Original research

# All-cause and cause-specific mortality in a cohort of WTC-exposed and non-WTC-exposed firefighters

Ankura Singh,[1,2] Rachel Zeig-Owens ,[1,2,3] Madeline Cannon,[1,2] Mayris P Webber,[1,3] David G Goldfarb ,[1,2] Robert D Daniels ,[4] David J Prezant,[1,2,3] Paolo Boffetta,[5,6] Charles B Hall [3]

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/oemed-2022-108703).

[1]Bureau of Health Services, Fire Department of the City of New York, Brooklyn, New York, USA
[2]Department of Medicine, Montefiore Medical Center, Bronx, New York, USA
[3]Department of Epidemiology and Population Health, Albert Einstein College of Medicine, Bronx, New York, USA
[4]Division of Science integration, National Institute for Occupational Safety and Health, Cincinnati, Ohio, USA
[5]Stony Brook Cancer Center, Stony Brook University, Stony Brook, New York, USA
[6]Department of Medical and Surgical Sciences, University of Bologna, Bologna, Italy

**Correspondence to**
Dr Rachel Zeig-Owens, Department of Medicine, Montefiore Medical Center, Bronx, NY 11201, USA; rachel.zeig-owens@fdny.nyc.gov

Received 17 October 2022
Accepted 10 March 2023
Published Online First 27 March 2023



**To cite:** Singh A, Zeig-Owens R, Cannon M, *et al*. *Occup Environ Med* 2023;**80**:297–303.

## ABSTRACT

**Objective** To compare mortality rates in World Trade Center (WTC)-exposed Fire Department of the City of New York (FDNY) firefighters with rates in similarly healthy, non-WTC-exposed/non-FDNY firefighters, and compare mortality in each firefighter cohort with the general population.

**Methods** 10 786 male WTC-exposed FDNY firefighters and 8813 male non-WTC-exposed firefighters from other urban fire departments who were employed on 11 September 2001 were included in the analyses. Only WTC-exposed firefighters received health monitoring via the WTC Health Programme (WTCHP). Follow-up began 11 September 2001 and ended at the earlier of death date or 31 December 2016. Death data were obtained from the National Death Index and demographics from the fire departments. We estimated standardised mortality ratios (SMRs) in each firefighter cohort versus US males using demographic-specific US mortality rates. Poisson regression models estimated relative rates (RRs) of all-cause and cause-specific mortality in WTC-exposed versus non-WTC-exposed firefighters, controlling for age and race.

**Results** Between 11 September 2001 and 31 December 2016, there were 261 deaths among WTC-exposed firefighters and 605 among non-WTC-exposed. Both cohorts had reduced all-cause mortality compared with US males (SMR (95% CI)=0.30 (0.26 to 0.34) and 0.60 (0.55 to 0.65) in WTC-exposed and non-WTC-exposed, respectively). WTC-exposed firefighters also had lower rates of all-cause mortality (RR=0.54, 95% CI=0.49 to 0.59) and cancer-specific, cardiovascular-specific and respiratory disease-specific mortality compared with non-WTC-exposed firefighters.

**Conclusion** Both firefighter cohorts had lower than expected all-cause mortality. Fifteen years post 11 September 2001, mortality was lower in WTC-exposed versus non-WTC-exposed firefighters. Lower mortality in the WTC-exposed suggests not just a healthy worker effect, but additional factors such as greater access to free health monitoring and treatment that they receive via the WTCHP.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Rescue/recovery workers who responded to the World Trade Center (WTC) disaster have lower mortality rates compared with general populations; these findings may have been influenced by healthy worker effects or better access to care.

### WHAT THIS STUDY ADDS

⇒ In the first 15 years post 11 September 2001, male firefighters, both WTC-exposed and non-WTC-exposed, had lower than expected all-cause mortality when compared with demographically similar US males. Further, WTC-exposed firefighters had significantly lower rates of all-cause and cause-specific mortality compared with non-WTC-exposed firefighters.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our findings suggest that lower mortality rates observed in WTC-exposed firefighters may be due, in part, to the no-cost health monitoring and treatment these firefighters receive as part of the WTC Health Programme, over and above the advantage conferred by the healthy worker effect.

## INTRODUCTION

Firefighters, emergency medical service (EMS) providers and other first responders who participated in rescue/recovery work at the World Trade Center (WTC) site on and after 11 September 2001 (9/11) were exposed to known and suspected carcinogens, irritants and other potentially toxic substances in the WTC dust and fires that burned at the WTC site.[1 2] In the two decades that followed, WTC rescue/recovery work was found to be associated with adverse health outcomes such as obstructive airway diseases, chronic rhinosinusitis, certain cancers and post-traumatic stress disorder.[3–9] The increased risk of these and other chronic illnesses in WTC-exposed rescue/recovery workers has not resulted in elevated mortality rates, however, when compared with general populations. Studies conducted in three different WTC rescue/recovery worker cohorts and, most recently, in a large combined cohort of WTC rescue/recovery workers showed significantly lower than expected mortality among participants compared with USA, New York State and New York City populations.[10–13] These findings may reflect healthy worker effects, a phenomenon in which workers experience better health outcomes than the general population because they were healthier at the time of

their employment.[14] Alternatively, reduced mortality may be attributed, in part, to the no-cost health monitoring and treatment that WTC-exposed workers receive, even after their retirement, as part of the WTC Health Programme.[15 16] No study has compared mortality rates in WTC-exposed workers to those in a comparable occupational cohort.

Firefighters are routinely exposed to hazardous materials and situations in their work environments.[17 18] The International Agency for Research on Cancer (IARC) has recently classified occupational exposure from firefighting as carcinogenic to humans.[19] While several studies have linked firefighting to an increased risk of cancer,[3 19–22] pulmonary dysfunction or obstructive airways diseases,[23 24] studies assessing all-cause and cause-specific mortality in non-WTC exposed firefighters compared with general populations have had inconsistent results.[20 21 25–29] Individuals seeking employment as career firefighters must meet strict prehire health and fitness requirements,[30] potentially creating an even stronger healthy worker hire effect[14 31] than observed in other working populations. In the present investigation of mortality in WTC-exposed Fire Department of the City of New York (FDNY) firefighters, we account for this potential healthy worker bias by using a referent cohort of non-WTC-exposed career firefighters, the same population included in our 2021 cancer study.[3] The main objective of the current study was to compare all-cause and cause-specific mortality rates in the WTC-exposed and comparison firefighter populations during the first 15 years following 9/11. We also compared mortality in each group of firefighters with that of the US general population during this time period. The results from this study should aid our interpretation of the previously observed protective associations between WTC rescue/recovery worker cohort membership and mortality, that is, whether lower mortality can be explained by the healthy worker hire effect or improved access to comprehensive care.

