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"The Need to Reauthorize the September 11th Victim Compensation Fund"

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Good morning Chairman Cohen, Ranking Member Johnson, Members of the Committee.

I am honored to be here this morning. My name is Dr. Jacqueline Moline. I am a board certified physician, specializing in Occupational and Environmental Medicine. I am currently the Chairperson of the Department of Occupational Medicine, Epidemiology and Prevention at the Zucker School of Medicine at Hofstra University/Northwell Health. I am the Director of the Northwell Health Queens World Trade Center Health Program. My specialty, occupational and environmental medicine, deals with the impact of exposures on the health of individuals. It is part of Preventive Medicine, since we know that individuals without these exposures would likely not be afflicted with the conditions they later develop.

Prior to my current position, I worked at the Mount Sinai School of Medicine, where I collaborated with amazing physicians who had dedicated their careers to the treating patients experiencing the health effects of asbestos exposure. I evaluated hundreds of workers who had been exposed to asbestos decades earlier; we know that the health effects from asbestos exposure take years to develop. On September 11th, I, like every person in New York City, watched in shock and horror as our nation was attacked. Shortly after the towers collapsed, I, along with all physicians in New York City, was called to the hospital as part of the all-hands-on deck coverage. Tragically, there was little we could do that day. However, based on our knowledge of the potential for health effects related to asbestos and the other 150 toxicants individuals were exposed on 9/11, we knew that there was potential for disease – in the short term, and the long term. We knew the air wasn't safe to breathe, but our immediate concern was for those with acute health effects, since we knew that other diseases would take years to develop.

At Mount Sinai, we began treating patients with World Trade Center related health conditions in September 2001. Through the tremendous efforts of the New York Congressional Delegation and organized labor, in April 2002 we were given one year of funding to begin the medical surveillance programs for rescue and recovery workers, construction workers and volunteers who were exposed at "the pile," and surrounding areas after 9/11. These surveillance programs later evolved into the WTC Health Program, authorized by the James Zadroga Act of 2010, which monitors and treats World Trade Center related health problems. Initially in 2002, we were only able to evaluate patients and tell them what their health conditions were – we were not given funding for and not allowed to provide treatment. This initial program was extended one year, and we continued our partnership with SUNY Stony Brook, Queens College, New York University, and Rutgers University to see patients in locations convenient for them. In 2004, we were awarded a five year contract to continue the medical screening program, and to have patients come back for repeat, or monitoring examinations. Similar contracts were awarded to the other four institutions. We were still not able to treat the patients we saw, even if they had World Trade Center related conditions; we had to refer them to other clinicians, or to a WTC treatment program we had started through philanthropic donations, not through government funding. As part of our contract, we were prohibited from collecting data using federal dollars. We could evaluate the patients, but we needed separate grants to be able to describe what we were finding in these patients. In 2006, on the fifth anniversary of the WTC disaster, the federal government allowed our programs to treat patients with World Trade Center conditions. This was a great day for

our patients, and allowed us to provide the high quality care these men and women deserved, from clinicians who were experts in identifying World Trade Center related health diseases. The grant ended in 2009; then there were yearly scrambles, and many trips to Capitol Hill, that allowed continued appropriations for the WTC health programs to continue until 2011, when funding through the Zadroga Act became available. Seventy five years of funding for medical care for disorders related to the World Trade Center, as well as dedicated research into these diseases was provided. The Victim's Compensation Fund was re-established, but only for five years.

As of March 31, 2019, 95,320 first responders – including those first responders who came from every state in our nation, and survivors - those residents, school children and individuals who worked in lower Manhattan and returned to their offices and businesses - have been evaluated. There was a tremendous response throughout our country after we were attacked. Yes, it was an attack in New York City, but it was an attack on our nation, and individuals from every state participated in the rescue and recovery efforts. Over time, some individuals who initially lived in the metropolitan New York area have moved or retired to different parts of the country. As a result, as part of the WTC Health Program, there is a national program dedicated to monitoring the health of, and providing care for WTC responders and survivors who live outside of the New York metropolitan area. As of May 2019, 6,732 individuals have enrolled in the national program. Not only first responders were affected after the Towers fell. Downtown Manhattan, home to thousands of residents, was blanketed in thick dust. Individuals who worked in lower Manhattan, including the financial district, returned to work within a week of the disaster when the stock markets re-opened and businesses set about cleaning up and getting back to work. Residents returned to their homes, often inadequately cleaned, and began to rebuild their lives in an area devastated by the collapse of around 270 floors of buildings. School children, who had been evacuated from the places of learning on September 11th, returned to their schools, like Lila sitting here with me, despite fires that continued to rage at Ground Zero, and dust that was elaborated from the extensive recovery efforts that continued through May 30, 2002. Thankfully, these survivors, the neighborhood residents, school children and building re-occupants are also covered by the Zadroga Act, and the number of survivors entering the program has increased dramatically in the past several years. There has been extraordinary growth in the survivor program over the past eight years: an astonishing increase of 327%.

Exposures to the toxicants at the World Trade Center caused immediate health effects – we have all seen the pictures of dust laden first responders and building occupants – these conditions occurred whether you were a first responder, building re-occupant, school child, or construction worker. Many people developed immediate respiratory symptoms. This was the first wave of disease. As was outlined in the Environmental Health Perspectives by Dr. Mayris Webber and colleagues in 2009, 53% of firefighters developed a cough, and 41% developed gastroesophageal reflux disease within the first year after 9/11[1]. In 2006, Dr. Robin Herbert and I, along with many of our colleagues, described the health effects for police officers, construction workers and other responders who had health problems 1-3 years after 9/11[2]. Dr. Shao Lin, Dr. Joan Reibman and their colleagues described similar health findings among community residents who were exposed to the same toxicants, simply by living or working in the area for months after 9/11[3]. These conditions persist, and constitute the second wave

[1] Webber, M. P., J. Gustave, R. Lee, J. K. Niles, K. Kelly, H. W. Cohen and D. J. Prezant (2009). "Trends in respiratory symptoms of firefighters exposed to the World Trade Center disaster: 2001-2005." Environmental Health Perspectives **117**(6): 975-980.

[2] Herbert, R., J. Moline, G. S. Skloot, K. Metzger, S. Baron, B. Luft, S. Markowitz, I. Udasin, D. Harrison, D. Stein, A. C. Todd, P. Enright, J. Mager Stellman, P. J. Landrigan and S. Levin (2006). "The World Trade Center disaster and the health of workers: Five-year assessment of a unique medical screening program." Environmental Health Perspectives **114**(12): 1853-1858.

[3] Lin, S., J. Reibman, J. A. Bowers, S.-A. Hwang, A. Hoerning, M. I. Gomez and E. F. Fitzgerald (2005). "Upper respiratory symptoms and other health effects among residents living near the World Trade Center site after September 11, 2001." American Journal of Epidemiology **162**(2): 499-507.

of diseases; the initial conditions improved for some, but for many people, they have continued to have health effects related to their 9/11 exposures. Dr. Juan Wisnivesky and others published a paper describing the lasting health effects from 9/11 in 2011[4]. Rates of asthma that developed following 9/11 were elevated, along with sinus disease, gastrointestinal issues, post-traumatic stress disease and other health problems. As my colleague Dr. Benjamin Luft and colleagues have described, for those individuals with both physical and mental health conditions related to their WTC exposures, these co-morbidities have contributed to worse health[5]. A copy of all these publications is attached to my written testimony.

