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Grenfell Tower Fire

Toxic Effluents and Assessment of Firefighters' Health Impacts

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Objective: This study assesses the health symptoms and longer-term health outcomes of firefighters who attended the Grenfell Tower fire. **Methods:** All available data sources were analyzed, including databases published by the Public Inquiry, the Firefighter Cancer and Disease Registry, incident logs, and sickness reports up to 3 years postfire. **Results:** More than three times as many firefighters who reported exposure to smoke during the fire also reported digestive and respiratory diseases following the fire, compared with those not reporting exposure to smoke. Other more complex relationships are reported among smoke exposure, immediate health symptoms, and longer-term health outcomes. **Conclusions:** The incident's urgency led professional firefighters to operate without respiratory protection equipment, resulting in debilitating health effects.

Keywords: cancer, disease, fire, firefighter, Grenfell Tower, health, respiratory protection equipment

LEARNING OUTCOMES

- Emergency services need better preparation for dealing with predictable and unforeseen incidents such as the Grenfell Tower fire.
- Detailed logging of activities and conditions endured during major incidents, together with immediate health symptoms and longer-term health outcomes, need to be routinely recorded.
- Detailed health monitoring of all exposed emergency service personnel should be undertaken over an extended post-exposure period (a minimum of 10 years).

Recently, the World Health Organization's International Agency for Research on Cancer classified the firefighting occupation as carcinogenic.[1,2] Studies show that the incidence and mortality of cancers and other diseases in firefighters are higher compared with the population they serve.[2] Recent data from the UK studies revealed that more than 4% of surveyed firefighters have received a cancer diagnosis.[3] Furthermore, the age-specific cancer rate was up to 323% higher for firefighters aged 35 to 39 years when compared with the general population.[3]

Firefighters' exposure to fire effluents occurs through different phases of fire intervention (eg, attack, knockdown) and in firefighters' work environments, such as fire stations, vehicles, and firefighters' turnout gear.[2,4] These residues may be inhaled or ingested via hand-to-mouth contact, depending on hygiene practices after firefighting.[3,5,6] Moreover, they have been detected on firefighters' skin due to gear penetration, contact with contaminated gear, or contact with exposed skin areas such as the face and neck.[2,3,5]

With the exception of the World Trade Center (WTC), there are no data on firefighters' health symptoms from major high-rise-building fires. In this investigation, relationships have been identified between various long-term exposures to toxicants from fire and different health disorders. For instance, exposure to fire effluents such as benzene, polycyclic aromatic hydrocarbons, 1,3-butadiene, ethylene oxide, and formaldehyde has been linked to myeloid leukemia.[7,8] Similarly, prostate cancer has been associated with exposure to benzene and styrene.[2]

Inhaling fire effluents such as carbon monoxide and hydrogen cyanide results in hypoxic stress, forcing the heart to exert extra effort during firefighters' physical stress. Also, the inhalation and absorption into the bloodstream of ultrafine soot particles enhance atherosclerosis and thrombosis. Both effects can lead to cardiovascular diseases.[9] Exposure to asbestos, silica, and inorganic dust through inhalation is also believed to contribute to firefighters' heightened risk of pulmonary diseases.

There is mounting evidence from both human and animal studies indicating that inhalation of air pollutants (carbon monoxide, particulate matter, nitrogen oxides, etc) can also increase the risk of neurological diseases including neurodegenerative health and cognitive impairment.[10,11] Furthermore, nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter have been linked to adverse respiratory outcomes.[12] The combined effects of frequent dehydration and chronic exposure to fire effluents may also synergistically damage the kidneys.[8] Furthermore, certain metals such as cadmium, chromium, copper, and lead can adversely affect multiple bodily systems, including the gastrointestinal tract; hematopoietic, cardiovascular, central and peripheral nervous systems; kidneys; and immune and reproductive systems, potentially leading to cancers.[2]

The Grenfell Tower Inquiry was instructed to examine evidence relating to the circumstances in which the 72 victims lost their lives. It was not instructed to consider any short- and long-term health effects of the emergency responders, evacuees, or residents who live within the vicinity of Grenfell Tower (GT).[13] The aim of this study was to collect and evaluate all available data from the GT fire, assessing firefighters' self-reported exposure to fire smoke and heat and physiological and toxicological health symptoms and outcomes related to their activities and the use of respiratory protective equipment (RPE) during the first 20 hours of the GT fire.

