

Incidence of Sudden Cardiac Death in a Young Active Population

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Background—Little is known about the burden of sudden cardiac death (SCD) among active, presumably healthy persons. We investigated the incidence of SCD among US male career firefighters.

Methods and Results—All on-duty SCDs among US male career firefighters between 1998 and 2012 were identified from the US Fire Administration and the US National Institute for Occupational Safety and Health databases. Age-specific incidence rates (IRs) of SCD with 95% CIs were computed. A joinpoint model was fitted to analyze the trend in IR and to help estimate the annual percentage change of SCD rates over the years. The effects of seasonality were assessed through a Poisson regression model. We identified 182 SCDs; based on 99 available autopsy reports, the leading underlying cause of death was coronary heart disease (79%). The overall IR was 18.1 SCDs per 100 000 person-years. The age-specific IRs of SCD ranged between 3.8 (for those aged 18 to 24 years) and 45.2 (for those aged 55 to 64 years) per 100 000 person-years. The annual rate of SCD steadily declined over time (annual percentage change -3.9% , 95% CI -5.8 to -2.0). SCD events were more frequent during January (peak-to-low ratio 1.70; 95% CI 1.09 to 2.65). In addition, the IR was 3 times higher during high-risk duties compared with low-risk duties. IRs among firefighters were lower than those observed among the US general population and US military personnel.

Conclusions—SCD risk in this active working population is overestimated using statistics from the general population. To address public health questions among these subpopulations, more specific studies of active adults should be conducted. (*J Am Heart Assoc.* 2015;4:e001818 doi: 10.1161/JAHA.115.001818)

Key Words: death • epidemiology • men • registries • statistics • sudden

Sudden cardiac death (SCD) is a natural death resulting from cardiac causes.¹ According to the widely accepted definition, SCD is heralded by abrupt loss of consciousness within 1 hour of the onset of the symptoms.¹ When the event is unwitnessed, the definition of SCD is extended to deaths occurring in normally functioning persons last seen alive and well within 24 hours.¹

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The etiology of SCD has been investigated thoroughly in 2 different groups: the general population and young athletes.^{2–5} The leading cause of SCD in the general population is coronary heart disease (CHD), which accounts for 80% of the deaths, followed by cardiomyopathies (10% to 15% of the SCDs).⁶ In contrast, among young athletes, CHD is responsible for only 3% of SCDs.⁷ In this group, most SCDs are attributable to hypertrophic cardiomyopathy (10% to 51%), myocarditis (5% to 22%), arrhythmogenic right ventricular cardiomyopathy (up to 25%), and ion channel diseases (ie, long QT syndrome, short QT syndrome, Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia; 2% to 10%).^{5,8,9}

The incidence of SCD among athletes is 1 to 2 deaths per 100 000 person-years.^{5,8} As expected, estimates of SCD incidence in the general population are much higher, ranging from 40 to 100 deaths for 100 000 person-years.^{2,6} Statistics on SCD are useful to inform policy makers and scientists about the global burden of SCD and the need for prevention efforts, including screening protocols, identification of risk-stratification tools, availability of public-access defibrillators, and implementation of primary prevention strategies.^{2,6}

Unfortunately, little is known about the incidence of SCD in active adult populations. SCD rate estimates in the general population are probably driven by incidence among high-risk subjects, such as those with a long history of chronic disease.

At the same time, current knowledge about competitive or young athletes cannot be easily translated to other settings because of the significant differences in the age distributions and underlying etiology.¹⁰

The study of the active workforce would present a valuable source of information on the incidence of SCD among presumably “healthy” adults. Unfortunately, previous studies have demonstrated that the retrospective assessment of SCD based on death certificates alone is not as accurate, and SCD rates may be largely overestimated.^{11,12} Only a few occupational cohorts have sample sizes adequate to study the incidence of SCDs. At present, the only study of SCD incidence among young active male adults was conducted among US military personnel.¹³

The US Fire Administration (USFA) collects data on all on-duty firefighter fatalities occurring in the United States, and reliable estimates of the number of US career firefighters are available from the Current Population Survey (CPS).^{14,15} In addition, the National Institute for Occupational Safety and Health (NIOSH) performs independent investigations of firefighter line-of-duty deaths¹⁶; the investigative reports have already proven to be a valuable source of information for etiologic studies.^{17–20}

The aim of the present study is to investigate the rate of SCD among US male career firefighters using data from the USFA, to compare this rate with the corresponding rates among military personnel and the general population, and to assess the change in incidence rate (IR) over the study period and the effects of seasonality on SCD.

Methods

Study Population

The study population is the dynamic cohort of ≈300 000 US full-time male career firefighters employed between January 1, 1998, and December 31, 2012. Only firefighters aged 18 to 64 years were included in the cohort.

The CPS, conducted by the US Census Bureau for the Bureau of Labor Statistics, is the primary source of labor statistics in the United States. The CPS uses a complex stratified sampling technique that identifies 824 (formerly 754 until July 2004) geographic sample areas and then selects clusters of households within each area.²¹ Of the roughly 72 000 households selected each month, about 60 000 are occupied and eligible for interview; among eligible households, the response rate is ≈92.5%.²¹ On average, information is collected from around 112 000 persons aged ≥16 years every month.²¹ The survey inquires about the calendar week that includes the 12th day of the month. Since January 2003, occupational titles have been classified according to the 2002 Census Industry and

Occupation Classification Codes²¹; the 1990 version of the classification was used through December 2002. Persons who usually work ≥35 hours per week are defined as full-time workers.