## METHODS

### Study population

The source population consisted of firefighters enrolled in the Career Firefighter Health Study, which includes career firefighters from FDNY as well as from the Chicago Fire Department (CFD), Philadelphia Fire Department (PFD) and San Francisco Fire Department (SFFD).[32] The non-FDNY group (N=29 992) was initially assembled by the National Institute for Occupational Safety and Health (NIOSH), using data from the fire department rosters, for a longitudinal study of firefighting and cancer.[20] To ensure that the FDNY and non-FDNY firefighters had a similar baseline status, current analyses were restricted to the subpopulation of male Career Firefighter Health Study firefighters who were actively employed by their respective fire departments on 11 September 2001. We excluded 613 females due to low numbers in the FDNY group (online supplemental table S1). Male FDNY firefighters were required to have participated in rescue/recovery work at the WTC site any time between 11 September 2001 and 24 July 2002 to be considered WTC-exposed; those who died on 11 September 2001 (N=341) or were not exposed (N=82) were excluded from the study. The final study population included 10 786 FDNY and 8813 non-FDNY firefighters.

### Demographic and lifestyle variables

Dates of birth and employment and race/ethnicity information were available via the FDNY employee database for FDNY members and the respective fire department roster data for CFD, PFD and SFFD members.[32] We obtained FDNY participants' WTC-exposure level, or initial arrival time at the WTC site, from their first post 9/11 FDNY health monitoring survey. FDNY firefighters who arrived at the WTC site on the morning of 9/11 were classified as having had the highest exposure, followed by those who arrived on the afternoon of 9/11, those who arrived any time on 12 September 2001, and, lastly, those with an arrival date of 13 September 2001 or later (lowest exposure level).[6] Smoking status (current, former or never smoker) was taken from their most recent self-administered health survey. Between 2019 and 2020, a similar survey was used to collect smoking status and other health and lifestyle information from a subset of the CFD, PFD and SFFD participants (N=2878, 32.7%), as detailed elsewhere.[32]

### Deaths

Vital status data, including death dates and underlying causes of death, were obtained via linkages to the Centers for Disease Control and Prevention's National Death Index (NDI). We provided the following data to NDI for linkage: social security numbers (SSNs), names, sex and dates of birth. Full SSNs were provided for 100% of FDNY and >99% of non-FDNY cohort members. The NDI has been shown to be highly sensitive, capturing between 87% and 98% of deaths.[33] At the time that Career Firefighter Health Study members' identifying information was provided to NDI for linkage, NDI had complete data through 31 December 2016.[32] All deaths that occurred between 12 September 2001 and 31 December 2016 were analysed. Participants whose information did not match the NDI records were considered alive at the end of 2016. NDI provided an underlying cause of death for each match in the form of International Classification of Diseases codes, 10th revision (ICD-10).[34] When assessing cause-specific mortality, we used NIOSH's major cause of death categorisation, which classifies the ICD codes for underlying cause of death into 28 major and 119 minor categories.[34 35] Demographic-specific US mortality rates for each of the 119 causes of death were obtained from NIOSH's Life Table Analysis System (LTAS) 1960–2019 rate file.[35]

### Statistical analyses

Participant follow-up began on 11 September 2001 and ended at the earliest of the following dates: death date or 31 December 2016. We estimated means (±SD) and proportions (%) to summarise demographic and other characteristics of the WTC-exposed FDNY and non-WTC-exposed firefighters. Fifteen non-WTC-exposed firefighters were excluded from the following analyses due to missing race/ethnicity information.

To examine how mortality rates in the firefighter populations compared with those of the US general population during the study period, we estimated standardised mortality ratios (SMRs) and 95% CIs. Stratum-specific all-cause and cause-specific US mortality rates, obtained from the LTAS 119 cause of death rate file for 1960–2019, were available for the following strata: sex, race (non-Hispanic white, non-white) and age group and calendar period in 5-year intervals (2000–2004, 2005–2009, 2010–2014 and 2015–2019). We calculated the expected number of deaths between 11 September 2001–31 December 2016 in each firefighter population by multiplying the stratum-specific US mortality rates by the number of person-years in the corresponding stratum in both the WTC-exposed and non-WTC-exposed groups and then summing across strata to get the totals. Dividing the observed number of deaths by the total number expected in each population yielded the SMRs. Ninety-five per

cent CIs for the SMRs were estimated using Poisson assumptions (Byar's approximation).[36]

Poisson regression analyses controlling for age on 9/11 and race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic and other) determined the association between firefighter group and mortality; first, the relative rate (RR) and 95% CIs were estimated for all-cause mortality in WTC-exposed versus non-WTC-exposed firefighters using deaths as the outcome and the log of person-years as an offset. We then repeated this analysis with selected cause-specific mortality outcomes, including cancer-specific mortality, heart disease-related and respiratory disease-related mortality, and suicide. These outcomes were selected because they were the most common causes of death in the study cohort and/or they were found to be elevated in previous studies of mortality in rescue/recovery workers.[11 29]

In secondary analyses, we used Poisson regression models to measure associations between WTC exposure level and all-cause mortality. We estimated RRs (95% CIs) comparing mortality in each of the four WTC exposure intensity groups with that of the non-WTC-exposed group, controlling for age on 9/11 and race/ethnicity. We then restricted the analyses to the WTC-exposed FDNY population only and compared participants in the three higher exposure groups versus those in the lowest exposure group, controlling for smoking status in addition to the above demographic variables. Sixty-three participants were excluded from the latter analysis due to missing smoking status (total N=10 723). Data analyses were conducted using SAS V.9.4 (SAS Institute, https://www.sas.com).