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METHODS

Data Sources

The project was reviewed and approved by the Science Ethics Review Panel at the University of Central Lancashire (SCIENCE 01043).

All data were collected for up to 3 years after the fire incident (July 2020). Firefighters' arrival, attendance, activities, fire smoke exposures and health symptoms/outcomes, and so on, during and after attending the GT fire, collated from nine different sources are summarized and reported in Table 1. An inclusion/exclusion decision tree was summarized and reported in our coupled study.[14]

Firefighters' Activities and Smoke Exposure Variables

Free-text data sources were manually and iteratively coded against all databases (eg, witness statements, UK Firefighters Cancer and Disease Registry, Grenfell Tower Inquiry, www.uclan.ac.uk/FCDR). Variables included self-reported firefighters' activities (reported in our coupled publication[14]), health symptoms, smoke exposures, and so on, which occurred during the incident. In addition, the subsequent long-term health outcomes self-reported by firefighters were also identified and collected up to over 3 years postevent. A list of all variables is provided in Table 3. Many firefighters were present in multiple locations/categories at different times during the incident.

Data Analysis

Where appropriate, the proportion of firefighters for whom health outcomes could be recorded were correlated to the coded groups (eg, exposure groups such as "inside the Tower," "outside the Tower"). Co-occurrence matrices for variables of interest counted the number of times variables co-occurred among firefighters. A z score test for difference in proportions was used to assess the significance of these differences. A P value of less than 0.05 was considered statistically significant.

RESULTS AND ANALYSIS

Fire Conditions and Fire Emissions

The GT was a 23-story residential block with six flats per floor, linked by a single central stairwell and two lifts in centrally located lobbies. The only means of entry/exit were the lifts and a narrow stairwell, both in the center of the Tower.[13] On June 14, 2017, at 12:54 AM, the London Fire Brigade received the first emergency call reporting a fire in a fourth-floor flat at GT. The fire rapidly engulfed the building, resulting in the deaths of 72 occupants. During the fire, the lifts stopped operating, and some fire doors between the stairwell and lobbies (linking the flats to the stairwell on each floor) were kept open by the firefighters' hoses and equipment. This, and smoke penetration into the stairwell from smoke-filled lobbies on most floors, resulted in the stairwell filling with smoke.

The rapid fire spread was attributed to the combustible cladding (polyethene-filled aluminum composite panels and polyisocyanurate foam insulation) on the outside of the Tower.[22–24] The burning cladding spread the fire from the exterior to most of the flats, igniting their contents over the following 6 hours. Both the burning cladding and contents produced large quantities of toxic smoke. The acute toxic products released from mixed burning fuels include asphyxiants (carbon monoxide and hydrogen cyanide) and irritants (hydrogen chloride, acrolein, formaldehyde, nitrogen oxides, sulfur dioxide, etc). The chronic toxicants include deep-lung irritants (organics, soot, and tar), respiratory sensitizers (isocyanates), and metals.[25–27] Short respirable lengths of synthetic vitreous fibers were released from insulation materials during the GT fire.[28,29]

Firefighter Activities and Their Exposure to Smoke and Heat

Of 628 operational firefighters who attended the first 20 hours of the fire, data on their firefighting activities, exposures, health symptoms, and health outcomes up to 3 years after the fire were available for 83%, totaling 524 individuals.

Summary tables for 524 firefighters, encompassing their health symptoms/outcomes, are consolidated in Table 3. Around 76% (n = 397) firefighters reported working at some point inside the tower. Fifty-three percent (n = 280) of all firefighters reported working at some point outside, within close vicinity of the tower (eg, firefighting, turning over fallen debris, hose management).

In our coupled study,[14] it was reported that around 89% (n = 466) of firefighters did not wear RPE at some time. Firefighters' activities and their exposure to smoke and heat were discussed in detail[14] and are summarized in Table 2.