Now here we are, nearly 20 years later. Unfortunately, we have moved into the third wave of diseases. For example, over 50% of firefighters who worked at the World Trade Center site have developed a respiratory condition. While people continue to suffer from aerodigestive disorders and mental health conditions, we are seeing additional diseases. As someone who specializes in occupational diseases, I am used to diseases with long latency – asbestos, that I discussed earlier in my testimony – is one of the most well-known examples of an exposure that can cause disease decades – 40, 50, 60 or more years after someone has had exposure. While we do know a lot about asbestos, we do not know a lot about the actual dust and fumes that enveloped lower Manhattan and thousands of people. There was inadequate measurement for fumes in the week after 9/11, so we do not have a good sense of what was in the air, and what we, as clinicians, should look out for. I would like to reiterate that as medical professionals, we did not think then, and it is amply apparent now, that the air was safe to breathe.

The WTC Health Program is now collecting additional data on diseases that have been classified as WTC-related. This is critical, since early data collection on who was exposed was lacking. Further research is ongoing to determine whether there will be sufficient evidence to add additional disorders to the list of conditions, which now includes respiratory conditions, mental health conditions, certain gastrointestinal conditions, and of course, cancer. Since 2012, when over 50 cancers were considered to be WTC-related, there have been 11,824 people with cancers certified by the program. This includes 2,614 prostate cancers, 552 lung cancers, 741 breast cancers, as well as over 35 male breast cancers, 667 thyroid cancers, and dozens more. The survivor program has had 3,030 individuals with cancers, and in the national program, there has been an increase in the number of cancer cases certified: from 7 in 2013 to 708 in 2018.

Blood cancers, such as leukemia, lymphoma, and multiple myeloma, were identified within several years of September 11th in responders, survivors and school children, but it is expected that more of these cancers will continue to occur in the future. To date, there have been 571 cases of lymphoma certified. Solid tumors, like lung cancer, prostate cancer, thyroid cancer, kidney cancer, and breast cancer, occur years if not decades after exposures. Given that those exposed at Ground Zero were exposed to over 150 toxicants in that deadly brew, there is concern for what is yet to come with respect to cancers. Nearly 20,000 children attended school below Houston Street on September 11, 2001, and were exposed to the toxic mixture. We do not know what World Trade Center diseases these now-young adults will develop. Overall, approximately 49,000 people have been certified for at least one WTC health conditions in the responder and survivor programs, and over 6,200 have been certified for WTC health conditions in the national program. The effects from exposures at 9/11 have not

[4] Wisnivesky, J. P., S. L. Teitelbaum, A. C. Todd, P. Boffetta, M. Crane, L. Crowley, R. E. de la Hoz, C. Dellenbaugh, D. Harrison, R. Herbert, H. Kim, Y. Jeon, J. Kaplan, C. L. Katz, S. Levin, B. Luft, S. Markowitz, J. Moline, F. Ozbay, R. H. Pietrzak, M. Shapiro, V. Sharma, G. S. Skloot, S. Southwick, L. A. Stevenson, I. Udasin, S. Wallenstein and P. Landrigan (2011). "Persistence of multiple illnesses in World Trade Center rescue and recovery workers: a cohort study." The Lancet **378**: 888-897.

[5] Luft, B., C. Schechter, R. Kotov, J. Broihier, D. Reissman, K. Guerrera, I. Udasin, J. Moline, D. Harrison, G. Friedman-Jimenez, R. Pietrzak, S. Southwick and E. Broment (2012). "Exposure, probable PTSD and lower respiratory illness among World Trade Center rescue, recovery and clean-up workers." Psychological Medicine **42**(5): 1069-1079.

only been measured in the numbers of deaths, numbers of cancers, number of lung transplants, or countless cases of new asthma. Studies have shown the impact of 9/11 exposures, not only on health, but also on employment, as individuals with WTC related health conditions were more likely to retire before age 60[6].

Sometimes it's easier to understand what the health impact of 9/11 is by learning about a real person, rather than hearing statistics and types of diseases that have occurred. I'd like to tell you about Ellie Engler, who is in the hearing room today and has allowed me to give a brief description of her health issues. She has had significant health problems since 9/11. Ellie, a certified industrial hygienist, was in charge of health and safety for the United Federation of Teachers on September 11, 2001. She went into every school in lower Manhattan and assessed the immediate health risks to staff and children in these schools. In 2008, she developed breast cancer – a second primary, since she has been cured of breast cancer in 1985, and this new tumor was of a different genetic signature than her first cancer. She has also had a worsening of her asthma, a condition she developed shortly after 9/11 but was under control. Recently, she has had recurrent asthma attacks that have been difficult to control. Ellie, like so many in the WTC community, has fought these illnesses with courage. She realized that all of the staff at these schools should enroll in the WTC health program if they had any WTC-related conditions and began outreach to over 500 teachers and school staff. In addition to ensuring that the staff were aware of the WTC health programs, she began to advocate on behalf of the 19,871 school children in lower Manhattan, highlighting the need for outreach to these students, who have now all graduated from high school and are all over the country. Her clinical future, like so many others, is uncertain, and she will require close monitoring and care for the rest of her life. She is my hero and the hero to many in the WTC community.

On September 11, 2001, we lost 343 members of FDNY, 23 members of NYPD[7], 8 EMS workers from private emergency medical services[8], 37 Port Authority police officers[7], and countless others who were simply going to work, or were in lower Manhattan. 2,973 people lost their lives on that day[7]. Since 9/11, we have become aware of an additional 204 police officers[9], 180 FDNY firefighters[10], and in total, an estimated 2,000 responders and survivors who have died as a result of 9/11 illnesses. Soon, the day will come when there are more people who have died of WTC related illnesses after 9/11 than perished on that horrible day when our nation was attacked. As a doctor, I don't have a crystal ball, but based on the trends we have seen in the research, the numbers of affected individuals – those with life threatening injuries – will continue in this third wave of 9/11 diseases. Throughout our country, brave men and women who were exposed to the fallout from 9/11 will continue to develop cancers at rates above what might be expected absent these exposures. Because of the monitoring programs, we are able to identify new clusters of diseases that will develop – such as neurological conditions, auto-immune disorders, and other diseases we haven't thought of yet. The World Trade Center registry recently

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[7] National Commission on Terrorist Attacks upon the United States, "The 9/11 Commission Report," https://www.9-11commission.gov/report/, accessed on June 3, 2019.

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[9] New York City Police Department, "9/11 Tribute," https://www1.nyc.gov/site/nypd/about/memorials/9-11-tribute.page, accessed on June 3, 2019.

[10] Workers' Compensation Institute, "Death Toll from Cancer for 9/11 Responders Expected to Outnumber Victims of Attack," https://www.wci360.com/death-toll-from-cancer-for-9-11-responders-expected-to-outnumber-victims-of-attack/, accessed on June 3, 2019.

reported that those who were injured on 9/11 had lower life satisfaction and more functional impairment after fifteen years[11]. We expect this type of functional impairment to continue to grow in WTC exposed individuals.

I consider myself fortunate to have been in New York City on 9/11 – so that I could contribute to caring for the thousands of men and women who suffered occupational and environmental exposures from the World Trade Center dust and fumes. Being able to serve my patients, and our nation, as a physician involved in the WTC Health Programs is one of the greatest honors of my life.

I would be happy to take questions.

[11] Gargano, L., H. K. Mok, M. H. Jacobson, P. Frazier, S. K. Garrey, L. Petrspric, J. and R. M. Brackbill (2019). "Comparing life satisfaction and functioning 15 years after September 11, 2001 among survivors with and without injuries: a mixed-method study." Quality Life Research: [Epub ahead of print].

