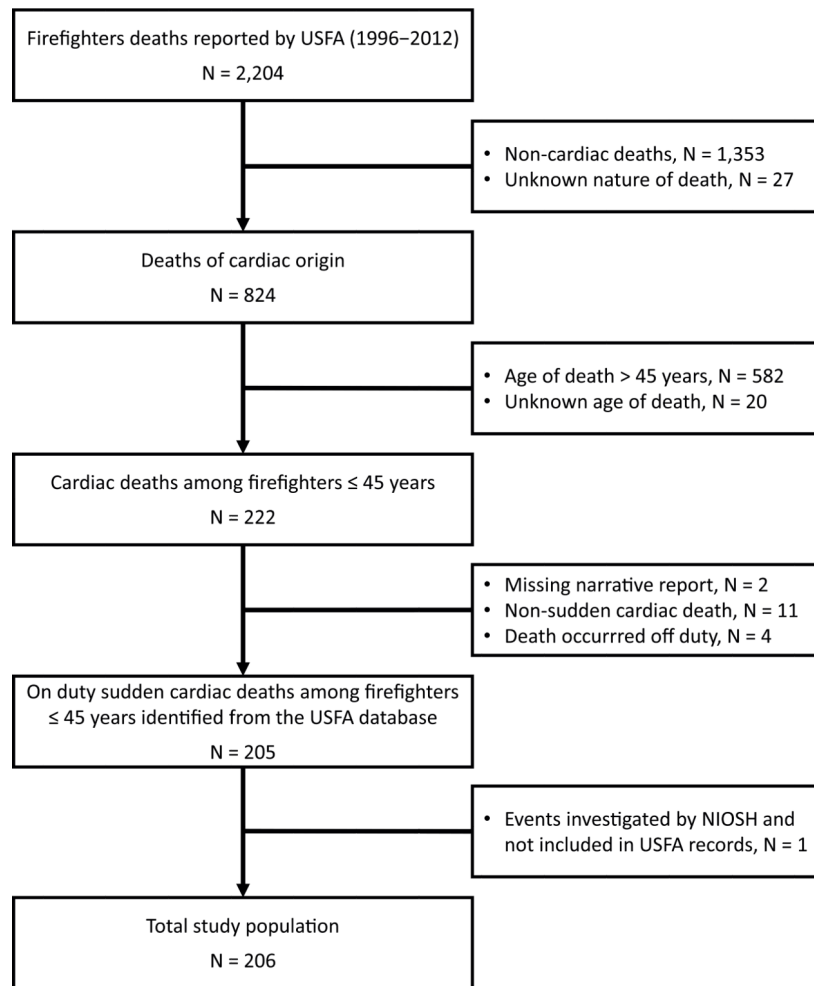
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**Key points**

- Performing strenuous duties is associated with an increased risk of sudden cardiac death among young firefighters, particularly those with a preexisting history of a cardiovascular condition.
- Firefighters with symptoms or abnormal electrocardiogram findings should receive sufficient evaluation to exclude underlying heart disease.
- Restricted emergency medical service duties might be considered for selected firefighters with known cardiovascular disease.



**Figure 1.** Flow chart of the study population. Identification of on-duty SCDs among US firefighters aged 45 or younger.

**Table 1.**

Estimated proportion of time spent in specific firefighting duties by various fire service estimates<sup>a</sup>

Duty	Municipal fire department <sup>b</sup> % of time	Large metropolitan fire department <sup>c</sup> % of time	National data <sup>d</sup> % of time
Fire station and other non-emergency duties	51	29	65
EMS and other non-fire emergencies	23	34	15
Physical training	8	8	8
Alarm return	10	15	7
Alarm response	6	9	4
Fire suppression	2	5	1

<sup>a</sup> Adapted from Kales *et al.* [4].

<sup>b</sup> Estimates based on municipal data from the Cambridge Fire Department, Cambridge, MA [2].

<sup>c</sup> Estimates based on a survey of 17 large metropolitan fire departments conducted by the International Association of Fire Fighters (L. Moore-Merrell, personal communication) [2].

<sup>d</sup> Estimates based on annual national surveys conducted by the National Fire Protection Association [3].

**Table 2.**

Proportion of 205 USFA reported SCD cases (1996–2012) investigated by the NIOSH Fire Fighter Fatality Investigation and Prevention Program<sup>a</sup>

Duty	Investigated by NIOSH Fire Fighter Fatality Investigation and Prevention Program		Pearson's $\chi^2$ P value
	No n (%)	Yes n (%)	
Fire station and other non-emergency duties		37 (71)	15 (29)
EMS and other non-fire emergencies		7 (58)	5 (42)
Physical training		12 (31)	27 (69)
Alarm return		32 (76)	10 (24)
Alarm response		12 (75)	4 (25)
Fire suppression		19 (43)	25 <sup>b</sup> (57)
Total		119 (58)	86 (42)

<sup>a</sup>Data stratified by type of duty.

<sup>b</sup>One case from 2012 investigated by NIOSH was not included in the US Fire Administration Database at the study date.