Table 1 presents the study population at risk for SCD and the corresponding person-years. We estimated the number of US career firefighters based on the CPS surveys conducted monthly between January 1998 and December 2012. We included as career firefighters all full-time workers classified as *first-line supervisors/managers firefighting and fire prevention workers* (1990 classification: code 413/2002 classification: code 3720), *fire inspectors* (code 416/3750), and *firefighters* (code 417/3740). Of note, the number of active firefighters ascertained through the CPS databases was very close to the figures reported annually by the National Fire Protection Agency.²² Because ascertainment of SCD is virtually complete only for on-duty events, we considered only working time as the exposure or time for being at risk.

Firefighting duties have been associated with an increased risk of SCD.^{23,24} In particular, studies showed an increased risk of SCD during physical training, alarm response, alarm return, and fire suppression (including all operational activities on the fire ground).^{17,18,25,26} In contrast, the risk of SCD during emergency medical services, rescues, and other nonfire emergencies has been consistently reported to be in line with the risk associated with nonemergency or routine duties.^{17,18,25,26} Furthermore, increased rates of SCD during stressful duties have been reported among other emergency-worker categories, such as law enforcement officers.²⁷ Moreover, we distinguished between SCDs that occurred during low-risk duties (eg, fire station tasks and other nonemergency or routine duties, emergency medical services, rescues, and other nonfire emergencies) and those that occurred during high-risk duties (eg, physical training, alarm response, alarm return, and fire suppression). Estimates of the average time spent by firefighters in low- and high-risk duties have been reported in previous studies^{17,25}; therefore, we assumed that 74% of the total observed person-years had been spent on low-risk duties (23% emergency medical services and other nonfire emergencies and 51% fire station and other nonemergency duties) and that the remaining 26% of the observed person-years was spent on high-risk duties (8% physical training, 6% alarm response, 10% alarm return, and 2% fire suppression).

The present study, involving only deceased persons, was exempt from institutional review board review, based on US federal law, which classifies research on deceased, nonliving subjects as exempt non-human subjects investigation.²⁸ All data were extracted from publicly available electronic databases maintained by US federal agencies. We created a database that excluded any personal identifiers, and to

Table 1. Career Firefighters in the United States (1998–2012)

Year	SCD	Firefighters*	Person-Time†	Crude Estimates		Age-Adjusted Estimates	
	n	n	pyrs	IR	95% CI	IR	95% CI
1998	15	248 509	58 966	25.4	15.3 to 42.2	27.5	13.4 to 41.7
1999	10	244 192	57 942	17.3	9.3 to 32.1	20.0	7.5 to 32.6
2000	12	240 183	56 991	21.1	10.7 to 34.9	21.5	9.3 to 33.7
2001	12	257 545	61 110	19.6	11.2 to 34.6	19.9	8.6 to 31.1
2002	13	256 179	60 786	21.4	12.4 to 36.8	23.6	10.6 to 36.6
2003	16	277 004	65 728	24.3	14.9 to 39.7	24.8	12.6 to 36.9
2004	13	280 625	66 587	19.5	11.3 to 33.6	20.0	9.0 to 31.1
2005	12	260 689	61 856	19.4	11.0 to 34.2	19.8	8.6 to 31.0
2006	11	269 062	63 843	17.2	9.5 to 31.1	16.7	6.8 to 26.6
2007	15	305 439	72 475	20.7	12.5 to 34.3	21.2	10.4 to 31.9
2008	7	317 734	75 392	9.3	4.4 to 19.5	9.0	2.3 to 15.7
2009	10	310 675	73 717	13.6	7.3 to 25.2	13.0	4.9 to 21.2
2010	12	312 019	74 036	16.2	9.2 to 28.5	15.9	6.9 to 25.0
2011	12	315 725	74 915	16.0	9.1 to 28.2	17.3	7.5 to 27.1
2012	12	332 732	78 951	15.2	8.6 to 26.8	15.0	6.4 to 23.6

IR indicates incidence rate; pyrs, person-years; SCD, sudden cardiac death.

*The yearly number of career firefighters was estimated as the average of the firefighters reported by the monthly Current Population Survey.

†Person-time for each year was estimated as the total number of working hours.

preserve the anonymity of the study population, we present only aggregate data.

Databases on Firefighter Fatalities

We collected on-duty SCD data from the USFA and from the NIOSH Fire Fighter Fatality Investigation and Prevention Program. The USFA maintains a systematic database of all deaths associated with firefighting in the United States since 1981.¹⁴ Of note, identifying and reporting cardiac death among firefighters is mandatory in the United States (section 1201 of the Omnibus Crime Control and Safe Streets Act of 1968 [42 U.S.C. 3796] and Hometown Heroes Survivors Benefits Act of 2003). The USFA actively collects information of firefighter deaths directly from fire services and from many external sources, including the USFA Public Safety Officers’ Benefits program administered by the US Department of Justice, NIOSH, the Occupational Safety and Health Administration, the US Department of Defense, the National Interagency Fire Center, and other federal agencies. Furthermore, the USFA exchanges information with fire service organizations. Each USFA record includes the deceased person’s name, age, rank, and classification (volunteer versus career) and the date of incident, date of death, type of location (eg, residential, street), cause and nature of death, duty (type, specific activity, emergency context), and a

narrative summary of the event (systematically available after 1993). For the years 1998–2000, we cross-validated the information contained in the USFA databases with the records included in the Firefighters Fatality Retrospective Study.²⁹

The NIOSH program aims to investigate firefighter line-of-duty deaths for prevention purposes.¹⁶ The NIOSH database is neither representative nor comprehensive; however, all reports present a detailed description of the event and, if relevant, a summary of the clinical history (including emergency medical services records) and postmortem examination findings. Since 1994, the USFA has recommended the performance of an autopsy for all fatalities possibly associated with firefighting¹⁴; however, the final decision to undertake an autopsy is at the discretion of the local coroners.