Twenty-six percent (n = 136 of 524) of the firefighters who attended the GT fire in the first 20 hours reported overall 301 adverse health outcomes, which are summarized in Table 3. In many cases, firefighters suffered from more than one health disorder. The health

TABLE 1. Data Sources Used for This Study

Abbreviations	Database	Information Provided	No. of Identified Firefighters	Source	Ref
GTI-Chr	Chronology of events	Firefighter's activities and timings		GTI	15
GTI-R&R	Grenfell riders and roles	Firefighters' rank, description, mobilized, and attendance time	2,000	GTI	16
GTI-IMS	Incident management system and the staff attendance rota system	Firefighter's rank, watch/crew, and station	988	GTI	17
GTI-BA	Breathing apparatus telemetry data	Firefighter's arrival and attendance time; BA cylinder's initial and final pressure, tally's time in and off, air used, and duration of wear	186	GTI	18
GTI-WS	Witness statement reports	Firefighter's recounted activities, experiences, exposures, and health symptoms	350	GTI	19
GTI-FILR	Firefighter's incident log report	Firefighter's arrival time and duration on the scene	125	GTI	20
FCDR	UK Firefighter Cancer and Disease Registry	Firefighter's rank, recounted activities, exposures, health symptoms, and outcomes	558	FCDR	21
LFB-HSIL	Health and safety incident log report	Firefighter's hazard classification, injury type, and health symptoms	208	LFB	
FBU-FSR	Firefighter's sickness report	Firefighter's injuries and health outcomes	96	FBU	

GTI, Grenfell Tower Inquiry; LFB, London Fire Brigade; UCLan, University of Central Lancashire; FBU, Fire Brigades Union.

TABLE 2. Summary of Firefighters' Activities and Their Exposure to Smoke and Heat[29]

89% Firefighters Reported Not Wearing RPE	
Inside the Tower	
48%	Reported waiting in the lobby, on the ground floor, reporting at some point smoke presence
24%	Used RPE to assist casualties both inside and outside the tower
23%	Ascended to the highest reachable floor (near-zero visibility or the absence of irritating and choking smoke)
23%	Reported seeing and smelling smoke while working in the stairwell above the bridgehead
18%	Did not return their RPE tally and reported exposure to fire smoke
15%	Reported working at the bridgehead
14%	Ran out of air in their RPE
6%	Removed their RPE
Outside the Tower	
44%	• Firefighters, within 0–50 m from the base of the Tower, engaged in firefighting, providing riot shields, or both
32%	• Reported encountering a hazy and "foggy" atmosphere accompanied by a continuous fall of debris Firefighters, within 50–300 m from the base of the Tower, reported and smelled light smoke

RPE, respiratory protective equipment.

disorders included 66 cases of digestive diseases, 64 respiratory diseases, 22 neurological, 31 ocular, 12 infectious, 11 cancers, 8 cardiovascular, 6 genitourinary, 5 dermatological diseases, and 7 others. In addition, 48 firefighters reported upper and lower limb injuries and 21 others back and neck injuries.

Health Symptoms During Attendance at the Fire and Subsequent Long-term Health Outcomes Reported by Firefighters

Table 4 presents the immediate symptoms, and Table 5 presents the longer-term health outcomes, both reported as a function of reason for not wearing RPE, by location. The longer-term health outcomes were collected up to 3 years after the incident. Many firefighters were present in more than one location and undertook different activities at different times during the fire.

A statistically significantly higher proportion of firefighters working inside of the tower reported smoke inhalation, breathing difficulties, physical exhaustion, and cognitive impairment (reduced mental performance) compared with firefighters working outside the Tower ($P < 0.05$).

For those firefighters whose activities were inside the tower, smoke inhalation was the most commonly reported by 76% (n = 301 of 397) firefighters compared with only 32% (n = 38 of 117) of firefighters who worked outside the tower, as summarized in Table 4.

Smoke inhalation was frequently accompanied by breathing difficulties, headache, sore throat, vomiting (nausea), and fatigue. Approximately 13% (n = 68 of 524) of all firefighters reported breathing difficulties, lasting on average from a few hours to a few months. This included cough, gasping, choking, wheezing, and so on. Four firefighters continued to experience breathing difficulties up to 3 years after the fire. Overall, 35% (n = 186 of 524) of all firefighters observed the presence of soot in their nose and throat. Among them, 82% (n = 153) noted the persistence of soot for up to a day, whereas the remaining 18% (n = 33) reported its presence for an extended duration of up to 10 days. These health symptoms coincided with physical exhaustion for firefighters who removed their RPE while assisting casualties, worked in the stairwell, and waited in a smoky environment.

More than 6% (n = 33 of 524) of all firefighters reported hoarseness and sore throat, which lasted on average from a few hours to several weeks. More than 5% (n = 29) of firefighters described sensations of "burning" and tightness in the chest, which lasted on average from several weeks to a few months.

More than 15% (n = 80 of 524) of all firefighters reported cognitive impairment during the incident, with around 91% of them (n = 73) while being engaged in various tasks inside the tower. These symptoms consisted of blurred vision, confusion, disorientation, and a sense of daze, which were found to be strongly correlated to firefighters' physical exertion and heat and smoke exposures.