## RESULTS

### Study population characteristics

As shown in table 1, the male WTC-exposed FDNY population was slightly younger than the comparison firefighter population, with mean ages on 9/11 of 40.4±7.5 and 43.9±9.2, respectively. The WTC-exposed population also had a greater portion of participants who were non-Hispanic white compared with the non-WTC-exposed (93.8% vs 69.4%), and, among the participants who completed a health survey, a greater proportion of self-reported never-smokers (66.4% vs 56.4%). Among WTC-exposed FDNY firefighters, 99.8% (10764/10786) had at least one WTC Health Programme visit during the study period, and the median number of medical monitoring visits between 11 September 2001 and 31 December 2016 was 10 (IQR: 7–11).

Over the study period, there were 261 deaths among 10 786 WTC-exposed firefighters with a total of 163 583 person-years of follow-up, and 605 deaths among 8813 non-WTC-exposed firefighters with 130 971 person-years of follow-up. The most common cause of death in the firefighter populations was heart disease, followed by digestive cancers, respiratory cancers, violence and other injuries (table 2).

**Table 1** Population characteristics

| | Male WTC-exposed FDNY firefighters actively employed on 11 September 2001 | Male non-WTC-exposed, non-FDNY firefighters actively employed on 11 September 2001 |
|---|---|---|
| Total N | 10 786 | 8813 |
| Age on 11 September, mean±SD | 40.4±7.5 | 43.9±9.2 |
| Race/ethnicity, N (%)* | | |
| Non-Hispanic white | 10 121 (93.8) | 6117 (69.5) |
| Non-Hispanic black | 282 (2.6) | 1589 (18.1) |
| Hispanic | 353 (3.3) | 736 (8.4) |
| Other† | 30 (0.3) | 356 (4.0) |
| Smoking status, N (%) | | |
| Current | 373 (3.5)‡ | 192 (6.6)§ |
| Former | 3233 (30.2)‡ | 1062 (37.0)§ |
| Never | 7117 (66.4)‡ | 1624 (56.4)§ |
| WTC exposure/site arrival time, N (%) | | |
| Morning of 11 September | 1741 (16.1) | |
| Afternoon of 11 September | 5683 (52.7) | |
| 12 September 2001 | 1873 (17.4) | |
| 13 September 2001–24 July 2002 | 1489 (13.8) | |
| FDNY medical monitoring visits during study period, median (IQR) | 10 (7–11) | |
| Deceased by 31 December 2016, N (%) | 261 (2.4) | 605 (6.9) |
| Deceased among ever-smokers, N (%)¶ | 132 (3.6) | |
| Follow-up years, mean±SD | 15.2±1.1 | 14.9±2.0 |
| Total follow-up years | 163 583.4 | 130 971.0 |

*Excludes n=15 non-WTC-exposed firefighters missing race/ethnicity.
†Includes Asian and Native American race categories.
‡N=10 723 who self-reported smoking status on most recent FDNY health monitoring survey.
§N=2878 who completed Career Firefighter Health Study survey during 2019–2020.
¶N=3606 WTC-exposed FDNY firefighters who self-reported ever smoking. Smoking status was not available for deceased non-WTC-exposed firefighters as the Career Firefighter Health Study survey was only administered to firefighters alive in 2019–2020.
FDNY, Fire Department of the City of New York; WTC, World Trade Center.

### Mortality in the WTC-exposed and Non-WTC-exposed firefighter populations compared with the US general population

Both WTC-exposed and non-WTC-exposed male firefighters had significantly fewer deaths than expected based on US rates (SMR=0.30, 95% CI=0.26 to 0.33 and SMR=0.60, 95% CI=0.55 to 0.65, respectively; table 2). The firefighter populations had lower than expected mortality in most of the major cause of death categories assessed. The reduction in mortality was statistically significant for the following causes of death: all cancers combined, digestive cancers, respiratory cancers, heart disease, other circulatory diseases, respiratory diseases, digestive diseases, diabetes and mental disorders. However, only the WTC-exposed FDNY group had significantly reduced oral cancer-related, kidney/urinary organs cancer-related, other/unspecified cancer-related, nervous system disorder-related, transportation injury-related and suicide-related mortality compared with the US population.

### RRs of mortality in the WTC-exposed as compared with the non-WTC-exposed firefighter populations

Shown in table 3 are the RRs for mortality in WTC-exposed compared with non-WTC-exposed firefighters during follow-up, after controlling for age on 9/11 and race/ethnicity. Between 11 September 2001 and 31 December 2016, male WTC-exposed FDNY firefighters had a significantly lower rate of all-cause mortality (RR=0.54, 95% CI=0.49 to 0.59) than male non-WTC-exposed, non-FDNY firefighters. We observed that the WTC-exposed group also had significantly reduced rates of mortality from all cancers combined, respiratory cancers, male genital cancers, kidney/urinary organs cancers, heart disease, other circulatory diseases, digestive diseases, respiratory diseases and suicide. One exception was digestive cancer mortality, which was modestly elevated in the WTC-exposed versus

**Table 2** Standardised mortality ratios (SMRs) of all-cause and cause-specific mortality in male WTC-exposed FDNY and non-WTC-exposed non-FDNY firefighters versus US males*, 11 September 2001–31 December 2016