Eight records included only in the USFA database presented missing or insufficient information on age, cause and dynamic of death, or career status. We were able to retrieve missing information through an Internet search for data from newspapers, firefighters associations (eg, the line-of-duty deaths database of the International Association of Firefighters, <http://www.iaff.org/hs/LODD>), and obituaries. To validate the accuracy of the data retrieved with the above methods, we cross-checked the name, date and circumstances of death, and firefighter employment in the retrieved

information against the USFA database records. In this way, we were able to retrieve all missing data.

Identification of SCD Cases and Data Extraction

We examined all USFA records for on-duty fatalities that occurred between January 1998 and December 2012 that were listed as heart attacks, cerebrovascular accidents, heat exhaustion, or “other.” We also reviewed all “medical related” deaths from the NIOSH database. Two physicians independently examined the summary report of each record. We extracted the following information: age, sex, cause of death (cardiac or noncardiac), onset of symptoms (within 1 hour of collapse or not), dynamic of the event (directly witnessed versus subject last seen alive and symptom free within 1 hour or 24 hours before death), and the type of duty performed during the onset of the symptoms. From NIOSH records, we were also able to retrieve information on the presence of a shockable rhythm during resuscitation efforts (as assessed through the use of automated external defibrillators). We classified an event as *on duty* if the onset of the symptoms occurred during the firefighter’s work shift. For cases in which the information extracted from the USFA and NIOSH reports were not in agreement, we relied on the more comprehensive narrative information provided by the NIOSH reports.

SCD was defined as an unexpected death of cardiac origin that occurred within 1 hour of the onset of symptoms (witnessed) or within 24 hours of having been seen alive and without symptoms (unwitnessed). In our analysis, we included only cardiovascular deaths in which, after the collapse, the person never regained consciousness prior to biological death. We excluded pulmonary embolisms and cerebrovascular and aortic events and deaths associated with trauma, violent death, overdose, or drowning.

Comparison With the General Population and Military Personnel

We compared the rates of SCD registered in our study population with those reported for the US male general population and US male military personnel.

The military study by Eckart and colleagues represents the only source of information on the incidence of SCD in a large working population.¹³ Like firefighters, military personnel represent a highly selected population undergoing pre-employment screening and health surveillance. Eckart and colleagues reported solid findings based on high autopsy rates and reliable identification of the source population. Moreover, their case definition, like ours, included only SCD of cardiac origin, excluding pulmonary embolisms and aortic dissections.

Highly reliable estimates of the incidence of SCD in the US general population are available from multiple-source surveillance of inhabitants of Multnomah County, Oregon^{11,30}; however, the case definition of SCD in this study also included thoracic aortic dissection. Consequently, when comparing our figures with those reported by Chugh and colleagues, we extended our case definition to include thoracic aortic dissections.

Statistical Analysis

We assessed the agreement between the USFA and the NIOSH databases with Cohen’s κ . We compared non-normally distributed continuous variables, expressed as median and interquartile range, between groups using the Mann–Whitney U test and categorical variables, described as number and percentage, with Pearson’s chi-square test.

We calculated the age-specific (10-year categories) IRs of SCD per 100 000 person-years and computed the 95% CI associated with each rate. Assuming a full-time equivalent of 2080 work hours per year,³⁰ we estimated the total at-risk person-years (ie, the total amount of working hours among full-time career firefighters) using the following formula:

$$\text{Person-years} = \frac{2,080}{365.25 \times 24} \times \sum_{\text{year}=1998}^{2012} \left[\sum_{\text{month}=\text{Jan}}^{\text{Dec}} \frac{\text{N of days of the month}}{365.25} \times \text{N of firefighters} \right]$$

For purposes of external comparison, we calculated age-standardized mortality rates with exact CI. We also calculated age-adjusted (10-year classes) monthly and annual rates of SCD through direct standardization using the entire study population as the reference standard.

To estimate the seasonal intensity of SCD based on monthly counts, we fitted the following Poisson model³¹:

$$\log E(Y) = \beta_0 + \beta_1 \times \sin(2\pi \times \text{month}/12) + \beta_2 \times \cos(2\pi \times \text{month}/12),$$

We modeled monthly counts adjusted for the size of the denominators and rescaled to sum up to the total number of observed events. Periodic models are used to study seasonal effects through standard regression models adapting a sine curve to a time series of frequencies. Consequently, through the inclusion of sine and cosine terms (the number of terms introduced determines the number of peaks allowed by the model), it is possible to fit the observed data using traditional maximum likelihood estimators (usually a Poisson regression model for counts). Overdispersion in our data was assessed

through the likelihood ratio test for the overdispersion parameter. A simple parameterization of the model including only 1 sinusoid was chosen based on the observed data and a previous report that highlighted only a very small secondary peak of CHD deaths among firefighters in the late summer.³² The single sinusoid parameterization allowed a closed-form estimation of the peak-to-low ratio (a measure that compares the periods with the highest and lowest incidence) with CI.³¹

To estimate the annual percentage change in age-standardized SCD rates, we applied joinpoint regression models.³³ A joinpoint represents a knot at which an important change in the temporal trend occurs; joinpoints are estimated iteratively and do not require the specification of an a priori hypothesis about the location of the knots to be tested. We fitted a log-linear joinpoint model maximized on standard error-weighted least squares to account for heteroscedasticity. We also allowed for autocorrelation of the residuals to account for the fact that the observed rates are not independent. We tested for up to 2 joinpoints through a Monte Carlo permutation test based on 10 000 repetitions.

Statistical analyses were performed using Stata 12.1 SE (Stata Corp) and the Joinpoint Regression Program 4.1 (Statistical Research and Applications Branch, National Cancer Institute). We defined statistical significance as a 2-sided *P* value of <0.05.