Of the 136 firefighters who reported health disorders, the majority said they had not worn any respiratory protection at some point during their activities. One hundred seven firefighters who reported health disorders were involved in tasks inside or both inside and outside the Tower, whereas 20 of them were exclusively working outside. The nine remaining firefighters did not specify their location.

A statistically significantly higher proportion of firefighters working inside of the Tower reported gastrointestinal, respiratory, ocular, neurological, and upper and lower limb injuries compared with firefighters working outside of the tower ($P < 0.05$). The largest proportion of back/neck/limb injuries were found to be linked to firefighters reporting feeling physically exhausted.

Table 6 shows the relationship between exposure-related health effects and long-term health outcomes reported by firefighters up to 3 years after their fire attendance. The results suggest that sore throat, vomiting, headaches, and chest pain were most associated with subsequent respiratory, neurological, and cardiovascular health effects probably because these were associated with more severe exposure. Cancer incidence was highest in those reporting soot in their nose or throat.

Moreover, more than 15% (n = 81) of all firefighters reported being struck by falling debris/objects, receiving burns from the parts of molten and burning cladding, or both. This included 50 firefighters entering and leaving the tower who reported being struck by falling debris/objects, 6 firefighters who received burns (on the back of the neck, face, and hands) from falling parts of molten or burning facade outside of the tower, and an additional 25 firefighters who were both struck by falling debris and received burns.

DISCUSSION

To facilitate interpretation of the longer-term health outcomes based on the locations, types of exposure, and immediate health symptoms, the data from Table 6 have been expressed in terms of proportions of firefighters and are presented in Table 7. All data are expressed as percentages to the nearest whole number.

The strongest correlation was observed between immediate vomiting and nausea, headaches, and chest pain with longer-term respiratory diseases (>40%). Among the group exposed to smoke, there seems to be a high proportion of digestive diseases among all those reporting any immediate health symptoms. In contrast among those not reporting exposure to smoke, the incidence of the most common longer-term health outcomes is significantly lower, typically a third of the incidence of those exposed to smoke.

TABLE 3. Health Symptoms and Health Outcomes Reported by Firefighters by Locations at the Fire

No. of Firefighters	Total No. (n = 524)	Inside the Tower (Only) (n = 234)	Outside of the Tower (Only) (n = 117)	Both Inside and Outside (n = 163)	Unknown Location (n = 10)
Immediate symptoms: What symptoms did firefighters report during their attendance at the incident?					
Smoke inhalation	340	172	38	129	1
Soot in nose/throat	186	81	31	74	
Physical exhaustion	124	68	4	51	
Breathing difficulties (heavy breathing, cough, choking, etc)	68	27	4	36	
Cognitive impairment (blurred vision, confusion, disorientation, etc)	80	37	6	36	
Trip/fall/slip	51	21	5	24	
Headache	36	12	4	20	
Chest pain	29	3	14	12	
Sore throat	33	12	5	16	
Nausea/vomiting	24	9	2	11	
Burns	31	10	5	16	
Subsequent health outcome: What potentially longer-term health outcomes did firefighters report as persisting after the fire?					
Digestive diseases	66	28	6	25	7
Respiratory diseases	64	29	4	23	8
Upper and lower limb injuries	48	22	5	18	3
Neurological diseases	22	10	1	6	5
Back and neck injuries	21	8	2	9	2
Ocular diseases	31	17	1	13	
Infectious diseases	12	6	2	1	3
Cancer	11	5	5	1	
Genitourinary diseases	6	4		2	
Cardiovascular diseases	8	3	3	2	
Dermatological	5	2		2	1
Other	7	1	4	1	1

Data are collected from all data sources for 524 firefighters. Data came from data sources (GTI-WS, FCDR, LFB-HSIL, FBU-FSR) summarized in Table 1. A firefighter may appear in multiple locations/categories at different points during the incident. In each case, "n" represents the total number of firefighters in that category.

Firefighter Health Effects From GT and Other High-Rise Building Fire Incidents

Comparing data on firefighters' smoke and heat exposures, their activities, and health outcomes from major high-rise building fires presents significant challenges due to the scarcity and disparity of available information. Most of the existing data are derived from training fire scenarios (prescribed wildland fires, containers, etc) or controlled physical exertion activities (such as body temperature and breathing rates). This greatly impacts any possible comparisons and ability to draw meaningful conclusions about the health and safety of firefighters in such environments.