| | Male WTC-exposed FDNY firefighters | | | Male non-WTC-exposed non-FDNY firefighters | | |
|---|---|---|---|---|---|---|
| Cause of death (NIOSH major category)† | N | SMR | 95% CI | N | SMR | 95% CI |
| All | 261 | 0.30 | 0.26 to 0.34 | 603‡ | 0.60 | 0.55 to 0.65 |
| Tuberculosis and HIV-related disease (01) | ≤5§ | N/A | | ≤5 | N/A | |
| All cancers | 86 | 0.40 | 0.32 to 0.49 | 205 | 0.73 | 0.64 to 0.84 |
| MN buccal and pharynx (02) | ≤5 | 0.15 | 0.00 to 0.86 | ≤5 | 0.65 | 0.21 to 1.51 |
| MN digestive organs and peritoneum (03) | 37 | 0.54 | 0.38 to 0.74 | 56 | 0.65 | 0.49 to 0.85 |
| MN of pancreas¶ | 11 | 0.74 | 0.37 to 1.32 | 9 | 0.47 | 0.22 to 0.90 |
| MN respiratory system (04) | 12 | 0.19 | 0.10 to 0.34 | 55 | 0.63 | 0.48 to 0.83 |
| MN male genital organs (07) | ≤5 | 0.54 | 0.15 to 1.38 | 12 | 0.91 | 0.47 to 1.60 |
| MN urinary organs (08) | ≤5 | 0.25 | 0.05 to 0.74 | 15 | 1.01 | 0.56 to 1.66 |
| MN other/unspecified sites (09) | 15 | 0.40 | 0.22 to 0.66 | 37 | 0.87 | 0.61 to 1.20 |
| MN lymphatic and haematopoietic tissues (10) | 14 | 0.74 | 0.40 to 1.24 | 25 | 1.03 | 0.67 to 1.52 |
| Benign and unspecified neoplasms (11) | ≤5 | 0.72 | 0.08 to 2.58 | ≤5 | 0.31 | 0.00 to 1.72 |
| Diseases of blood and blood-forming organs (12) | ≤5 | N/A | | 8 | 1.94 | 0.83 to 3.82 |
| Diabetes mellitus (13) | ≤5 | 0.14 | 0.04 to 0.36 | 14 | 0.38 | 0.21 to 0.64 |
| Mental, psychoneurotic and personality disorders (14) | 7 | 0.39 | 0.16 to 0.80 | 6 | 0.33 | 0.12 to 0.72 |
| Nervous system disorders (15) | ≤5 | 0.15 | 0.03 to 0.44 | 15 | 0.63 | 0.35 to 1.03 |
| Multiple sclerosis** | ≤5 | N/A | | ≤5 | 0.55 | 0.01 to 3.06 |
| Other diseases of the nervous system†† | ≤5 | 0.17 | 0.03 to 0.49 | 14 | 0.63 | 0.35 to 1.06 |
| Heart diseases (16) | 52 | 0.27 | 0.20 to 0.35 | 120 | 0.51 | 0.42 to 0.60 |
| Other diseases of the circulatory system (17) | 8 | 0.18 | 0.08 to 0.35 | 23 | 0.38 | 0.24 to 0.56 |
| Diseases of the respiratory system (18) | 14 | 0.31 | 0.17 to 0.51 | 36 | 0.57 | 0.40 to 0.79 |
| Diseases of the digestive system (19) | 8 | 0.13 | 0.06 to 0.26 | 24 | 0.42 | 0.27 to 0.62 |
| Diseases of the skin and subcutaneous tissues (20) | ≤5 | N/A | | ≤5 | 1.4 | 0.16 to 5.05 |
| Diseases of the musculoskeletal and connective tissue systems (21) | ≤5 | N/A | | ≤5 | 0.29 | 0.00 to 1.61 |
| Diseases of the genitourinary system (22) | ≤5 | N/A | | ≤5 | 0.28 | 0.09 to 0.65 |
| Symptoms and ill-defined conditions (23) | 7 | 0.55 | 0.22 to 1.14 | 7 | 0.55 | 0.22 to 1.14 |
| Transportation injuries (24) | 9 | 0.24 | 0.11 to 0.46 | 22 | 0.77 | 0.48 to 1.16 |
| Falls (25) | ≤5 | 0.26 | 0.03 to 0.94 | 12 | 1.55 | 0.80 to 2.70 |
| Other injury (26) | 31 | 0.51 | 0.34 to 0.72 | 27 | 0.61 | 0.40 to 0.88 |
| Fire in building‡‡ | 9 | 5.79 | 2.64 to 10.99 | 7 | 4.56 | 1.83 to 9.39 |
| Violence (27) | 20 | 0.34 | 0.21 to 0.53 | 34 | 0.79 | 0.54 to 1.10 |
| Intentional self-harm (suicide)§§ | 17 | 0.36 | 0.21 to 0.58 | 31 | 1.01 | 0.68 to 1.43 |
| Other and unspecified causes (28) | 7 | 0.17 | 0.07 to 0.36 | 41 | 0.93 | 0.67 to 1.26 |

*US race, age group and calendar period-specific mortality rates used as reference.
†Categories based on International Classification of Diseases codes, 10th revision.[34]
‡Excludes n=2 missing race/ethnicity.
§Cells with 5 or fewer deaths are noted as ≤5.
¶NIOSH minor category 13

**NIOSH minor category 51
††NIOSH minor category 52
‡‡NIOSH minor category 109
§§NIOSH minor category 116
FDNY, Fire Department of the City of New York; MN, malignant neoplasm; NIOSH, National Institute for Occupational Safety and Health; WTC, World Trade Center.

non-WTC-exposed firefighters and was driven by increased pancreatic cancer mortality among the WTC-exposed. Rates of lymphatic/haematopoietic cancer-related mortality and other injury-related mortality were similar in the two groups.

Secondary analyses comparing mortality in the four different WTC exposure intensity groups versus in the non-WTC-exposed group yielded similar results. The overall rate of mortality was lower in each of the WTC exposure groups than in the non-WTC-exposed when controlling for demographic characteristics (online supplemental table S2). Finally, an internal analysis that compared FDNY firefighters in the three higher-level WTC exposure groups to those with the lowest exposure did not indicate a dose–response relationship between WTC exposure intensity and mortality (online supplemental table S3).