Results

Figure 1 summarizes the flowchart for the 182 SCD cases included in the analysis. Using the deaths included in the USFA database from 1998 onward, we selected 872 records of potential cardiovascular deaths. After the exclusion of events that did not meet our case definition, we ended up with 182 SCD events that occurred among full-time male career firefighters aged 18 to 64 years during the study period (1998–2012). In 143 of these cases (79%), the deceased person was reported to be symptom-free 1 hour before a witnessed collapse.

After examining all medical-related deaths among firefighters from the NIOSH databases (*n*=255), we identified 141 potential SCD cases. All of these deaths were included among the 872 events listed by USFA as “heart attacks, cerebrovascular accidents, heat exhaustions, or other.” After further assessment, we excluded 12 of these deaths because they did not satisfy our case definition and 9 additional deaths that occurred off duty; therefore, the NIOSH reports included 120 (66%) of the SCDs reported by the USFA database. The assessment of SCD cases, events occurring on duty, and duty at the time of the death (high or low risk) showed a very high level of agreement between the 2 databases (all Cohen’s κ

0.95). An autopsy report was available for 99 (83%) of the cases investigated by NIOSH (corresponding to 54% of the total study population).

Table 2 presents several characteristics of the SCD events by the availability of an autopsy report. The ages of the firefighters and the years of events were comparable between the 2 groups; however, autopsy reports were more likely to be available for SCDs that occurred during high-risk duties, during the daytime, and in the presence of a witness.

The IRs of SCD in groups of 10-year increments are reported overall and separately for low- and high-risk duties in Table 3. The overall IR in the study population is 18.1 per 100 000 person-years (95% CI 15.7 to 21.0); as expected, the IR is lower for low-risk duties (IR 11.0 per 100 000 person-years, 95% CI 8.9 to 13.7) compared with high-risk duties (IR 38.3 per 100 000 person-years, 95% CI 31.5 to 46.6). We observed the highest IR among firefighters aged 54 to 64 years (IR 45.2 per 100 000

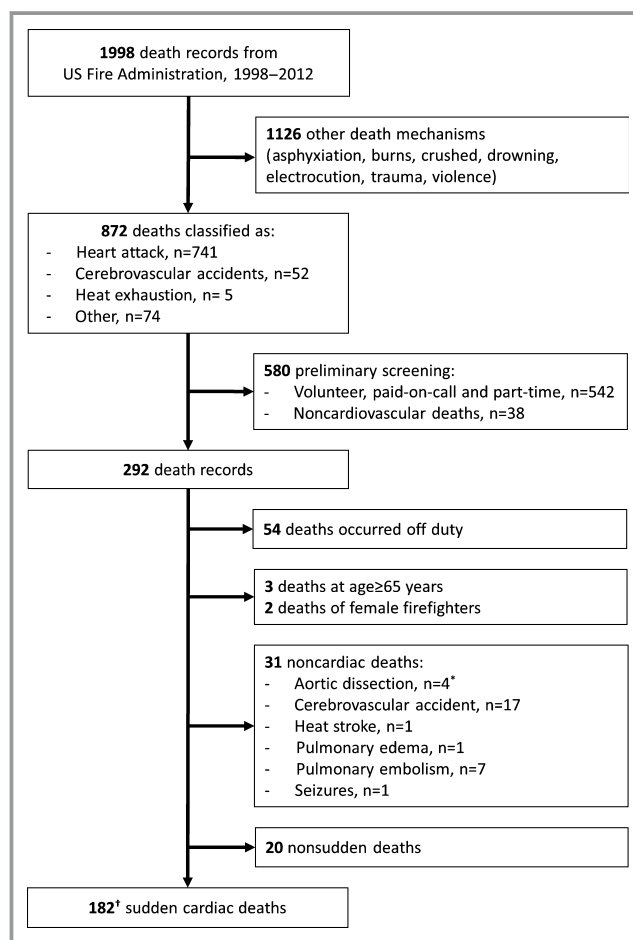


Figure 1. Identification of the sudden cardiac deaths from the US Fire Administration records (1998–2012). *One aortic dissection satisfied the definition of sudden death; †183 sudden cardiac deaths when applying the broader case definition also including thoracic aortic dissection.

Table 2. Characteristics of Sudden Cardiac Death Events by Availability of an Autopsy Report

Characteristic	Autopsy Report		P Value
	Not Available (n=83)	Available (n=99)	
Age, y, median (IQR)	49 (44 to 53)	48 (43 to 52)	0.08*
Duty at the time of the death			
Low-risk duty, n (%)	51 (61)	31 (31)	
High-risk duty, n (%)	32 (39)	68 (69)	<0.001 [†]
Time of the death			
Night (00:00 to 05:59), n (%)	22 (29)	16 (16)	
Morning (06:00 to 11:59), n (%)	18 (24)	25 (25)	
Afternoon (12:00 to 17:59), n (%)	19 (25)	36 (36)	
Evening (18:00 to 23:59), n (%)	17 (22)	22 (22)	0.008 ^{†,‡}
Unknown, n (%)	7	0	
Witnessed event			
No, n (%)	22 (27)	14 (14)	
Yes, n (%)	58 (72)	85 (86)	0.027 ^{†,‡}
Unknown, n (%)	3	0	
Year			
1998–2002, n (%)	23 (28)	39 (39)	
2003–2007, n (%)	32 (39)	35 (35)	
2008–2012, n (%)	28 (34)	25 (25)	0.218 [†]

*Mann–Whitney U test.

[†]Pearson’s chi-square test.

[‡]Test performed excluding the “unknown” category.

person-years, 95% CI 31.2 to 65.5) and the lowest IR in the group aged 25 to 34 years (IR 3.8 per 100 000 person-years, 95% CI 2.1 to 6.9).