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Comparing life satisfaction and functioning 15 years after September 11, 2001 among survivors with and without injuries: a mixed-method study

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Abstract

Purpose This study compares life satisfaction and limited activity days among 9/11 survivors with and without physical injuries using quantitative and qualitative approaches.

Methods The study population included World Trade Center Health Registry enrollees who reported being injured on 9/11 in 2003–2004 and a sample of non-injured enrollees who participated in a cross-sectional substudy. We used multivariable logistic regression to examine differences in life satisfaction and number of limited activity days in the last 30 days between those with and without injuries. The free-response section of the survey was analyzed qualitatively to compare themes of those with and without injuries.

Results The final sample consisted of 2821 adult enrollees. Compared to those who were not injured, those who were injured on 9/11 were more likely to report being unsatisfied with their life (adjusted odds ratio (AOR): 1.5, 95% confidence intervals (CI) 1.1–2.0) and have 14 or more limited activity days in the last 30 days (AOR: 1.4, 95% CI 1.0–1.9). Among those who were injured, being partially or completely prevented from working increased the odds of being unsatisfied with life and having 14 or more limited activity days. In qualitative analysis, the emotional trauma experienced from 9/11 was a major and common theme, regardless of injury status. Those with injuries were more likely to express anger/lack of recognition/appreciation, describe substance use/abuse, and have financial/health care access issues.

Conclusions More than 15 years after 9/11, those who were injured continue to be impacted, reporting lower life satisfaction and more functional impairment.

Keywords World Trade Center · Injury · Qualitative · Life satisfaction · Quality of life

Introduction

Exposure to disasters is associated with long-term sequelae including psychological, occupational, functional, and quality of life (QoL) impairments [1–3]. QoL refers to general well-being and satisfaction with various aspects of life, including physical health, family, education, employment, and finances [4]. QoL among survivors of the terrorist attacks on the World Trade Center (WTC) on September 11, 2001 (9/11) is poorly understood, despite evidence that both physical [5–7] and mental health conditions [5, 8, 9] associated with the disaster can persist for years.

Despite using different definitions of QoL, 9/11-related chronic physical [5, 10, 11] and mental health conditions [5, 8, 12] consistently are associated with a diminished QoL. For example, one year after 9/11, QoL (measured with the Quality of Life Enjoyment and Satisfaction Questionnaire-short form) was inversely related to mental health symptoms among 9/11-exposed adults [12]. A study of New York City (NYC) firefighters found that, as the number of aerodigestive conditions increased, both physical and mental component summary scores from the SF-12 decreased, indicating a lower health-related QoL [10]. Finally, 10–11 years after

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9/11, exposed persons with persistent lower respiratory symptoms reported significantly lower life satisfaction and more poor physical and mental health days [11].

Outside of the disaster literature, traumatic injury, in particular, is associated with long-term negative outcomes, including poorer mental health and self-rated health, more functional limitations, and lower QoL [13–15]. Studies of disaster-related injuries have also found more adverse mental and physical health outcomes in those who were injured. For instance, injured survivors of the Oklahoma City bombing had higher rates of PTSD than those who were not injured [16]. Among survivors of the 1998 US embassy bombings in East Africa, injury was the only factor significantly associated with posttraumatic stress reactions [17]. Finally, studies of those injured on 9/11 have found an increased risk of PTSD and chronic physical health conditions up to 11 years after 9/11 [18, 19].

There is a paucity of literature on the long-term impact of injury on 9/11 on QoL (e.g., life satisfaction) as opposed to physical and mental health outcomes. A previous exploratory qualitative study of persons injured on 9/11 identified themes regarding long-term recovery and QoL issues, including poor ongoing health status, functional limitations and disabilities, lifestyle/economic impact, and lack of social support [20]. This exploratory qualitative study served as the basis for the development of the current quantitative survey.

The purpose of this study was to build upon these previous findings of decreased QoL in persons injured on 9/11 by exploring differences among 9/11 survivors with and without physical injuries using (1) quantitative analysis of self-reported life satisfaction and number of limited activity days and (2) qualitative analysis of free-response text. Because previous research has shown that persons injured on 9/11 have chronic mental and physical health problems [18, 19] and that these health conditions are associated with poorer QoL assessed using several different measures [5, 8, 10–12], we hypothesized that injured survivors would report lower life satisfaction and more days of limited activity compared to survivors without injuries. Similarly, we hypothesized that qualitative analysis of the free-response data would underscore the long-term effects of the 9/11 disaster for injured survivors compared to those without injuries.

Methods

Study design and sample

"The Health and Quality of Life 15 Years after 9/11 study" (HQoL study) sampled from the World Trade Center Health Registry (WTCHR), a cohort study of over 70,000 individuals exposed to the events of 9/11 in NYC [21]. The WTCHR has disseminated four extensive survey waves that included questions on enrollees' physical and mental health status: Wave 1 (W1; 2003–2004), Wave 2 (W2; 2006–2007), Wave 3 (W3; 2011–2012), and Wave 4 (W4; 2015–2016). The HQoL study population was restricted to enrollees who completed all prior WTCHR surveys. All enrollees who, on the W1 survey, reported being south of Chambers Street on the morning of 9/11 and an injury on 9/11 (at least one of the following: cut, abrasion, or puncture wound; sprain or strain; burn; broken bone, fracture, or dislocation; concussion, head injury, or knocked out by being hit on the head; or any other type of injury) were included ($n=2701$) along with a simple random sample of those who were eligible but not injured ($n=2598$). Data collection was from March to July 2017 by web or paper survey, with 4033 completed surveys (76.1% response rate), including 2038 injured (50.5%) and 1995 non-injured (49.5%) respondents. To be included in analyses regarding medical intervention sought after injury on 9/11, respondents needed to say "yes" to being injured on the HQoL survey. In addition, to reduce recall bias, those with inconsistent reporting of injury from the W1 and HQoL surveys ($n=1212$) were excluded. The final sample size was 2821: 1003 (35.6%) were injured and 1818 (64.4%) were non-injured. The study protocol was approved by the NYC Department of Health and Mental Hygiene's Institutional Review Board.

Quantitative analysis

Outcome measures

There were two QoL outcomes of interest. The first was life satisfaction which was assessed using the question: "In general, how satisfied are you with your life: very satisfied, satisfied, dissatisfied, or very dissatisfied?" Response categories were dichotomized into very satisfied/satisfied vs. dissatisfied/very dissatisfied, consistent with previous research [11, 22–24], because the distribution of responses, particularly at the extremes which had smaller numbers, was inadequate to detect associations. The second was the number of limited activity days: "For about how many days did poor physical or mental health keep you from doing your usual activities during the last 30 days?" [25] Responses were dichotomized into <14 days versus ≥ 14 days, consistent with previous studies [25]. Scores on both of these measures have good validity and reliability [22, 25].

Injury measures

HQoL survey participants were asked if they were injured on 9/11 (Y/N). Among those who reported "yes," we examined injury severity using responses from the HQoL survey. Injury severity was defined by the degree of medical intervention sought after the injury and was defined as a

three-level measure: severe (using a wheelchair in the week following the injury or having sought treatment at a hospital, emergency room, or doctor's office, and/or having surgeries due to their injury on 9/11), moderate (using a cane or crutch in the week following the injury, needing bed rest for at least 1 day, and/or needing physical therapy due to their injury on 9/11), and low (those who did not report any intervention or care) [26, 27]. We also examined whether the injury affected their ability to work. Work was defined as full or part-time employment including self-employment, housework, and/or being a college or university student. Participants were asked whether at any time since 9/11 their injury (1) completely prevented them from working (Y/N) or (2) partially restricted their ability to work (Y/N). If participants said yes to the first question, they were categorized as "injury completely prevented work," if they said no to question 1 but yes to question 2 they were categorized as "injury partially restricted work," and if they said no to both questions they were categorized as "injury did not prevent or restrict work."