The most notable literature data from such fires come from the WTC disaster, which provided insights into the acute and long-term health effects on firefighters. It is essential that any apparent correlation must be examined with caution. One notable difference is that this article contains firefighters' self-reported health symptoms and outcomes, whereas WTC data and reports are based on confirmed medical diagnoses or clinically based studies.

It is also important to recognize that WTC and GT disasters involved emissions of very different composition and concentrations. When comparing firefighter health from WTC and GT, crucial considerations are the difference in releases from construction products used in each building. At GT, the construction products were combustible, and the main releases were fire effluents. At the WTC, the main releases (and exposure) were to mineral particulates resulting from the WTC towers' collapse. Although the underlying structures of both towers were noncombustible, the exterior fabric of the WTC was primarily noncombustible, whereas the GT had a combustible external facade that supported the fire spread around the building. The WTC fire started with a large volume of aviation fuel, whereas both fires subsequently involved considerable combustion of contents.[30] These differences are likely to result in different firefighters' exposures and likely health effects.

In both instances (WTC and GT), firefighters reported similar health symptoms. Within the initial 48 hours following WTC collapse, the majority of firefighters (about 90%) reported coughing and upper-airway problems such as nasal congestion and sore throat as well as chest "burning" and tightness.[31,32] Some continued to experience declines in lung function and other respiratory disorders nearly two decades after their exposure.[32–35]

Firefighters experienced various types of health disorders, such as respiratory, digestive, and musculoskeletal, as summarized in Table 8.[36,37] Studies from the WTC have also identified the latency period for some cancers commonly identified among firefighters. The latency period between WTC exposure and the incidence of prostate cancer (the most frequent cancer among WTC firefighters) was found to be around 5.25 years, significantly shorter than in non-9/11 occupational exposure studies.[39] Elevated risks were also observed for other cancer types, including thyroid (with a latency time of 2.5 years) and lymphoproliferative and hematopoietic cancers (including all types of leukemia and lymphoma, with a latency time of 0.4 years) (Table 8).[38,40] A significant number of WTC firefighters have already been diagnosed with asbestosis and pulmonary fibrosis, a condition known to manifest typically over a prolonged period, spanning anywhere from 11 years after asbestos exposure (Table 8).[38,41]

Health Services and Surveillance

The data presented raise the question of whether firefighters from the GT fire incident should receive regular health surveillance. Following the WTC disaster, a health program was set up for a lifetime for those who lived, worked or went to school in the disaster area, or participated for at least 1 day in the rescue and recovery efforts. It

TABLE 4. Immediate Symptoms as a Function of Reason for Not Wearing RPE, by Location

	No. of Firefighters (Without Wearing RPE)									
	Smoke Inhalation*	Breathing Difficulties*	Soot in Nose/Throat	Sore Throat	Headache	Chest Pain	Nausea/ Vomiting	Cognitive Impairment*	Physical Exhaustion*	Trip/Fall/Slip
Working outside of the tower only (n = 117)	37	4	30	5	4	3	2	6	4	5
Working inside the tower:	301	64	156	28	32	26	22	74	120	46
Run out of air (n = 54)	50	9	21	2	3	3	2	13	25	7
Removed RPE (n = 25)	24	9	14	5	5	6	5	10	13	6
RPE tally not returned (exposure to smoke reported) (n = 70)	70	11	27	7	8	5	4	19	34	9
Casualty management (inside the tower only) (n = 22)	21	11	13	7	6	6	2	11	14	11
Casualty management (inside/outside the tower) (n = 72)	61	24	37	11	14	9	6	19	31	12
Ascending higher floors (n = 92)	79	20	41	9	11	7	5	18	34	15
Working at the bridgehead (n = 58)	42	12	20	6	5	3	3	9	12	8
Working in the stairwell (n = 93)	75	27	48	19	21	11	7	23	29	13
Waiting in smoky environment (n = 189)	168	40	85	15	18	16	13	44	78	28

Data came from data sources (GTI-BA, GTI-WS, FCDR, LFB-HSIL) summarized in Table 1. A firefighter may appear in multiple locations/categories at different times during the incident. In each case, "n" represents the total number of firefighters in that category.

RPE, respiratory protective equipment.