Table 4 presents the causes of deaths as reported in the available autopsy reports (n=99). CHD was the most common underlying cause of death (n=77, 78%); in 57 of 77 cases, CHD was accompanied by an enlarged heart (58%). Left ventricular hypertrophy coupled with hypertensive heart disease was the underlying cause of death in 7 events (7%). Four cases of SCD were attributed to valvular heart diseases. The 2 cases of SCD in persons aged <25 years were determined to be due to cardiac arrhythmias (in both cases, the specific etiopathogenesis remained undetermined). CHD accounted for 43% of the SCDs in the group aged 25 to 34 years and for 68% in the group aged 35 to 44 years.

Figure 2 shows the annual age-standardized rates of SCD (also reported in Table 1). The joinpoint model highlighted a constant decline of SCD during the study period (annual percentage change –3.9%, 95% CI –5.8 to –2.0). The decrease in SCD incidence was driven mainly by a decline of rates among firefighters aged ≥55 years (Table 5).

The monthly counts of SCD presented seasonal variation over the study period (Figure 3A). The incidence peaked in January, with a peak-to-low ratio of 1.70 (95% CI 1.09 to 2.65). The distribution of SCD events by period of day is also reported in Figure 3B, indicating that the higher number of events occurred during the afternoon (31%), followed by the morning (25%).

Figure 4 presents a comparison between the incidence of SCD events among US firefighters and data reported in the medical literature on other populations. The age-specific IRs observed among US firefighters are similar to those reported for the US military personnel for subjects aged up to 49 years (Figure 4A); however, among people aged >50 years, the US firefighters do not show the sharp increase in IR that was documented among military personnel. This finding is confirmed when looking at the ratios between the observed numbers of SCD among firefighters and the expected numbers of SCD calculated based on the rates presented by Eckart and colleagues (Table 6). Indeed, only the ratios for

Table 3. Incidence of Sudden Cardiac Death Among US Male Career Firefighters

Age	All Duties				Low-Risk Duties*				High-Risk Duties*			
	SCDs	pyrs [†]	IR	95% CI	SCDs	pyrs [†]	IR	95% CI	SCDs	pyrs [†]	IR	95% CI
Overall rate	182	1 003 296	18.1	15.7 to 21.0	82	742 439	11.0	8.9 to 13.7	100	260 857	38.3	31.5 to 46.6
18 to 24 years	3	55 888	5.4	1.7 to 16.6	2	41 357	4.8	1.2 to 19.3	1	14 531	6.9	1.0 to 48.9
25 to 34 years	11	286 989	3.8	2.1 to 6.9	7	212 372	3.3	1.6 to 6.9	4	74 617	5.4	2.0 to 14.3
35 to 44 years	45	360 067	12.5	9.3 to 16.7	14	266 450	5.3	3.1 to 8.9	31	93 618	33.1	23.3 to 47.1
45 to 54 years	95	238 430	39.8	32.6 to 48.7	49	176 438	27.8	21.0 to 36.7	46	61 992	74.2	55.6 to 99.1
55 to 64 years	28	61 921	45.2	31.2 to 65.5	10	45 822	21.8	11.7 to 40.6	18	16 100	111.8	70.4 to 177.5

Data are from the US Fire Administration (1998–2012). IR indicates incidence rate; pyrs, person-years; SCD, sudden cardiac death.

*The proportion of time spent in low- or high-risk duty was estimated based on the Cambridge (Massachusetts) Fire Department.^{17,25}

[†]Estimates based on the Current Population Survey (1998–2012).¹⁵

Table 4. Cause of Death as Presented in Autopsy Reports

Cause of Death	Age Category																	
	Total			18 to 24			25 to 34			35 to 44			45 to 54			55 to 64		
	n	%	95% CI	n	%	95% CI	n	%	95% CI	n	%	95% CI	n	%	95% CI	n	%	95% CI
Arrhythmia*	3	3	1 to 9	2	100	16 to 100	1	14	0 to 58	0	0	0 to 12	0	0	0 to 7	0	0	0 to 25
Cardiac sarcoidosis	2	2	0 to 7	0	0	0 to 84	0	0	0 to 41	2	7	1 to 24	0	0	0 to 7	0	0	0 to 25
CHD	20	20	13 to 29	0	0	0 to 84	0	0	0 to 41	5	18	6 to 37	10	20	10 to 34	5	38	14 to 68
CHD and cardiomegaly	57	58	47 to 67	0	0	0 to 84	3	43	10 to 82	14	50	31 to 69	34	69	55 to 82	6	46	19 to 75
Dilated cardiomyopathy	1	1	0 to 5	0	0	0 to 84	1	14	0 to 58	0	0	0 to 12	0	0	0 to 7	0	0	0 to 25
HCM	4	4	1 to 10	0	0	0 to 84	1	14	0 to 58	2	7	1 to 24	1	2	0 to 11	0	0	0 to 25
LVH/HHD	7	7	3 to 14	0	0	0 to 84	0	0	0 to 41	3	11	2 to 28	3 [†]	6	1 to 17	1	8	0 to 36
Myocarditis	1	1	0 to 5	0	0	0 to 84	0	0	0 to 41	1	4	0 to 18	0	0	0 to 7	0	0	0 to 25
Valvular disease	4	4	1 to 10	0	0	0 to 84	1	14	0 to 58	1	4	0 to 18	1	2	0 to 11	1	8	0 to 36
Total	99			2			7			28			49			13		

Data are from the NIOSH Fire Fighter Fatality Investigation and Prevention Program (1998–2012). CHD indicates coronary heart disease; HCM, hypertrophic cardiomyopathy; HHD, hypertensive heart disease; LVH, left ventricular hypertrophy; NIOSH, National Institute for Occupational Safety and Health.