Covariates

Sociodemographic variables included age at HQoL survey, gender, and race/ethnicity from W1, and income, employment status, and marital status at W4. Other WTC exposures collected at W1 included witnessing traumatic events (i.e., seeing planes hit the buildings, buildings collapsing, people falling or jumping from buildings, people injured, or people running), being caught in the dust cloud, and being a rescue/recovery worker (RRW). Probable 9/11-related PTSD was assessed at each survey Wave using a 9/11-specific PTSD Checklist-Civilian Version (PCL-17). The PCL-17 is a self-reported, 17-item scale corresponding to PTSD criteria in the DSM-IV. It is commonly used in epidemiological research and has good psychometric properties, with sensitivity ranging from 0.94 to 0.97, specificity from 0.86 to 0.99, and diagnostic efficiency from 0.83 to 0.96 [28, 29]. Cronbach's alpha in this sample was 0.95. Enrollees with a PCL score of ≥ 44 at any Wave were considered to have ever had probable PTSD [19]. Chronic health conditions were defined based on self-report at W4 of having ever received a physician diagnosis for angina, heart attack, asthma, diabetes, or non-neoplastic lung disease (chronic bronchitis, emphysema or COPD, reactive airway dysfunctions syndrome, sarcoidosis).

Analysis

Quantitative analysis Chi square tests were used to test for significant associations between outcome measures and selected sociodemographic characteristics, WTC exposures, 9/11-related PTSD, and 9/11-related injury. Cramer's V and phi coefficients were used to estimate effect sizes. Adjusted odds ratios (AOR) were calculated using logistic regression to estimate the association between injury and life dissatisfaction or ≥ 14 limited activity days, adjusting for covariates found to be significant in the bivariate analysis. A separate analysis was conducted among the injured to estimate the associations between outcomes and injury severity and functional impairment. For the regressions, we used case-wise deletion. There was approximately 8% missing in each of the models, which still provided adequate statistical power to detect the effects of interest; therefore, we do not believe this had any practical effect on the outcome [30–32]. All data analyses were conducted using SAS version 9.4 (Cary, NC).

Qualitative analysis At the end of the HQoL survey, participants were given a free-response area, which followed the question: "Do you have any additional comments about your 9/11 experiences and health?" Content analysis, a systematic classification process of coding and identifying themes or patterns [33], was used to analyze these data using Microsoft Excel. Two team members (LMG and HKM) independently iteratively reviewed the data for themes and subthemes until meaningful patterns emerged. Recurrent themes were identified, and common themes were grouped together into categories. Discrepancies in coding were discussed and resolved by the two coders. A high level of interrater reliability was achieved after several rounds of discussion (kappa > 0.90; $p < 0.01$). Quotes were used to illustrate final themes. Coders were blinded to participant injury status until all thematic coding was completed. Themes were then compared between participants with and without injuries.

Results

Quantitative results

Study population characteristics

Of the 2821 enrollees in this study, the largest proportions were male (56.3%), aged 45–64 years at the time of HQoL study (59.6%), non-Hispanic white (74.5%), had household incomes between $75,000 to ≥ $150,000 (34.8%), employed (63.3%), and married or living with a partner (68.3%) at W4 (Table 1). Just over one-third had ever had 9/11-related PTSD and 40.5% reported at least one chronic health condition. For the WTC exposures, over half witnessed three or more traumatic events, 44.8% were caught in the dust cloud, and 23.5% were RRW. Those who were male, 45–64 years of age, Hispanic, had an income of less than $25,000, unemployed due to health, or divorced/separated were more likely to have been injured as were those who ever had 9/11-related PTSD, had at least one chronic health condition, witnessed 0–2 horrific events, were exposed to the dust cloud, or were RRW.

Table 1 Sociodemographic characteristics, mental and physical health, and World Trade Center (WTC) exposures by injury status among participants in the Health and Quality of Life 15 years after 9/11 study

	Total *N* (%)*	Injured *N* (%)	Non-injured *N* (%)	*p* value
Total	2821 (100)	1003 (35.6)	1818 (64.4)	
Gender				**0.0001**
Male	1589 (56.3)	614 (38.6)	975 (61.4)	
Female	1232 (43.7)	389 (31.6)	843 (68.4)	
Age (at HQoL survey)				**< 0.0001**
65 +	822 (29.1)	265 (32.2)	557 (67.8)	
45–64	1682 (59.6)	670 (39.8)	1012 (60.2)	
30–44	317 (11.2)	68 (21.5)	249 (78.6)	
Race/ethnicity				**0.0011**
White Non-Hispanic	2101 (74.5)	715 (34.0)	1386 (66.0)	
Black Non-Hispanic	267 (9.5)	112 (42.0)	155 (58.1)	
Hispanic	267 (9.5)	117 (43.8)	150 (56.2)	
Asian/other	186 (6.6)	59 (31.7)	127 (68.3)	
Income (W4)				**< 0.0001**
> 150K	883 (33.1)	236 (26.7)	647 (73.3)	
75K– < 150K	929 (34.8)	319 (34.3)	610 (65.7)	
50K- < 75K	366 (13.7)	134 (36.6)	232 (63.4)	
25K- < 50K	291 (10.9)	138 (47.4)	153 (52.6)	
< 25K	198 (7.4)	112 (56.6)	86 (43.4)	
Employment status				**< 0.0001**
Employed	1764 (63.0)	520 (29.5)	1244 (70.5)	
Unemployed—health	212 (7.6)	162 (76.4)	50 (23.6)	
Unemployed—others	826 (29.5)	310 (37.5)	516 (62.5)	
Marital status (W4)				**< 0.0001**
Married or living with partner	1909 (68.3)	624 (32.7)	1285 (67.3)	
Divorced or separated	360 (12.9)	182 (50.6)	178 (49.4)	
Widowed	106 (3.8)	50 (47.2)	56 (52.8)	
Never married	419 (15)	128 (30.6)	291 (69.5)	
9/11-related PTSD				**< 0.0001**
Ever	1008 (36.1)	650 (64.5)	358 (35.5)	
Never	1785 (63.9)	345 (19.3)	1440 (80.7)	
Chronic health conditions				**< 0.0001**
0	1679 (59.5)	434 (25.9)	1245 (74.2)	
1 +	1142 (40.5)	569 (49.8)	573 (50.2)	
WTC exposure				
Witness traumatic events				**< 0.0001**
0–2	1380 (48.9)	761 (55.1)	619 (44.9)	
3–5	1441 (51.1)	242 (16.8)	1199 (83.2)	
Dust				**< 0.0001**
No	1556 (55.2)	232 (14.9)	1324 (85.1)	
Yes	1265 (44.8)	771 (61)	494 (39.1)	
RRW				**< 0.0001**
No	2157 (76.5)	580 (26.9)	1577 (73.1)	
Yes	664 (23.5)	423 (63.7)	241 (36.3)	

*Missing data: Income $n = 154$; Employment status $n = 19$; Marital status $n = 27$; 9/11-related PTSD $n = 28$

Quality of life

Overall, 16.1% of respondents reported being dissatisfied/very dissatisfied with life and 16.8% reported having ≥ 14 limited activities days. Enrollees who were 45–64 years of age, Hispanic, had a household income of < $25,000, unemployed due to health, divorced or separated, ever had 9/11-related PTSD, had a least one chronic health

condition, witnessed ≥ three traumatic events on 9/11, were caught in the dust cloud on 9/11, or were injured on 9/11 had a higher prevalence of reporting being dissatisfied/very dissatisfied with life and having ≥ 14 limited activities days (Table 2). In addition, having been a RRW was associated with greater limited activity days but not life satisfaction. The magnitude of the effect sizes for most of these associations was small to medium (Table 2).