*A statistically significantly higher proportion of firefighters working inside of the tower reported smoke inhalation, breathing difficulties, physical exhaustion, and cognitive impairment (reduced mental performance) compared with firefighters working outside the tower ($P < 0.05$).

included health surveillance for a number of mental health conditions (anxiety, posttraumatic stress disorder, etc), cancers, and musculoskeletal disorders, detailed in Table 8.[36] Data show that the care provided for those affected can reduce disease burden over time. For example, any prevalence for lower respiratory tract symptoms among emergency responders (firefighters and emergency medical services providers) declined by about 45% over the past two decades; while cancers continue to take a toll on WTC firefighters, the majority (83%) of those diagnosed 5 to 10 years ago are still alive, which highlights the effectiveness of early detection and prompt treatment.[10,36]

To date, no established regular health monitoring program has been implemented for cancers and other diseases among the emergency responders and residents affected by the GT fire. This absence is primarily due to the lack of scientific evidence supporting the necessity for such screening.[42] Yet, following the GT fire, Her Majesty's Senior Coroner released a warning under Regulation 28 on "Action to Prevent Future Death," raising concerns that those who were exposed to risks of smoke and dust inhalation during the fire are at risk of developing health conditions, in particular respiratory illness.[43] Furthermore, her report states "That without an appropriate system of health screening, there is a risk that illness may arise unnoticed or present later in survivors, first responders and site workers, and thus reduce their life expectancy."[43]

Considering that certain cancers have a long latency period, it is anticipated that the number of health disorders in GT firefighters may increase over the next decade. Recently identified additional contributing factors may potentially even further exacerbate the occurrence of firefighters' diseases.[43]

Strengths and Limitations

This study provides greater insight into the extent of firefighters' exposure to smoke and heat, their health symptoms and outcomes in relation to their activities, and the utilization of RPE during a major high-rise-building fire incident for the first time. Specifically, firefighters' self-reported health symptoms such as smoke inhalation, breathing difficulties, physical exhaustion, and cognitive impairment, along with outcomes related to digestive health disorders, demonstrate the importance of enhancing firefighter health and safety protocols when tackling high-rise-building fires.

This is the first classified assessment of health symptoms/outcomes of Grenfell firefighters. As the analysis relies heavily on self-reported statements from firefighters (witness statements, FCDR, etc), their perception of their activities, fire smoke exposures, and health symptoms (duration, type, etc.), it needs to be treated with caution as judgments are subjective and may not be consistent from one firefighter to another. Moreover, for reported cancer cases, the authors were unable to validate self-reported data to firefighters' medical records.

Data collection from all sources was completed up to 3 years after the fire. The range and mean/median of this timeframe will vary, compared with firefighters who reported their health symptoms or outcomes immediately, versus those who reported them at a later time. It is also possible that firefighters who reported their health effects soon after the fire may have reported more symptoms or differed in their likelihood of reporting health effects compared with those who provided reports later.

To date, demographic details such as age, sex, years of service, preexisting health conditions, lifestyle factors, and career exposures of the firefighters are unavailable. Therefore, data modeling and analysis with these potential confounders were not possible. In addition, no comparable group of firefighters who did not attend the GT fire has been studied, making it challenging to assess the extent to which identified health outcomes are solely attributable to Grenfell fire exposures.

Furthermore, the data used in this study for GT firefighters cover only the first 3 years after the fire, which is significantly less than the latency period for most cancers. Therefore, adverse health

TABLE 5. Longer-term Health Outcomes as a Function of Reason for Not Wearing RPE, by Location

	No. of Firefighters (Without Wearing RPE)											
	Digestive Diseases*	**Respiratory Diseases***	**Upper and Lower Limb**	**Back and Neck Injuries**	**Ocular Diseases***	**Neurological Diseases***	**Cardiovascular Diseases**	**Infectious Diseases**	**Genitourinary Diseases**	**Dermatological Diseases**	**Digestive Diseases***	**Respiratory Diseases***
Working outside of the tower only (n = 117)	6	3	4	2	1		3	1			5	4
Working inside the tower:	53	53	41	17	30	17	5	8	6	4	6	2
Run out of air (n = 54)	9	6	11	6	4	2		1	1		1	
Removed RPE (n = 25)	6	7	4	2	4	1	1		1			1
RPE tally not returned (exposure to smoke reported) (n = 70)	12	13	13	6	8	5		3			2	1
Run out of air (n = 54)	9	6	11	6	4	2		1	1		1	
Casualty management (inside the tower only) (n = 22)	5	6	4	1	4	2	1	1		1		
Casualty management (inside/outside the tower) (n = 72)	12	12	7	6	10	3	1		2		1	
Ascending higher floors (n = 92)	12	12	10	4	13	1	4	1	2			
Working at the bridgehead (n = 58)	7	6	5	1	8	1	1	2		1		
Working in the stairwell (n = 93)	11	18	11	4	9	5	3	3	1	1	2	1
Waiting in a smoky environment (n = 189)	26	30	23	11	18	8	1	3	1	3	2	2