*Presumed arrhythmic event in the absence of structural disease.

[†]One subject presented acute ethanol intoxication.

subjects aged 45 to 49 or ≥50 years demonstrate a decrease in SCD for firefighters compared with military personnel. When we compared our figures with those from the US male general population, we documented a lower incidence of SCD in almost all age categories, with the only exception being those aged 45 to 54 years (Figure 4B and Table 4). Nevertheless, we observed the most dramatic difference between the 2 populations among those aged 55 to 64 years, for whom the observed-to-expected ratio was as low as 0.23 (95% CI 0.15 to 0.33).

Using data on witnessed events investigated by NIOSH (N=102), we estimated the proportion of deceased persons that presented a shockable rhythm during their collapse. Four cases were excluded from this analysis because of insufficient information in the NIOSH reports (n=2) or late assessment of cardiac rhythm (n=2). Among 98 subjects with complete information, 78 (80%, 95% CI 70% to 87%) presented a shockable rhythm; 96 received 1 or more series of shocks, whereas in 2 cases, defibrillator use was not possible because of device malfunction or the presence of very wet conditions.

Discussion

In a dynamic cohort of about 300 000 US firefighters followed between 1998 and 2012, we observed an IR of SCD of 18.1 per 100 000 person-years; the rate was lower when consid-

ering low-risk duties (11.0 per 100 000 person-years). We documented a decline of SCD incidence over the study period, driven mainly by a decrease in the rates among firefighters aged ≥55 years. As expected, the incidence of SCD peaked in January, whereas we did not observe the typical excess of morning deaths compared with other periods of day. Based on NIOSH reports, CHD was the main cause of SCD; this finding also applies to relatively young (aged 25 to 44 years) firefighters. Taken together, hypertrophic cardiomyopathy,

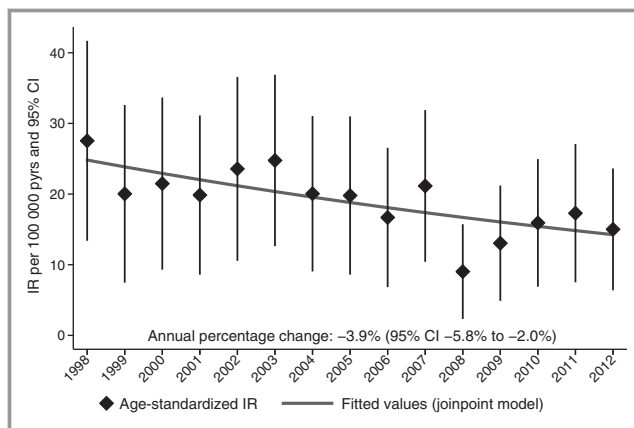


Figure 2. Age-adjusted incidence rates of sudden cardiac death by year for US male career firefighters, 1998–2012. IR indicates incidence rates; pyrs, person-years.

Table 5. Incidence Rates of Sudden Cardiac Death by Calendar Period and Age

Age	1998–2002				2003–2007				2008–2012			
	SCDs	pyrs*	IR	95% CI	SCDs	pyrs*	IR	95% CI	SCDs	pyrs*	IR	95% CI
Overall rate	62	295 796	21.0	16.3 to 26.9	67	330 489	20.3	16.0 to 25.8	53	377 011	14.1	10.7 to 18.4
18 to 24 years	0	17 002	0.0	0.0 to 21.7	2	17 761	11.3	2.8 to 45.0	1	21 126	4.7	0.7 to 33.6
25 to 34 years	6	79 897	7.5	3.4 to 16.7	2	98 843	2.0	0.5 to 8.1	3	108 250	2.8	0.9 to 8.6
35 to 44 years	13	115 764	11.2	6.5 to 19.3	17	115 385	14.7	9.2 to 23.7	15	128 919	11.6	7.0 to 19.3
45 to 54 years	28	69 326	40.4	27.9 to 58.5	40	77 967	51.3	37.6 to 69.9	27	91 136	29.6	20.3 to 43.2
55 to 64 years	15	13 807	108.6	65.5 to 180.2	6	20 533	29.2	13.1 to 65.0	7	27 581	25.4	12.1 to 53.2

IR indicates incidence rate; pyrs, person-years; SCD, sudden cardiac death.
 *Estimates based on the Current Population Survey (1998–2012).

myocarditis, and arrhythmias accounted for only 6% of the observed SCDs. We observed a high proportion (80%) of shockable rhythms among SCDs investigated by NIOSH.

Firefighters are generally regarded as a selected group of healthy workers.³⁴ By the very nature of their presumably high levels of fitness and health, they are expected to show a lower risk of cardiac events compared with the general population

(“healthy worker effect”).³⁴ The healthy worker effect is determined by 2 main components: the initial selection process and the continuing employment of healthy persons.³⁵ Both components seem to contribute to the decreased risk of SCD observed when we compared our population with the US