In the logistic regression analyses, after adjusting for covariates—women (vs. men), 45–64 years of age (vs. 65 years or older), divorced or separated (vs. married or living with a partner), and unemployed due to health (vs. employed)—were more likely to report being dissatisfied/very dissatisfied with life (Table 3). There was a dose–response relationship between household income and life satisfaction—the lower the income the more likely enrollees were to report being dissatisfied/very dissatisfied with life (trend test $p < 0.01$). Those who were injured on 9/11 were 50% more likely to report being dissatisfied/very dissatisfied with life compared with those who were not injured (AOR: 1.5, 95% CI 1.1–2.0). Compared with those who never had 9/11-related PTSD, those who had ever had 9/11-related PTSD were 4.1 times more likely to report being dissatisfied/very dissatisfied (AOR: 4.1, 95% CI 3.1–5.4). RRWs were less likely to report being dissatisfied/very dissatisfied with life (AOR: 0.7, 95% CI 0.5–0.9). Similar patterns of associations with ≥ 14 limited activity days were observed, including a dose–response relationship between income and reporting ≥ 14 limited activity days. Those who were injured on 9/11 were 40% more likely to report ≥ 14 limited activity days compared with those who were not injured (AOR: 1.4, 95% CI 1.0–1.9).

Among those who were injured, 45.0% reported that their injury completely prevented them from working at some point after 9/11, and 13.7% reported that their injury partially restricted their ability to work at some point after 9/11 (Table 4). Almost two-thirds were categorized as severely injured. In adjusted analyses, those who reported that their injury completely prevented them from working were 3.3 times more likely to report being dissatisfied/very dissatisfied with life (95% CI 2.2–5.0) and 3.7 times more likely to report ≥ 14 limited activity days (95% CI 2.4–5.6) compared with those who reported no work restrictions because of their injury. Those who reported that their injury partially restricted them from working were 1.6 times more likely to report being dissatisfied/very dissatisfied with life (95% CI 0.9–2.9) and 2.0 times more likely to report ≥ 14 limited activity days (95% CI 1.1–3.5) compared with those who reported no work restrictions because of their injury. There was no significant associations between injury severity and either reporting being dissatisfied/very dissatisfied with life or ≥ 14 limited activity days.

Qualitative results

Of the 2821 enrollees who completed the study survey, 884 (31.3%) wrote responses in the free-response section. Of these, 451 (51.0%) were injured on 9/11 and 433 (49.0%) were not (Table 5). Thematic analysis yielded nine themes: (1) anger/lack of recognition or appreciation, (2) health issues/cancer/breathing issues, (3) emotional trauma/depressed/anxious, (4) financial/health care access issues, (5) gratitude to investigators, (6) worry/life disrupted, (7) substance use/abuse, (8) moved on, and (9) not impacted.

Thematic analysis

For both injured and non-injured respondents, the most common theme that emerged was emotional trauma/depressed/anxious. One enrollee wrote how after 9/11, "I find myself more emotional and nervous." Another enrollee wrote of personal and loved ones' emotional trauma, "The mental effects of 9/11 have worsened over time for me and my family." Other enrollees wrote of avoiding the subject of 9/11, "I still get emotional when I think about 9/11… It's been so many years and yet I can't always talk about it." A high number also reported health issues/cancer/breathing problems, with comments like, "[I] recently developed stomach cancer despite a healthy lifestyle. No cancer [history] in family. One of my doctors feels that it could [be]related to 9/11." Others wrote about chronic health issues since 9/11, "Within 3 months of the event, I found it difficult to walk up the 3 flights of stairs to our home and had rashes. All these years later those conditions continue." Comments around health and healthcare were also seen within the financial/healthcare access issues theme. For example, one enrollee wrote, "I was very disappointed that there was no compensation for [PTSD] which I am experiencing daily." Another enrollee wrote of financial hardship, "[I am] financially not as successful [its] more of a struggle to maintain employment and normal life."

To a lesser extent, enrollees expressed worry/life disrupted, especially a fear of the future: "Yes I am constantly concerned about getting some kind of cancer from 9/11 because I have lost about 6 fireman friends to post 9/11 cancers." Some expressed anger or a lack of appreciation. One RRW wrote, "I wish it never happened - it ruined my life…. I never got any recognition or appreciation for what I did on 9/11 and for the next 6 years at ground zero."

A smaller number wrote on the theme of substance use/abuse: "I took up daily marijuana use, a small amount, each evening. I had done this from time to time earlier in my life. After 9–11, it became daily. It works for me and doesn't impact my professional life. It has some impact on my personal life–wife disapproves of daily intake."

Table 2 Sociodemographic characteristics, mental and physical health, and World Trade Center (WTC) exposures by life satisfaction and limited activity days among participants in the Health and Quality of Life 15 years after 9/11 study

	Life satisfaction			Limited activity days		
	Very satisfied/satisfied	Very dissatisfied/dissatisfied	Effect size	< 14 days	≥ 14 days	Effect size
	N (%)	*N* (%)	*V* or ϕ	*N* (%)	*N* (%)	*V* or ϕ
Total	2352 (83.9)	450 (16.1)		2314 (83.2)	468 (16.8)	
Gender						
Male	1333 (84.4)	246 (15.6)	0.01	1315 (84.0)	251 (16.0)	0.02
Female	1019 (83.3)	204 (16.7)		999 (82.2)	217 (17.9)	
Age (at HQoL survey)						
65+	711 (87.4)	103 (12.7)	0.09	676 (83.8)	131 (16.2)	0.10
45-64	1359 (81.3)	312 (18.7)		1348 (81.1)	314 (18.9)	
30-44	282 (89.0)	35 (11.0)		290 (92.7)	23 (7.4)	
Race/ethnicity						
White Non-Hispanic	1792 (85.7)	299 (14.3)	0.08	1751 (84.2)	328 (15.8)	0.07
Black Non-Hispanic	205 (78.2)	57 (21.8)		211 (81.2)	49 (18.9)	
Hispanic	204 (77.6)	59 (22.4)		196 (75.4)	64 (24.6)	
Asian/Other	151 (81.2)	35 (18.8)		156 (85.3)	27 (14.8)	
Income (W4)						
> 150K	817 (92.8)	63 (7.2)	0.29	813 (93.3)	58 (6.7)	0.28
75K–< 150K	809 (87.6)	115 (12.5)		783 (85.2)	136 (14.8)	
50K–< 75K	287 (79.1)	76 (20.9)		284 (78.0)	80 (22.0)	
25K–< 50K	198 (68.8)	90 (31.3)		199 (69.6)	87 (30.4)	
< 25K	112 (57.4)	83 (42.6)		106 (55.8)	84 (44.2)	
Employment status						
Employed	1542 (87.9)	213 (12.1)	0.29	1565 (89.7)	179 (10.3)	0.40
Unemployed—health	96 (46.2)	112 (53.9)		66 (31.6)	143 (68.4)	
Unemployed—others	699 (85.2)	121 (14.8)		668 (82.5)	142 (17.5)	
Marital status (W4)						
Married/living with partner	1663 (87.5)	238 (12.5)	0.16	1618 (85.9)	265 (14.1)	0.13
Divorced or separated	250 (70.8)	103 (29.2)		254 (71.4)	102 (28.7)	
Widowed	87 (82.9)	18 (17.1)		83 (79.8)	21 (20.2)	
Never married	333 (79.9)	84 (20.1)		343 (83.1)	70 (16.9)	
9/11-related PTSD						
Never	1660 (93.4)	118 (6.6)	0.35	1652 (93.5)	114 (6.5)	0.37
Ever	667 (66.9)	330 (33.1)		640 (64.7)	350 (35.4)	
Chronic health conditions						
0	1478 (88.4)	194 (11.6)	0.15	1489 (90.0)	166 (10.0)	0.22
1+	874 (77.4)	256 (22.7)		825 (73.2)	302 (26.8)	
WTC exposure						
Witness traumatic events						
0-2	1269 (88.7)	162(11.3)	0.13	1255(88.2)	168 (11.8)	0.14
3-5	1083 (79.0)	288(21.0)		1059(77.9)	300 (22.1)	
Dust						
No	1370 (88.6)	176 (11.4)	0.14	1376 (89.6)	160 (10.4)	0.19
Yes	982 (78.2)	274 (21.8)		938 (75.3)	308 (24.7)	
RRW						
No	1811 (84.5)	333 (15.5)	0.03	1810 (85.1)	317 (14.9)	0.09
Yes	541 (82.2)	117 (17.8)		504 (77.0)	151 (23.1)	
Injury						