Data came from data sources (GTI-BA, GTI-WS, FCDR, LFB-HSIL, FBU-FSR) summarized in Table 1. A firefighter may appear in multiple locations/categories at different times during the incident. In each case, "n" represents the total number of firefighters in that category.

RPE, respiratory protective equipment.

*A statistically significantly higher proportion of firefighters working inside of the tower reported gastrointestinal, respiratory, ocular, neurological, and upper and lower limb injuries compared with firefighters working outside of the tower ($P < 0.05$).

TABLE 6. The Number of Firefighters Without Wearing Breathing Apparatus Self-Reporting Health Symptoms During Fire Attendance and Long-term Health Outcomes (Collected up to 3 Years Postevent)

	No. of Firefighters											
	Digestive Diseases (n = 66)	**Respiratory Diseases (n = 64)**	**Upper and Lower Limb (n = 48)**	**Back and Neck Injuries (n = 21)**	**Ocular Diseases (n = 31)**				**Neurological Diseases (n = 22)**	**Infectious Diseases (n = 12)**	**Cancer (n = 11)**	
Genitourinary Diseases (n = 6)										**Cardiovascular Diseases (n = 8)**	**Dermatological Diseases (n = 5)**	**Other (n = 7)**
Exposure												
No smoke exposure (n = 58)	3	3	1	2		1	2		2			
Smoke exposure only (n = 344)	40	40	31	12	17	16	7	8	3	4	10	6
Exposure to both smoke and heat (n = 122)	22	20	16	7	14	4	1	2	1	1	1	1
Health symptoms												
Smoke inhalation (n = 340)	47	48	41	16	31	15	8	6	3	7	3	3
Breathing difficulties (n = 68)	13	22	14	3	17	6				4	3	1
Soot in nose/throat (n = 186)	33	35	28	12	16	8	3	6	3	7	2	2
Sore throat (n = 33)	8	13	9	3	8	4				3	2	1
Vomiting/nausea (n = 24)	7	10	6	3	2	3			1	3	1	
Headache (n = 36)	10	16	12	3	9	4	1			3	1	1
Chest pain (n = 29)	10	13	10	2	8	5	1			4	2	2
Cognitive impairment (n = 80)	23	26	21	6	16	9	2	1	1	3	2	1
Physical exhaustion (n = 124)	25	24	22	11	16	7	3	2	1	2	1	1
Slip/trip/fall (n = 51)	10	8	11	4	11	2		1		2		
Burns/burning debris (n = 31)	7	8	5	2	6	2	1				1	
Struck by burning/moving object (n = 75)	12	12	12	5	5	4	3	2		1		

Data came from data sources (GTI-WS, FCDR, LFB-HSIL, FBU-FSR) summarized in Table 1. Note a firefighter may appear in multiple locations/categories at different points during the incident. In each case, "n" represents the total number of firefighters in that category. The number shown as "no smoke exposure" comprised respondents indicating "no" and those who did not provide answer to the "exposure to smoke" question.

TABLE 7. Proportion of Firefighters' Longer-term Health Outcomes Based on their Exposure and Immediate Health Symptoms (Expressed as Percentages)