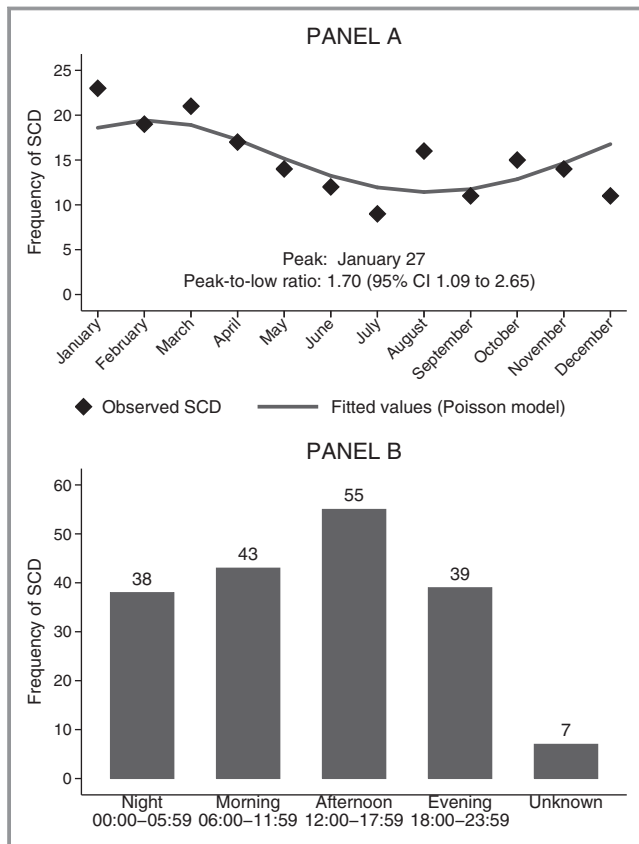


Figure 3. Distribution of sudden cardiac death events by month (A) and time of day (B) for US male career firefighters, 1998–2012. SCD indicates sudden cardiac death.

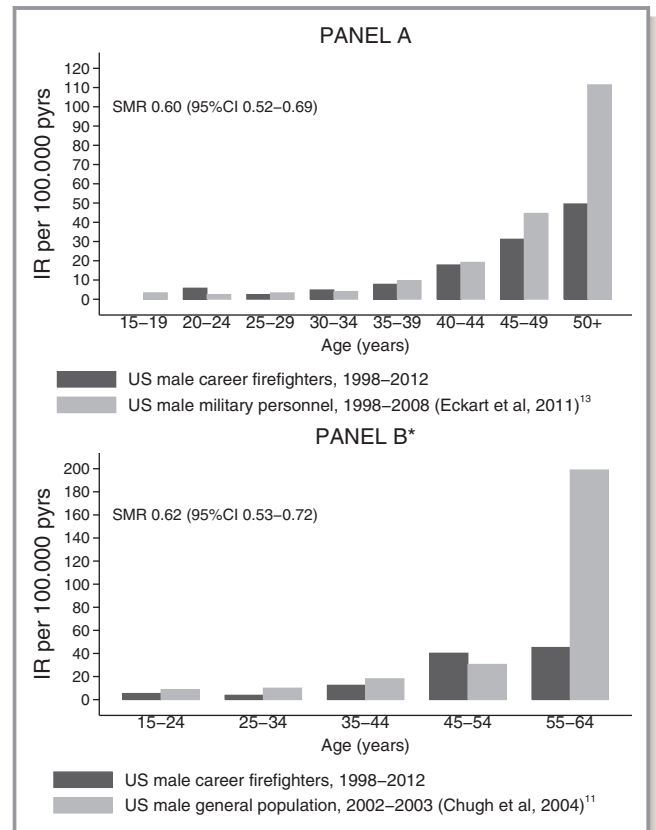


Figure 4. Comparison of the incidence of sudden cardiac death among US firefighters with the rates reported among the US general population (A) and among US military personnel (B). *Includes 1 sudden death caused by thoracic aortic dissection. IR indicates incidence rates; pyrs, person-years; SMR, standardized mortality ratio.

Table 6. Observed to Expected Ratios of Sudden Cardiac Death

Age	Person-Years	Obs SCD	Exp SCD	Obs/Exp	95% CI
Comparison with US male military personnel (Eckart et al ¹³)					
18 to 19 years	3936	0	0.13	0.00	0.00 to 27.81
20 to 24 years	51 952	3	1.27	2.37	0.49 to 6.92
25 to 29 years	122 261	3	4.06	0.74	0.15 to 2.16
30 to 34 years	164 729	8	6.57	1.22	0.53 to 2.40
35 to 39 years	191 975	15	18.60	0.81	0.45 to 1.33
40 to 44 years	168 092	30	32.31	0.93	0.63 to 1.33
45 to 49 years	140 929	44	62.92	0.70	0.51 to 0.94
≥50 years	159 422	79	177.68	0.44	0.35 to 0.55
Comparison with US male general population (Chugh et al ¹¹)					
18 to 24 years	55 888	3	4.87	0.62	0.13 to 1.80
25 to 34 years	286 989	11	28.64	0.38	0.19 to 0.69
35 to 44 years	360 067	45	65.28	0.69	0.50 to 0.92
45 to 54 years	238 430	96*	72.86	1.32	1.07 to 1.61
55 to 64 years	61 921	28	123.20	0.23	0.15 to 0.33

Exp indicates expected; Obs, observed; SCD, sudden cardiac death.

*Includes 1 sudden death caused by thoracic aortic dissection.

male general population. Indeed, even though we analyzed events occurring during strenuous duties characterized by an increased risk of SCD,^{17,18,25,26} we observed IRs of SCD lower than those previously reported by Chugh and colleagues among almost all age categories.^{11,36} Furthermore, we did not observe any dramatic rise in the incidence of SCD that usually characterizes the group aged 55 to 64 years.^{11,36} Compared with military personnel, the incidence of SCD among career firefighters was similar among younger persons, but important differences were observed after the age of 45 years. The pattern of SCD incidence that we observed in firefighters is similar to that reported for sports-related sudden death in the general population, although firefighters experience higher rates of SCD compared with athletes.¹⁰ Selection processes explain the similarities in the incidence of SCD in a healthy working population and among adult noncompetitive athletes, resulting in a lower proportion of high-risk subjects in the older age classes. Less fit persons are more likely to retire early from firefighting with age. In addition, many US states have laws entitling firefighters with heart disease to receive publicly funded disability benefits²³; this fact likely contributes to underrepresentation of subjects at high risk for cardiovascular events among occupational active firefighters aged 55 to 64 years. Our findings suggest that applying the rates of SCD estimated in the general population to a working population may lead to overestimation of the incidence of SCD, particularly in age groups characterized by high absolute risk. Our observation is consistent with previous studies of

aging workers that showed both early retirement and unemployment are associated with a remarkable increase in the risk of cardiovascular diseases.^{37,38}