**Table 3.**

Risk of SCD among young firefighters (age 45) engaged in emergency and strenuous duties compared with firefighters engaged in non-emergency duties<sup>a</sup>

Duty	Observed deaths (N = 206)												
	Municipal department					Large metropolitan fire department					National data		
	n (%)	E <sup>b</sup>	O/E	IRR	95% CI	E <sup>c</sup>	O/E	IRR	95% CI	E <sup>d</sup>	O/E	IRR	95% CI
Fire station and other non-emergency duties	52 (25)	105.1	0.5	1.0	Ref.	59.7	0.9	1.0	Ref.	133.9	0.4	1.0	Ref.
EMS and other non-fire emergencies	12 (6)	47.4	0.3	0.5	0.3–1.0	70.0	0.2	0.2	0.1–0.4	30.9	0.4	1.0	0.5–1.9
Physical training	39 (19)	16.5	2.4	4.8	3.2–7.2	16.5	2.4	2.7	1.8–4.1	16.5	2.4	6.1	4.0–9.2
Alarm return	42 (20)	20.6	2.0	4.1	2.7–6.2	30.9	1.4	1.6	1.0–2.4	14.4	2.9	7.5	5.0–11.3
Alarm response	16 (8)	12.4	1.3	2.6	1.5–4.6	18.5	0.9	1.0	0.6–1.7	8.2	1.9	5.0	2.9–8.8
Fire suppression	45 (22)	4.1	10.9	22.1	14.8–32.9	10.3	4.4	5.0	3.4–7.5	2.1	21.8	56.2	37.7–83.8

E, expected; IRR, incidence rate ratio; O, observed; Ref, reference category.

<sup>a</sup>Data from the US Fire Administration (1996–2012) and NIOSH Fire Fighter Fatality Investigation and Prevention Program (1996–2012).

<sup>b</sup>Expected deaths based on municipal data from the Cambridge Fire Department, Cambridge, MA [2].

<sup>c</sup>Expected deaths based on a survey of 17 large metropolitan fire departments conducted by the International Association of Fire Fighters (L. Moore-Merrell, personal communication) [2].

<sup>d</sup>Expected deaths based on a national survey conducted by the National Fire Protection Association [3].



**Table 4.**

Risk of SCD among young firefighters (age 45) engaged in emergency and strenuous duties compared with firefighters engaged in non-emergency duties: Analysis stratified on job position<sup>a</sup>

Duty	Volunteer firefighters				Career firefighters <sup>b,c</sup>					
	Observed deaths (N = 112)		Statistic		Observed deaths (N = 93)		Statistic			
	n (%)	O/E	IRR	95% CI	n (%)	O/E	IRR	95% CI		
Fire station and other non-emergency duties	24 (21)	57.1	0.4	1.00	Ref.	28 (30)	47.4	0.6	1.00	Ref.
EMS and other non-fire emergencies	8 (7)	25.8	0.3	0.74	0.3–1.7	4 (4)	21.4	0.2	0.3	0.1–0.9
Physical training	15 (13)	9.0	1.7	3.98	2.1–7.6	24 (26)	7.4	3.3	5.5	3.2–9.4
Alarm return	25 (22)	11.2	2.2	5.31	3.0–9.3	17 (18)	9.3	1.8	3.1	1.7–5.7
Alarm response	16 (14)	6.7	2.4	5.67	3.0–10.7	0 (0)	5.6	0.7 <sup>e</sup>	0.0	0.0–1.2 <sup>f</sup>
Fire suppression	24 (21)	2.2	10.7	25.5	14.5–44.9	20 (22)	1.9	10.8	18.2	10.3–32.3

E, expected; IRR, incidence rate ratio; Ref, reference category.

<sup>a</sup>Data from the US Fire Administration (1996–2012) and NIOSH Fire Fighter Fatality Investigation and Prevention Program (1996–2012).

<sup>b</sup>Including two trainees.

<sup>c</sup>The death of one wildland firefighter was excluded.

<sup>d</sup>Expected deaths based on municipal data from the Cambridge Fire Department, Cambridge, MA [2].

<sup>e</sup>Upper bound of the 95% confidence limit.

<sup>f</sup>Exact confidence interval.

**Table 5.**

Risk of SCD among young firefighters (age 45) engaged in emergency and strenuous duties compared with firefighters engaged in non-emergency duties: Analysis stratified on history of cardiovascular condition<sup>a</sup>

Duty	Firefighters with a positive history of cardiovascular condition <sup>b</sup>				Firefighters without a history of cardiovascular condition <sup>b</sup>					
	Observed deaths (N = 33) n (%)	Statistic	O/E	IRR	95% CI	Observed deaths (N = 54) n (%)	Statistic	O/E	IRR	95% CI
Fire station and other non-emergency duties	3 (9)	16.8	0.2	1.0	Ref.	13 (24)	22.4	0.6	1.0	Ref.
EMS and other non-fire emergencies	1 (3)	7.6	0.1	0.7	0.1–7.1	4 (7)	10.1	0.4	0.7	0.2–2.1
Physical training	12 (36)	2.6	4.6	25.5	7.2–90.4	15 (28)	3.5	4.3	7.4	3.5–15.5
Alarm return	5 (15)	3.3	1.5	8.5	2.0–35.6	4 (7)	4.4	0.9	1.6	0.5–4.8
Alarm response	2 (6)	2.0	1.0	5.7	1.0–33.9	2 (4)	2.6	0.8	1.3	0.3–5.8
Fire suppression	10 (30)	0.7	15.2	85.0	23.4–308	16 (30)	0.9	18.2	31.4	15.1–65.2

E, expected; IRR, incidence rate ratio; O, observed; Ref, reference category.

<sup>a</sup>Data from NIOSH Fire Fighter Fatality Investigation and Prevention Program (1996–2012).

<sup>b</sup>Includes history of irregular rhythm, CHD or equivalent, valvular disease, abnormal electrocardiogram, chest pain or shortness of breath.

<sup>c</sup>Expected deaths based on municipal data from the Cambridge Fire Department, Cambridge, MA [2].