Table 2 (continued)

	Life satisfaction			Limited activity days		
	Very satisfied/satisfied	Very dissatisfied/dissatisfied	Effect size	< 14 days	≥ 14 days	Effect size
	N (%)	*N* (%)	*V* or ϕ	*N* (%)	*N* (%)	*V* or ϕ
No	1634 (90.3)	176 (9.7)	0.23	1626 (90.6)	168 (9.4)	0.27
Yes	718 (72.4)	274 (27.6)		688 (69.6)	300 (30.4)	

Shaded cells are significant p <= 0.05

The theme of having moved on also emerged: "I moved on very quickly from 9/11, probably just weeks after." Some respondents wrote about not being impacted at all: "It never really changed me…"

Theme frequencies by injury status

Five of the nine themes were endorsed by similar proportions of injured and non-injured enrollees: health issues/cancer/breathing issues, emotional trauma/depressed/anxious, financial/health care access issues, gratitude to investigators, and worry/life disrupted (Table 5). Of those who reported on the theme of anger/lack of recognition/appreciation 62.9% were injured compared to 37.1% who were not injured. Those who reported on the theme of substance use/abuse 81.8% were injured compared to 18.2% for non-injured. Conversely, for the theme of "moved on", 85.7% were not injured, while 14.3% were injured and for "not impacted", 80.0% who reported this theme were not injured compared to 20.0% who were injured.

Discussion

Our two complementary analyses represent a longer-term, in-depth description of two aspects of QoL among both injured and non-injured persons exposed to the events of 9/11 in NYC, and support and deepen previous findings [20]. Specifically, we found that more than 15 years after the WTC attacks, those who were injured on 9/11 reported significantly diminished life satisfaction and more limited activity days, even after controlling for other factors such as PTSD, chronic health conditions, and unemployment due to health reasons. In addition, those whose injuries resulted in complete or partial restriction of work reported even lower life satisfaction and more limited activity days. Furthermore, a descriptive analysis of free-text responses demonstrated the depth of the psychological and physical consequences of 9/11 among those who both were injured and not injured 15 years after the event.

The long-term relationship between injury and QoL also has been documented in other populations. Combat-related injuries have been shown to be associated with lower health-related QoL [34–37]. These studies examined specific and very severe injuries, including traumatic brain injury [34], amputation [35], and spinal cord injury [36]. However, one study of veterans with mild to severe bodily injuries found that injury was associated with lower health-related QoL up to 5 years after the injury [37]. Aside from studies of veterans, a study of Danish adults found that, compared with non-injured, injured participants had lower self-reported general health up to 10 years after the injury [14]. Further, a study of persons aged 65 years or older who were hospitalized for an injury found that, compared to age-adjusted norms, there was a significant decrement in seven of the eight SF-36 domains among those who were injured, including physical functioning, role-physical and role-emotional functioning, social functioning, mental health, vitality, and general health [38].

We did not find an association between injury *severity* and life satisfaction or limited activity days. Previous research on the relationship between injury severity and different QoL measures is mixed. Although several studies found that injury severity was unrelated to QoL [39, 40], one study of military personnel found that those with minor injuries had the highest health-related QoL, whereas those with the most severe injuries had the lowest health-related QoL [37]. One potential explanation is that each of these studies, including ours, have used different definitions of QoL. However, we did find that, among those who were injured, being partially or completely prevented from working due to the injury was associated with greater likelihood of being dissatisfied with life and ≥ 14 limited activity days compared with those whose ability to work was not affected. This is consistent with previous research showing that the ability to work is strongly associated with QoL after injury using various measures of QoL including health-related QoL and SF-36 [41–43]. These findings were supported by qualitative analysis of the free-response section with financial issues being one of the most commonly mentioned themes, especially among the injured. There was a high correlation in this study between injury severity and ability to work ($p < 0.0001$, data not shown). Despite this, only ability to work was associated with the outcomes in adjusted models.

Table 3 Adjusted odds ratios (AOR) for life dissatisfaction and ≥ 14 limited activity days

	Life dissatisfaction* ($n=2602$)	≥ 14 limited activity days** ($n=2584$)
	AOR (95% CI)	AOR (95% CI)
Gender		
Male	Ref.	Ref.
Female	1.3 (1.0, 1.8)	1.1 (0.9, 1.5)
Age (at HQoL survey)		
65 +	Ref.	Ref.
45–64	1.8 (1.3, 2.5)	1.3 (0.9, 1.7)
30–44	1.2 (0.8, 2.1)	0.7 (0.4, 1.3)
Race/ethnicity		
White Non-Hispanic	Ref.	Ref.
Black Non-Hispanic	0.9 (0.6, 1.3)	0.6 (0.4, 1.0)
Hispanic	0.9 (0.6, 1.3)	1.0 (0.7, 1.4)
Asian/other	1.2 (0.7, 1.8)	0.8 (0.5, 1.3)
Income (W4)		
> 150K	Ref.	Ref.
75K–< 150K	1.4 (1.0, 2.0)	1.6 (1.2, 2.4)
50K–< 75K	2.2 (1.5, 3.4)	2.4 (1.5, 3.6)
25K–< 50K	2.9 (1.9, 4.5)	2.3 (1.5, 3.6)
< 25K	4.1 (2.5, 6.7)	4.1 (2.5, 6.8)
Employment status		
Employed	Ref.	Ref.
Unemployed—health	3.0 (2.1, 4.4)	6.1 (4.1, 9.0)
Unemployed—others	1.0 (0.8, 1.4)	1.3 (1.0, 1.8)
Marital status (W4)		
Married or living with partner	Ref.	Ref.
Divorced or separated	1.7 (1.3, 2.4)	1.4 (1.0, 2.0)
Widowed	1.1 (0.6, 2.0)	1.0 (0.6, 1.8)
Never married	1.2 (0.9, 1.8)	0.9 (0.6, 1.3)
9/11-related PTSD		
Never	Ref.	Ref.
Ever	4.1 (3.1, 5.4)	3.6 (2.7, 4.8)
Chronic health conditions		
0	Ref.	Ref.
1 +	1.2 (0.9, 1.5)	1.8 (1.4, 2.3)
WTC exposure		
Witness traumatic events		
0–2	Ref.	Ref.
3–5	1.0 (0.7, 1.3)	1.1 (0.8, 1.5)
Dust		
No	Ref.	Ref.
Yes	1.1 (0.8, 1.4)	1.3 (1.0, 1.7)
RRW		
No	Ref.	Ref.
Yes	0.7 (0.5, 0.9)	1.0 (0.8, 1.4)
Injury		
No	Ref.	Ref.
Yes	1.5 (1.1, 2.0)	1.4 (1.0, 1.9)