## DISCUSSION

Our study is the first to use an occupational cohort with similar work exposures as a comparison population when examining overall and cause-specific mortality in WTC-exposed workers. In the first 15 years post 9/11, we observed significantly lower rates of all-cause mortality in WTC-exposed firefighters

**Table 3** Adjusted relative rates (RR) of deaths in male WTC-exposed FDNY firefighters versus male non-WTC-exposed non-FDNY firefighters, 11 September 2001–31 December 2016

| Cause of death (NIOSH major category)* | Adj. RR (95% CI)†‡ |
|---|---|
| All | 0.54 (0.49 to 0.59) |
| All cancers | 0.72 (0.65 to 0.79) |
| MN digestive organs and peritoneum (03) | 1.13 (1.03 to 1.26) |
| MN of pancreas§ | 2.45 (2.19 to 2.75) |
| MN of the respiratory system (04) | 0.39 (0.35 to 0.44) |
| MN of male genital organs (07) | 0.84 (0.75 to 0.95) |
| MN of urinary organs (08) | 0.59 (0.52 to 0.66) |
| MN of lymphatic and haematopoietic tissue (10) | 0.93 (0.83 to 1.03) |
| Diseases of the heart (16) | 0.61 (0.55 to 0.67) |
| Other diseases of the circulatory system (17) | 0.74 (0.66 to 0.84) |
| Diseases of the respiratory system (18) | 0.69 (0.62 to 0.77) |
| Diseases of the digestive system (19) | 0.54 (0.48 to 0.60) |
| Other injury (26) | 0.90 (0.81 to 1.01) |
| Intentional self-harm (suicide)¶ | 0.44 (0.39 to 0.50) |

*Categories based on International Classification of Diseases codes, 10th revision.[34]
†Regression models adjusted for age on 11 September 2001 and race/ethnicity.
‡Excluding n=15 missing covariates.
§NIOSH minor category 13
¶NIOSH minor category 116
FDNY, Fire Department of the City of New York ; MN, Malignant neoplasm; NIOSH, National Institute for Occupational Safety and Health; WTC, World Trade Center.

compared with similar non-WTC-exposed non-FDNY firefighters in the Career Firefighter Health Study. This was in addition to observing lower all-cause mortality in male firefighters, both WTC-exposed and non-WTC-exposed, compared with the US male population. Our results showed 70% and 40% fewer deaths than expected in WTC-exposed and non-WTC-exposed male firefighters, respectively, based on US male mortality rates. These findings indicate strong healthy worker effects, and are consistent with many, though not all, previous studies of mortality in firefighters.[21 25–29] Since firefighters are subject to pre-hire screenings and strict health requirements,[30] those hired are healthier than the general population (ie, the healthy worker hire effect).[14 31] The healthy worker survivor effect[31] was less of a concern in this study because we required that both the WTC-exposed and non-WTC-exposed participants be actively employed as firefighters on 11 September 2001, and therefore, were similarly healthy at the start of follow-up. Both firefighter populations also had access to good healthcare, either via their respective fire departments/unions or via the WTC Health Programme.

We also observed lower overall cancer mortality in all male firefighters versus US males. Cancer-specific mortality was 60% reduced in the WTC-exposed cohort and 27% reduced in the non-WTC-exposed cohort. A recent study conducted in the full population of Chicago, Philadelphia and San Francisco firefighters that made up the source population for our firefighter comparison cohort showed modestly elevated levels of cancer-specific mortality during the years 1950–2016.[29] That study, however, included older firefighters who were further from their dates of employment than those in our study and may have had less effective personal protective equipment when actively employed.[3 26] In that study, the mean year of hire was 1968. When analyses were restricted to ages <65 years old, cancer-specific mortality was not significantly different from the US general population (SMR=0.96, 95% CI=0.90 to 1.01).[29] These results showing elevated mortality versus the US population in older but not younger firefighters highlight the attenuation of the healthy worker hire effect over time[37] and underscore the importance of finding an appropriate comparison population when assessing health outcomes in an occupational cohort.

While the recent IARC classification and our 2021 cancer incidence study found evidence of increased cancer risk,[3 19] we did not observe increased cancer mortality among firefighters in this study. Differences in endpoints used between studies may partly explain inconsistent findings. Also, given small numbers of site-specific cancer deaths, the current study did not estimate cancer-specific risks; therefore, results are not directly comparable to IARC findings. The lack of tumour-specific analyses and differences in endpoints may preclude comparisons with the IARC classification, which stemmed from 'sufficient' evidence in humans for excess mesothelioma and bladder cancer (a cancer site with relatively high survival) from firefighting exposure.

Findings from our present investigation are consistent with previous studies examining mortality in WTC-exposed rescue/recovery workers versus general populations. Previous analyses in the WTC-exposed FDNY cohort found significantly lower than expected all-cause and cause-specific mortality when compared with the US general population,[10] as did a study in a larger cohort of WTC-exposed general responders.[12] Another mortality study involving WTC rescue/recovery workers enrolled in the WTC Health Registry used the New York City population as a reference group and found similar results, with reduced all-cause, heart disease-specific and respiratory disease-specific mortality.[11] In that cohort the SMR for suicide was significantly elevated, however, while in our cohort of WTC-exposed firefighters suicide rates were lower than expected. These contrasting results might be explained by differences in access to care, and in the study populations; the WTC Health Registry rescue/recovery worker cohort included police officers, construction workers, EMS personnel and volunteers in addition to firefighters.[38] Our use of USA, rather than NYC, cause-specific mortality rates in SMR analyses may also have contributed to the observed differences in results.

Mortality rates in WTC-exposed FDNY firefighters were low even when compared with non-WTC-exposed non-FDNY firefighters. It is unlikely that healthy worker effects alone explain the lower rates in the WTC-exposed cohort. When directly comparing the two firefighter cohorts, we found that the rates of all-cause and cancer-specific mortality were 46% and 28% lower, respectively, in the WTC-exposed firefighters. The lower cancer-specific mortality rate was observed despite our 2021 cancer study showing a modestly higher incidence of all cancers combined in the WTC-exposed group versus the non-WTC-exposed/non-FDNY group.[3] One limitation of our current analyses was that we did not have individual-level information on routine firefighting exposures. We do not believe that the differences in mortality rates can be explained by differences in routine firefighting exposures, however, as all four fire departments are active in urban environments, use similar protective gear including a self-contained breathing apparatus and practice similar approaches to fires and other Hazmat responses.[39] Rather, the improved mortality outcomes might be attributed to the comprehensive health monitoring and treatment provided to WTC-exposed rescue/recovery workers. Major mortality outcomes unlikely to be affected by WTC health monitoring and treatment, such as 'other injury'-related mortality, were not significantly reduced in WTC-exposed versus non-WTC-exposed firefighters, while most of the mortality outcomes that could potentially be impacted by WTC Health Programme care had reduced rates. As part of the WTC Health Programme, the