	Proportion of Firefighters (%)											
	Digestive Diseases (n = 66)	**Respiratory Diseases (n = 64)**	**Upper and Lower Limb (n = 48)**	**Back and Neck Injuries (n = 21)**	**Ocular Diseases (n = 31)**	**Neurological Diseases (n = 22)**	**Infectious Diseases (n = 12)**	**Cancer (n = 11)**	**Genitourinary Diseases (n = 6)**	**Cardiovascular Diseases (n = 8)**	**Dermatological Diseases (n = 5)**	**Other (n = 7)**
Exposure												
No smoke exposure reported (n = 58)	5	5	2	3		2	3		3			
Smoke exposure only (n = 344)	12	12	9	3	5	5	2	2	1	1	3	2
Exposure to both smoke and heat (n = 122)	18	16	13	6	11	3	1	2	1	1	1	1
Health symptoms												
Smoke inhalation (n = 340)	14	14	12	5	9	4	2	2	1	2	1	1
Breathing difficulties (n = 68)	19	32	21	4	25	9				6	4	1
Soot in nose/throat (n = 186)	18	19	15	6	9	4	2	3	2	4	1	1
Sore throat (n = 33)	24	39	27	9	24	12				9	6	3
Vomiting/nausea (n = 24)	29	42	25	13	8	13			4	13	4	
Headache (n = 36)	28	44	33	8	25	11	3			8	3	3
Chest pain (n = 29)	34	45	34	7	28	17	3			14	7	7
Cognitive impairment (n = 80)	29	33	26	8	20	11	3	1	1	4	3	1
Physical exhaustion (n = 124)	20	19	18	9	13	6	2	2	1	2	1	1
Slip/trip/fall (n = 51)	20	16	22	8	22	4		2		4		
Burns/burning debris (n = 31)	23	26	16	6	19	6	3				3	
Struck by burning/moving object (n = 75)	16	16	16	7	7	5	4	3		1		

Data came from data sources (GTI-WS, FCDR, LFB-HSIL, FBU-FSR) summarized in Table 1. In each case, "n" represents the total number of firefighters in that category. Note that a firefighter may appear in multiple locations/categories at different points during the incident. The number shown as "no smoke exposure" comprised respondents indicating "no" and those who did not provide an answer to the "exposure to smoke" question. Correlations are enhanced by field coloring every 10%.

TABLE 8. Prevalent and Overlapping Medical Conditions Among World Trade Center Responders and Grenfell Tower Firefighters

	World Trade Center (Responders = 85,954)	World Trade Center Minimum Latency for the Cancers	Grenfell Tower Fire (Firefighters = 524)
Acute traumatic injuries	Burn		Reported
	Complex sprain		Reported (sprain)
	Fracture		Reported
	Tendon tear		Reported
Airway and digestive diseases	Asthma		Reported
	Chronic cough syndrome		Reported
	Chronic laryngitis and nasopharyngitis		
	Chronic respiratory disorder—fumes and vapors		
	Chronic rhinosinusitis		Reported
	Gastroesophageal reflux disorder		Reported
	Interstitial lung disease		
	Exacerbated chronic obstructive pulmonary disease		Reported (chronic obstructive pulmonary disease)
	Reactive airway dysfunction syndrome		
Cancer	Blood and lymphoid tissue (including lymphoma, myeloma, and leukemia)	0.4 y	Reported
	Breast (female)	4.0 y	
	Digestive system (including colon and rectum)	4.0 y	Reported
	Head and neck (oropharynx and tonsil)	4.0 y	
	Prostate	4.0 y	
	Respiratory system (including lung and bronchus)	4.0 y	
	Skin (melanoma, nonmelanoma and carcinoma in situ)	4.0 y	Reported
	Thyroid	2.5 y	
	Urinary system (including kidney and bladder)	4.0 years	Reported
	Other rare cancers	4.0 y	Reported (colon and kidney)
Other	Mesothelioma	11.0 y	Few cases of pulmonary fibrosis reported
Musculoskeletal disorders	Carpal tunnel syndrome		
	Low back pain		Reported
	Other musculoskeletal disorders		Lower and/or upper limb disorders

World Trade Center program and minimum latencies for different cancers eligible for coverage in the WTC Health program.[38]

effects not diagnosed within this timeframe are not included in this analysis. It is likely that more Grenfell firefighters will suffer adverse health conditions than presented here, and further trends are yet to be uncovered.

CONCLUSIONS

Given reported findings, it is important to conduct further studies to gain a more comprehensive understanding of the potential health risks experienced by firefighters and particularly those who were involved in the GT fire.

A multitude of physical and mental health effects have been reported by firefighters since the GT fire, but the full health impact of this incident is unknown. Concern about potential long-term effects on people remains.

The monitoring programs may not adequately capture all information about new conditions, chronic conditions, and diseases whose onset may occur decades after exposure to a harmful agent (cancers). Nevertheless, these programs may provide a more complete picture of the health impact of such events to allow the development of prevention and mitigation strategies, specifically tailored to reduce adverse health effects in populations affected by any fire disasters. A program of rapid and comprehensive health screening, followed by prioritized treatment, similar to that used for the WTC firefighters would be very likely to reduce the incidence of premature deaths among these firefighters.

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