*Adjusted for age at HQoL, race/ethnicity, income, employment status, marital status, 9/11-related PTSD, chronic health conditions, witnessing traumatic events, dust, and injury

**Adjusted for age at HQoL, race/ethnicity, income, employment status, marital status, 9/11-related PTSD, chronic health conditions, witnessing traumatic events, dust, RRW, and injury

Table 3 (continued)

A potential explanation is that working full- or part-time better meets a variety of needs (e.g., physiological, emotional, financial and social) [44] and provides the ability to be active in the community [43].

Table 4 Adjusted odds ratios of life dissatisfaction and ≥ 14 limited activity days among injured

	Total	Life dissatisfaction* ($n=874$)	≥ 14 limited activity days** ($n=871$)
	N (%)	AOR (95% CI)	AOR (95% CI)
Injury preventing or restricting work[a]			
Not at all	399 (41.4)	Ref.	Ref.
Partially restricted	132 (13.7)	1.6 (0.9, 2.9)	2.0 (1.1, 3.5)
Completely prevented	434 (45.0)	3.3 (2.2, 5.0)	3.7 (2.4, 5.6)
Injury severity[a]			
Low	110 (11.7)	Ref.	Ref.
Moderate	237 (25.2)	1.3 (0.7, 2.6)	1.4 (0.7, 2.8)
Severe	593 (63.1)	1.4 (0.7, 2.6)	1.4 (0.8, 2.6)

[a]Run in separate models for each of the two outcomes (four models total)

*Adjusted for age at HQoL, race/ethnicity, income, employment status, marital status, 9/11-related PTSD, chronic health conditions, witnessing traumatic events, dust, and injury

**Adjusted for age at HQoL, race/ethnicity, income, employment status, marital status, 9/11-related PTSD, chronic health conditions, witnessing traumatic events, dust, RRW, and injury

Table 5 Free-text free response themes by frequency

	Injured *N* (%)	Non-injured *N* (%)
Total	451 (51.0)	433 (49.0)
Themes		
Anger/lack of recognition/appreciation	22 (62.9)	13 (37.1)
Health issues/cancer/breathing issues	132 (53.0)	117 (47.0)
Emotional trauma/depressed/anxious	136 (50.2)	135 (49.8)
Financial/health care access issues	36 (58.1)	26 (41.9)
Gratitude to investigators	80 (47.6)	88 (52.4)
Worry/life disrupted	31 (54.4)	26 (45.6)
Substance use/abuse	9 (81.8)	2 (18.2)
Moved on	3 (14.3)	18 (85.7)
Not impacted	2 (20.0)	8 (80.0)

Row %

The descriptive analysis of the free-response section of the survey revealed a similar narrative of lower life satisfaction and more limited activity days among those who were injured on 9/11 compared with those not injured. Similar to another qualitative study conducted on persons injured on 9/11 [20], themes around poor ongoing mental and physical health, adverse economic impacts, and substance use emerged. However, regardless of injury, the survivors in our study reported that they struggled with the lasting impact of 9/11 on their physical and mental health. Similar to findings from a study comparing injured and non-injured survivors of The Station nightclub fire [45], the injury sustained on 9/11 was not the primary focus of the free text responses of those who were injured. Rather, the focus was mostly on emotional issues, health problems, and difficulties faced. These findings demonstrate the critical need for long-term follow-up of disaster survivors, regardless of injury status.

Proper treatment may be important, not only for the injury itself, but also for any long-term health effects of the injury. MacKenzie et al. compared adult patients with at least one lower-limb injury in hospitals with a level-I trauma center to those in a hospital without a trauma center and found that those in care at a trauma center had greater improvements in physical functioning and overall vitality at 1 year after the injury compared to those in care without a trauma center [46]. In addition, the known association between injury and mental health conditions [19, 35] and the current study's qualitative findings indicate that identification and treatment of mental health conditions early in the rehabilitation process may not only improve the mental health of injured individuals but also improve their QoL.

Limitations

The findings of this study are subject to several limitations. First, selection bias may be a concern because participants in the HQoL survey had to have completed all previous WTCHR survey waves. However, a previous study showed that, although those with PTSD symptoms were slightly less likely to continue to participate than those without, the degree of exposure to the WTC attacks, including sustaining an injury on 9/11, was not associated with participation over time [47]. Second, although we asked about treatment received after the injury, we lacked clinical information on treatment (e.g., type and duration of medication) that could have been included in the severity scale. Third, we did not have information on the length of time the person was out of work due to injury, which could have provided a more detailed analysis of the relationship between ability to work and the outcomes of interest. Fourth, we did not collect information on current disability status, which has been shown to be an important mediator between injury and QoL [48]. The analyses can therefore not differentiate whether observed relationships are, for example, due to the trauma/injury in 2001 or due to current physical health problems, which might have their (partial) origin in the injury sustained in 2001. Fifth, the exclusion of those with inconsistent responses to being injured, while potentially reducing recall bias, may have biased the sample toward those with more severe injuries. Those who said they were injured at W1 were more likely to report that they were not injured on 9/11 in the HQoL survey compared with those who said they were not injured on 9/11 at W1. Among those at W1 who reported they were injured on 9/11, those with more severe or several injuries were less likely to have discrepant reports compared with those with more superficial injuries or just one injury type, respectively. Finally, participants who contributed to the free-response section did not differ statistically from those who did not by injury status, the main independent variable of interest, but did by sex, age, and income ($p < 0.01$). Also, among the injured, free-text respondents differed by sex and race/ethnicity ($p < 0.05$). These differences could limit the generalizability of the findings, although this is not the purpose of qualitative findings [49].

Conclusions

The use of quantitative and qualitative analysis provided a more nuanced picture of the long-term effects of being injured on 9/11. Early treatment for disaster-related injuries, as well as identification and treatment of co-morbid mental health conditions, may improve long-term QoL-related outcomes.

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The World Trade Center Disaster and the Health of Workers: Five-Year Assessment of a Unique Medical Screening Program

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Background: Approximately 40,000 rescue and recovery workers were exposed to caustic dust and toxic pollutants following the 11 September 2001 attacks on the World Trade Center (WTC). These workers included traditional first responders, such as firefighters and police, and a diverse population of construction, utility, and public sector workers.

Methods: To characterize WTC-related health effects, the WTC Worker and Volunteer Medical Screening Program was established. This multicenter clinical program provides free standardized examinations to responders. Examinations include medical, mental health, and exposure assessment questionnaires; physical examinations; spirometry; and chest X rays.