WTC-exposed FDNY cohort receives routine medical monitoring exams, blood and urine tests, pulmonary function tests, and diagnostic procedures and treatment for WTC-related conditions, if needed. All of the above are provided at no cost to members, even after retirement.[15 16] Our data show that WTC-exposed firefighters had a high rate of healthcare utilisation, with >99% attending at least one medical exam at FDNY after 9/11, and attending near annual medical monitoring visits between 11 September 2001 and 31 December 2016. Non-WTC-exposed firefighters enrolled in standard healthcare plans do not receive the same level of proactive health monitoring, cancer screening and case management. The WTC Health Programme adheres, at a minimum, to cancer screening guidelines issued by the US Preventive Service Task Force.[40] These screening procedures, along with regular health monitoring exams, facilitate the early detection and treatment of certain types of cancer,[16] which may partly explain both the excess cancer cases and reduced cancer mortality in this population. For example, our 2021 cancer study showed elevated rates of prostate cancer in WTC-exposed firefighters compared with non-WTC-exposed/non-FDNY firefighters and US males,[3] but our current investigation in the same cohort found that male genital cancer mortality (which includes prostate cancer mortality) was lower compared with both reference populations. WTC-exposed FDNY firefighters were diagnosed with cancer at a younger age, on average, than those in the comparison population, and generally at an earlier, more localised stage of disease when treatment can be more effective.[3] A recent study of cancer survival in WTC-exposed responders, including but not limited to firefighters, found that responders enrolled in the WTC Health Programme who were diagnosed with cancer had lower all-cause and cancer-specific mortality between 2005 and 2016 compared with a reference population of non-responders without WTC exposure from New York State. WTC responders with cancer who were not enrolled in the WTC Health Programme, however, did not experience significantly lower mortality than the reference population.[41] Other non-occupational studies examining access to healthcare and cancer outcomes in the USA have shown that more comprehensive health insurance coverage is associated with reduced cancer mortality.[42 43]

We also cannot rule out the role that behavioural factors may have had on mortality outcomes. Cigarette smoking, diet, alcohol consumption and social support could contribute to differences in mortality rates. A main limitation of this study was our inability to control for these potential confounders in our analyses due to incomplete data. Ninety-nine per cent of the FDNY firefighter population and 33% of the non-FDNY firefighter population provided their smoking status via a self-administered health survey. The latter group were all alive at the end of this study's follow-up period, as they self-reported their smoking status during 2019–2020 on the Career Firefighter Health Study health survey.[32] The proportions of current smokers were 3.5% and 6.6% in these subsets of FDNY and non-FDNY firefighters, respectively. Therefore, current smoking differed between the two firefighter groups but remained lower than that in US males (16.7%).[44] Further, the FDNY group had a lower proportion of ever-smokers than the non-FDNY group (34% and 44%, respectively). These differences suggest a bias from smoking differences that may mask excess risk in FDNY firefighters; however, the crude mortality risk in FDNY ever-smokers (3.6% or 132/3606) was lower than that of the non-FDNY cohort overall (6.9% or 605/8813), therefore, it is unlikely that greater mortality in the non-FDNY cohort could be entirely explained by higher smoking rates. Our categorical smoking variable may be an imperfect measurement of smoking exposures, although recent internal analyses within a large combined cohort of WTC-exposed rescue/recovery workers that used a similar categorical measure found current and former smoking to be associated with increased all-cause and smoking-related mortality.[13] Future analyses in the subset of the current study population who were alive at the time of the Career Firefighter Health Study survey completion could examine associations between firefighter group and mortality outcomes over a later follow-up period, controlling for self-reported smoking status.

There were also differences in the demographics of the two firefighter groups, with the FDNY cohort being slightly younger and overwhelmingly non-Hispanic white, characteristics associated with lower mortality rates.[45] We controlled for racial/ethnic group and age when comparing the firefighter populations to reduce confounding. Another study limitation was our use of US mortality rates instead of regional rates when estimating SMRs for all-cause and cause-specific mortality. Since the Career Firefighter Health Study population consists of firefighters from four disparate states/regions, an area expanded further by post-retirement mobility, we felt that US population mortality rates were most appropriate. Lastly, the 15-year post 9/11 follow-up period may be relatively short for some cancer-specific mortality, especially for some solid tumours. In our previous studies examining cancer incidence, we found that similar follow-up periods were long enough to detect elevated rates of certain cancers in WTC-exposed cohorts.[3 46] For example, prostate cancer incidence was elevated in WTC-exposed workers versus the New York state population between 2007 and 2015.[46] These studies focused on incidence, however, and not mortality. We plan to continue monitoring both outcomes in these populations.

The main strength of our analyses was our use of a similar occupational cohort of males who were employed as career firefighters at urban fire departments as a reference population. By including a similar non-WTC-exposed firefighter referent group, we were able to reduce the potential for strong selection bias from the healthy worker hire effect, thereby uncovering a possible protective effect of WTC Health Programme membership on mortality. More favourable mortality outcomes in WTC-exposed firefighters are therefore likely to be due to a combination of the comprehensive healthcare they receive, healthy worker effects and possible differences in health behaviours. Future mortality analyses in the Career Firefighter Health Study population will involve additional years of follow-up, allowing us to obtain more complete information on health behaviours and to further explore the impact of ageing and the attenuation of healthy worker effects over time.

**Acknowledgements** The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

**Contributors** CBH and RZ-O designed the study, with significant input from PB and MPW. RZ-O, AS, MC and RDD acquired the data. RZ-O, AS and CBH analysed and interpreted the data. AS drafted the manuscript, with critical revisions from RZ-O, CBH, MPW, DJP, RDD and PB. DGG validated the analyses. All authors approved the final manuscript. As the guarantor, RZ-O, accepts full responsibility for the finished work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

**Funding** This research was supported through the National Institute for Occupational Safety and Health (NIOSH) cooperative agreement numbers U01 OH011480, U01 OH011309 and U01 OHO11934, and contracts 200-2017-93326 and 75D301-22-P-15204.