CHD, often coupled with cardiomegaly, was the main cause of SCD death in our study population. This finding is in line with current knowledge of the incidence of SCD in the general population.^{3,11,36} CHD has also been documented as a major cause of death among young (aged ≤45 years) firefighters, probably due to the obesity epidemic.²⁰ Eckart et al reported that CHD is a frequent cause (>20%) of SCD among military personnel aged <35 years and the main cause (>70%) among subjects aged ≥35 years.¹³ The available evidence suggests the need for preventive strategies aimed at reducing the prevalence of modifiable CHD risk factors.

It is well established that SCD events vary by time of day and by season of the year.^{39,40} We did not observe the typical excess of SCD events occurring in the morning and the low rate generally documented during the night³⁹; however, our findings are in line with current knowledge of SCD among firefighters and could be attributed to the shift work schedule and the daily distribution of emergency dispatches, which is higher from noon to midnight.^{17,41,42} With respect to season, we found that SCD among firefighters was most frequent in the winter (peaking in January), in agreement with the general population and a previous study on CHD deaths among firefighters.^{32,40}

Interestingly, we observed a constant decline of SCD between 1998 and 2012. This observation is consistent with

previous epidemiological studies on temporal trends of SCD.³ This significant decrease in SCD rates over the past decade has been attributed to improvements in the primary and secondary prevention of CHD and other underlying causes and to progress in acute treatment strategies.³

The proportion of shockable rhythms observed in our study population was higher than expected^{43,44}; however, previous studies showed that the probability of registering a shockable rhythm in a sudden cardiac arrest is higher when the event is witnessed and bystanders practice cardiopulmonary resuscitation.^{43,44} According to NIOSH reports, in our study population, cardiopulmonary resuscitation was performed promptly in most cases, and an automated external defibrillator was usually available. This is not surprising considering that firefighters are trained and equipped to face health emergencies. The timely availability of advanced life-support resources might also contribute to the reduced incidence of SCD documented when comparing US male firefighters with US male military personnel.

Study Strengths and Limitations

Our study has several limitations. Although the USFA provides a comprehensive database of all deaths among US firefighters, it presents only limited medical information. Nevertheless, we found that the identification of SCD based on USFA records was highly reliable when compared with the much more detailed NIOSH reports. In addition, our study is limited to only male firefighters; however, only 2 cases of SCD were observed among female firefighters. Specific firefighting activities have been previously associated with an increased risk of SCD.^{17–19,25} Consequently, the risk of SCD among firefighters might be higher when compared with other occupations, even those characterized by a high level of physical demand. For perspective on the magnitude of the incidence of SCD during low-effort, low-risk activities, we stratified our analyses based on the duty performed at the time of the onset of symptoms; we observed a 3-fold lower risk of SCD during low-effort duties compared with high-effort, high-risk activities. Another limitation of our study is that autopsy reports were available for our review only for the events reported by NIOSH. The NIOSH investigators selected the cases to be examined based on a priori criteria, and we found that reports were more often available for SCDs that occurred during high-risk duties. We cannot exclude the possibility that the underlying cause of SCD may vary according to the presence of an external trigger (eg, physical effort, psychological stress). Nonetheless, it is hard to hypothesize that the selection criteria adopted by NIOSH introduced a bias strong enough to explain the high proportion (76%) of SCD with underlying CHD observed in our study population. Finally, both the USFA and the NIOSH databases

provide information only on SCD and do not report data on survivors of cardiovascular events. Consequently, we could not evaluate whether the observed decline in annual SCD rates was determined by a decreasing number of sudden cardiac arrests or by an increased survival rate over the years. An obvious limitation of our study is the low number of deaths observed among young subjects; therefore, age-specific rates and proportions estimated among subjects aged <35 years present considerable levels of statistical uncertainty.

The main strength of our study is the comprehensive assessment of on-duty deaths provided by the USFA database and the availability of accurate denominators from the CPS. As expected for SCD occurring at the workplace, a high proportion of the events included in the present study were witnessed. This fact, combined with the noninclusion of persons affected by chronic and disabling conditions—a population in which a sudden cardiac arrest is likely to be explained by the underlying conditions—have likely limited any overestimation of SCD that usually characterizes the assessment of SCD events in the absence of autopsy reports.⁶ Furthermore, the NIOSH reports provide detailed information on the dynamics and details of the deaths, and thus we could use this second source of data to validate the analysis based on the USFA database. The use of multiple sources of ascertainment and information for the study of SCD has been highly recommended.¹¹ Our study, like those performed by Chugh et al and Eckart et al,^{11,13} was based on the retrieval of available postmortem examination reports and did not rely solely on death certificates. This fact ensures comparability between our estimates and those previously reported for US male military personnel and the US male general population.

Conclusions

We demonstrated that the incidence of SCD among US career firefighters is lower than among the general population and more comparable to rates among military personnel. Active, presumably healthy populations may show a reduced risk of SCD, particularly at ages characterized by high absolute risk, and have unique characteristics (eg, work shift) that make them quite different from the general population. To address relevant public health issues such as the need for preventive strategies in large working populations, more studies specific to these populations should be conducted.

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Disclosures

Dr Kales reported serving as a paid expert witness, independent medical examiner, or both in cases involving firefighters. No other potential conflict of interest relevant to this article was reported.

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