**Competing interests** None declared.

**Patient consent for publication** Not applicable.

**Ethics approval** This study was approved by the Albert Einstein College of Medicine/Montefiore Medical Center Institutional Review Board and a waiver of informed consent was obtained.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available on reasonable request. Data may be obtained from a third party and are not publicly available. Reasonable request for deidentified data will be considered by the investigators, the National Institute for Occupational Safety and Health, and the National Death Index.



**ORCID iDs**
Rachel Zeig-Owens http://orcid.org/0000-0002-8679-2306
David G Goldfarb http://orcid.org/0000-0003-2682-7543
Robert D Daniels http://orcid.org/0000-0002-3915-7991
Charles B Hall http://orcid.org/0000-0001-9982-8120

## REFERENCES

1 Landrigan PJ, Lioy PJ, Thurston G, *et al*. Health and environmental consequences of the world Trade center disaster. *Environ Health Perspect* 2004;112:731–9.
2 Lioy PJ, Weisel CP, Millette JR, *et al*. Characterization of the dust/smoke aerosol that settled East of the world Trade center (WTC) in lower Manhattan after the collapse of the WTC 11 September 2001. *Environ Health Perspect* 2002;110:703–14.
3 Webber MP, Singh A, Zeig-Owens R, *et al*. Cancer incidence in world trade center-exposed and non-exposed male firefighters, as compared with the US adult male population: 2001-2016. *Occup Environ Med* 2021;78:707–14.
4 Shapiro MZ, Wallenstein SR, Dasaro CR, *et al*. Cancer in general responders participating in world Trade center health programs, 2003-2013. *JNCI Cancer Spectr* 2020;4:pkz090.
5 Putman B, Zeig-Owens R, Singh A, *et al*. Risk factors for post-9/11 chronic rhinosinusitis in fire department of the city of New York workers. *Occup Environ Med* 2018;75:884–9.
6 Zeig-Owens R, Webber MP, Hall CB, *et al*. Early assessment of cancer outcomes in New York City firefighters after the 9/11 attacks: an observational cohort study. *Lancet* 2011;378:898–905.
7 Soo J, Webber MP, Gustave J, *et al*. Trends in probable PTSD in firefighters exposed to the world Trade center disaster, 2001-2010. *Disaster Med Public Health Prep* 2011;5 Suppl 2:S197–203.
8 Weakley J, Webber MP, Gustave J, *et al*. Trends in respiratory diagnoses and symptoms of firefighters exposed to the world Trade center disaster: 2005-2010. *Prev Med* 2011;53:364–9.
9 Wisnivesky JP, Teitelbaum SL, Todd AC, *et al*. Persistence of multiple illnesses in world Trade center rescue and recovery workers: a cohort study. *Lancet* 2011;378:888–97.
10 Colbeth HL, Zeig-Owens R, Hall CB, *et al*. Mortality among fire department of the city of New York rescue and recovery workers exposed to the world Trade center disaster, 2001-2017. *Int J Environ Res Public Health* 2020;17:6266.
11 Jordan HT, Stein CR, Li J, *et al*. Mortality among rescue and recovery workers and community members exposed to the september 11, 2001 world trade center terrorist attacks, 2003-2014. *Environ Res* 2018;163:270–9.
12 Stein CR, Wallenstein S, Shapiro M, *et al*. Mortality among world Trade center rescue and recovery workers, 2002-2011. *Am J Ind Med* 2016;59:87–95.
13 Li J, Hall CB, Yung J, *et al*. A 15-year follow-up study of mortality in a pooled cohort of world trade center rescue and recovery workers. *Environ Res* 2023;219:115116.
14 Li CY, Sung FC. A review of the healthy worker effect in occupational epidemiology. *Occup Med (Lond)* 1999;49:225–9.
15 Yip J, Webber MP, Zeig-Owens R, *et al*. FDNY and 9/11: clinical services and health outcomes in world trade center-exposed firefighters and EMS workers from 2001 to 2016. *Am J Ind Med* 2016;59:695–708.
16 Centers for Disease Control and Prevention. Covered conditions - World Trade center health program. 2022. Available: https://www.cdc.gov/wtc/conditions.html [Accessed 1 Aug 2022].
17 Campbell R, Evarts B. *United States firefighter injuries in 2019*. National Fire Protection Association, 2020.
18 International Agency for Research on Cancer. *IARC monographs on the evaluation of carcinogenic risks to humans: painting, firefighting, and shiftwork*. Lyon, France: IARC, 2010.
19 Demers PA, DeMarini DM, Fent KW, *et al*. Carcinogenicity of occupational exposure as a firefighter. *Lancet Oncol* 2022;23:985–6.
20 Daniels RD, Kubale TL, Yiin JH, *et al*. Mortality and cancer incidence in a pooled cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950-2009). *Occup Environ Med* 2014;71:388–97.
21 Glass DC, Pircher S, Del Monaco A, *et al*. Mortality and cancer incidence in a cohort of male paid Australian firefighters. *Occup Environ Med* 2016;73:761–71.
22 LeMasters GK, Genaidy AM, Succop P, *et al*. Cancer risk among firefighters: a review and meta-analysis of 32 studies. *J Occup Environ Med* 2006;48:1189–202.
23 Mathias KC, Graham E, Stewart D, *et al*. Decreased pulmonary function over 5 years in US firefighters. *J Occup Environ Med* 2020;62:816–9.
24 Pedersen JE, Ugelvig Petersen K, Ebbehøj NE, *et al*. Risk of asthma and chronic obstructive pulmonary disease in a large historical cohort of Danish firefighters. *Occup Environ Med* 2018;75:871–6.
25 Ahn YS, Jeong KS. Mortality due to malignant and non-malignant diseases in Korean professional emergency responders. *PLoS One* 2015;10:e0120305.
26 Casjens S, Brüning T, Taeger D. Cancer risks of firefighters: a systematic review and meta-analysis of secular trends and region-specific differences. *Int Arch Occup Environ Health* 2020;93:839–52.
27 Ma F, Fleming LE, Lee DJ, *et al*. Mortality in Florida professional firefighters, 1972 to 1999. *Am J Ind Med* 2005;47:509–17.
28 Petersen KU, Pedersen JE, Bonde JP, *et al*. Mortality in a cohort of Danish firefighters; 1970-2014. *Int Arch Occup Environ Health* 2018;91:759–66.
29 Pinkerton L, Bertke SJ, Yiin J, *et al*. Mortality in a cohort of US firefighters from San Francisco, Chicago and Philadelphia: an update. *Occup Environ Med* 2020;77:84–93.
30 National Fire Protection Association. *NFPA 1582, standard on comprehensive occupational medical program for fire departments*. National Fire Protection Association, 1992.
31 Arrighi HM, Hertz-Picciotto I. The evolving concept of the healthy worker survivor effect. *Epidemiology* 1994;5:189–96.
32 Zeig-Owens R, Singh A, Triplett S, *et al*. Assembling the career firefighter health study cohort: a methods overview. *Am J Ind Med* 2021;64:680–7.
33 Cowper DC, Kubal JD, Maynard C, *et al*. A primer and comparative review of major US mortality databases. *Ann Epidemiol* 2002;12:462–8.
34 Robinson CF, Schnorr TM, Cassinelli RT 2nd, *et al*. Tenth revision U.S. mortality rates for use with the NIOSH life table analysis system. *J Occup Environ Med* 2006;48:662–7.
35 National Institute for Occupational Safety and Health. Life table analysis system - rate file information. Available: https://www.cdc.gov/niosh/ltas/rates.html [Accessed 16 May 2022].
36 Breslow NE, Day NE. Statistical methods in cancer research. Volume II--the design and analysis of cohort studies. *IARC Sci Publ* 1987:1–406.
37 Pearce N, Checkoway H, Kriebel D. Bias in occupational epidemiology studies. *Occup Environ Med* 2007;64:562–8.
38 Perrin MA, DiGrande L, Wheeler K, *et al*. Differences in PTSD prevalence and associated risk factors among world Trade center disaster rescue and recovery workers. *Am J Psychiatry* 2007;164:1385–94.
39 National Fire Protection Association. *NFPA 1971, standard on protective ensembles for structural fire fighting and proximity fire fighting*. National Fire Protection Association, 2018.
40 U.S. Preventive Services Task force. Recommendations. Available: https://www.uspreventiveservicestaskforce.org/uspstf/topic_search_results?category%5B%5D=15&searchterm=Cancer [Accessed 13 Jul 2022].
41 Goldfarb DG, Zeig-Owens R, Kristjansson D, *et al*. Cancer survival among world Trade center rescue and recovery workers: a collaborative cohort study. *Am J Ind Med* 2021;64:815–26.
42 Ellis L, Canchola AJ, Spiegel D, *et al*. Trends in cancer survival by health insurance status in California from 1997 to 2014. *JAMA Oncol* 2018;4:317–23.
43 Myerson RM, Tucker-Seeley RD, Goldman DP, *et al*. Does Medicare coverage improve cancer detection and mortality outcomes? *J Policy Anal Manage* 2020;39:577–604.
44 Jamal A, King BA, Neff LJ, *et al*. Current cigarette smoking among adults-United States, 2005-2015. *MMWR Morb Mortal Wkly Rep* 2016;65:1205–11.
45 Kochanek KD, Xu J, Arias E. Mortality in the United States, 2019. *NCHS Data Brief* 2020:1–8.
46 Goldfarb DG, Zeig-Owens R, Kristjansson D, *et al*. Temporal association of prostate cancer incidence with world Trade center rescue/recovery work. *Occup Environ Med* 2021;78:699–706.

Supplementary Materials

**Table S1.** Characteristics of excluded WTC-exposed and non-WTC-exposed female firefighters actively employed on 9/11

| | **WTC-exposed** | **Non-WTC-exposed** |
|---|---|---|
| **Total N** | 28 | 585 |
| **Age on 9/11, mean ± SD** | 42.0±6.9 | 37.8±7.0 |
| **Race/ethnicity, N (%)** | | |
| White | 20 (71.4) | 362 (61.9) |
| Black | 6 (21.4) | 116 (19.8) |
| Hispanic | 2 (7.1) | 52 (8.9) |
| Other[a] | 0 | 55 (9.4) |
| **Smoking status, N (%)** | | |
| Current | 1 (3.6) | 14 (7.2)[b] |
| Former | 12 (42.9) | 56 (28.7)[b] |
| Never | 15 (53.6) | 125 (64.1)[b] |
| **Alive at end of study period (12/31/2016), N (%)** | 25 (89.3) | 572 (97.8) |

[a]Includes Asian and Native American race categories; [b]N=195 who completed CFHS survey

**Table S2.** Poisson regression model assessing associations between WTC exposure level and all-cause mortality rate in male WTC-exposed and non-WTC-exposed firefighters (N=19,584)

| **Variable** | **Rate Ratio[a,b]** | **95% Confidence Interval** |
|---|---|---|
| **WTC exposure/WTC site arrival time** | | |
| **Morning of 9/11** | 0.69 | 0.59-0.81 |
| **Afternoon of 9/11** | 0.45 | 0.40-0.51 |
| **9/12/2001** | 0.48 | 0.40-0.57 |
| **9/13/2001 and later** | 0.71 | 0.61-0.82 |
| **Not exposed** | ref | ref |

[a]Adjusted for age on 9/11 and race/ethnicity;
[b]Excluding N=15 due to missing covariates

**Table S3.** Poisson regression model assessing associations between WTC exposure level and all-cause mortality rate within male WTC-exposed firefighters (N=10,723)

| Variable | Rate Ratio[a] | 95% Confidence Interval |
|---|---|---|
| **WTC exposure/WTC site arrival time** | | |
| **Morning of 9/11** | 0.97 | 0.81-1.14 |
| **Afternoon of 9/11** | 0.70 | 0.61-0.82 |
| **9/12/2001** | 0.71 | 0.59-0.85 |
| **9/13/2001 and later** | ref | ref |

[a]Adjusted for age on 9/11, race/ethnicity, and smoking status