Results: Of 9,442 responders examined between July 2002 and April 2004, 69% reported new or worsened respiratory symptoms while performing WTC work. Symptoms persisted to the time of examination in 59% of these workers. Among those who had been asymptomatic before September 11, 61% developed respiratory symptoms while performing WTC work. Twenty-eight percent had abnormal spirometry; forced vital capacity (FVC) was low in 21%; and obstruction was present in 5%. Among nonsmokers, 27% had abnormal spirometry compared with 13% in the general U.S. population. Prevalence of low FVC among nonsmokers was 5-fold greater than in the U.S. population (20% vs. 4%). Respiratory symptoms and spirometry abnormalities were significantly associated with early arrival at the site.

Conclusion: WTC responders had exposure-related increases in respiratory symptoms and pulmonary function test abnormalities that persisted up to 2.5 years after the attacks. Long-term medical monitoring is required to track persistence of these abnormalities and identify late effects, including possible malignancies. Lessons learned should guide future responses to civil disasters.

Key words: air pollution, disaster response, occupational lung disease, pulmonary function, September 11, spirometry, World Trade Center. *Environ Health Perspect* 114:1853–1858 (2006). doi:10.1289/ehp.9592 available via *http://dx.doi.org/* [Online 6 September 2006]

An estimated 40,000 men and women worked at Ground Zero, the former site of the World Trade Center (WTC) in New York City, and at the Staten Island landfill, the principal wreckage depository in the days, weeks, and months after 11 September 2001 (Levin et al. 2004). These workers and volunteers included traditional first responders such as firefighters, law enforcement officers, and paramedics, as well as a diverse population of operating engineers, laborers, ironworkers, railway tunnel cleaners, telecommunications workers, sanitation workers, and staff of the Office of the Chief Medical Examiner. These men and women carried out rescue-and-recovery operations, restored essential services, cleaned up massive amounts of debris, and in a time period far shorter than anticipated, deconstructed and removed remains of buildings. Many had no training in response to civil disaster. The highly diverse nature of this workforce posed unprecedented challenges for worker protection and medical follow-up.

Workers were exposed to a complex mix of toxic chemicals and to extreme psychological trauma. These exposures varied over time and by location (Landrigan et al. 2004; Lioy et al. 2002). Combustion of 90,000 L of jet fuel immediately after the attacks created a dense plume of black smoke containing volatile organic compounds (including benzene), metals, and polycyclic aromatic hydrocarbons. The collapse of the twin towers (WTC 1 and WTC 2) and then of a third building (WTC 7) produced an enormous dust cloud containing thousands of tons of coarse and fine particulate matter (PM), cement dust, glass fibers, asbestos, lead, hydrochloric acid, polychlorinated biphenyls (PCBs), organochlorine pesticides, and polychlorinated dioxins and furans (Clark et al. 2003; Landrigan et al. 2004; Lioy et al. 2002; McGee et al. 2003). U.S. Environmental Protection Agency (EPA) estimates of airborne dust ranged from 1,000 to > 100,000 μg/m^3 (U.S. EPA 2002). The high content of pulverized cement made the dust highly caustic (pH 10–11) (Landrigan et al. 2004; Lioy et al. 2002).

Dust and debris gradually settled, and rains on 14 September further diminished the intensity of outdoor ambient dust exposure. However, rubble-removal operations repeatedly reaerosolized the dust, leading to continuing intermittent exposure for many months. Fires burned both above and below ground until December 2001 (Banauch et al. 2003; Chen and Thurston 2002; U.S. EPA 2003). Air levels of certain contaminants remained elevated well into 2002, with spikes in benzene and asbestos levels occurring as late as March and May 2002, respectively (U.S. EPA 2003).

Workers began noting symptoms soon after September 11, most commonly involving the aerodigestive tract (upper and lower respiratory tract and esophagus) (Banauch et al. 2006; Salzman et al. 2004; Szeinuk et al. 2003). New York City Fire Department (FDNY) firefighters experienced persistent cough, termed the "World Trade Center

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cough," which was accompanied by respiratory distress and bronchial hyperreactivity (Prezant et al. 2002). A sample of FDNY firefighters who had sustained extreme exposures on September 11 was nearly 8 times more likely to manifest bronchial hyperreactivity than firefighters with lower exposures when examined after 6 months (Banauch et al. 2003). Laborers and ironworkers manifested new-onset cough, wheeze, and sputum production (Geyh et al. 2005; Skloot et al. 2004), likely attributable to respiratory inflammation caused by the highly alkaline dust (Chen and Thurston 2002).

Other reported pulmonary effects included cough, asthma, and reactive airway dysfunction syndrome (Balmes 2006; Banauch et al. 2006). Chronic rhinosinusitis, vocal cord inflammation, and laryngitis (de la Hoz et al. 2004) and case reports of eosinophilic pneumonia (Rom et al. 2002), granulomatous pneumonia, and bronchiolitis obliterans (Mann et al. 2005; Safirstein et al. 2003) were also reported.

Although New York has an extensive hospital network and strong public health system, no existing infrastructure was sufficient for providing unified and appropriate occupational health screening and treatment in the aftermath of September 11. Local labor unions, who made up the majority of responders, became increasingly aware that their members were developing respiratory and psychological problems; they initiated a campaign to educate local elected officials about the importance of establishing an occupational health screening program. In early 2002, Congress directed the Centers for Disease Control and Prevention (CDC) to fund most of the WTC Worker and Volunteer Medical Screening Program (MSP), an action largely attributable to the collaborative efforts of organized labor and elected officials. The goals of the program were as follows:

- To rapidly build a regional and national consortium of occupational medicine clinics to conduct geographically convenient standardized medical evaluations
- To identify WTC responders, notify them about this program, and encourage participation
- To provide clinical examinations for eligible individuals to identify WTC-related physical and/or mental health conditions
- To coordinate referral for follow-up clinical care for affected individuals
- To educate workers and volunteers about exposures and associated risks to their health
- To advise affected individuals about available benefit and entitlement programs
- To establish "baseline" clinical status for individuals exposed at or near Ground Zero for comparison with future clinical assessments.

In April 2002, the Irving J. Selikoff Center for Occupational and Environmental Medicine (COEM) at Mount Sinai was awarded a contract by the National Institute for Occupational Safety and Health (NIOSH) to establish and coordinate the MSP. The Bellevue/New York University Occupational and Environmental Medicine Clinic, the State University of New York Stony Brook/Long Island Occupational and Environmental Health Center, the Center for the Biology of Natural Systems at Queens College in New York, and the Clinical Center of the Environmental & Occupational Health Sciences Institute at UMDNJ-Robert Wood Johnson Medical School in New Jersey were designated as the other members of the regional consortium. The Association of Occupational and Environmental Clinics was designated to coordinate a national examination program for responders who did not live in the New York/New Jersey area.

In this article we describe the design and implementation of the MSP and the prevalence of selected clinical findings from screening examinations conducted between July 2002 and April 2004 in those from whom informed consent and HIPAA (Health Insurance Portability and Accountability Act 1996) authorization were obtained. Mental health service provision and findings will be presented in a separate paper.

Materials and Methods

Establishing the cohort: identification and outreach. The target population was approximately 18,000 WTC responders not eligible to participate in other federally funded programs (e.g., FDNY, federal workers, New York State workers). Because responders came from many sectors, a high proportion as unpaid volunteers, no systematic roster of names and contact information was available. An MSP outreach unit was therefore established and staffed by people experienced in occupational health and familiar with key organizations, primarily labor unions representing responders.

The MSP executive steering committee. To ensure key stakeholder input into all aspects of program development and oversight, an executive steering committee (ESC) was established; the ESC included representatives from each of the consortium clinics, representatives from labor unions, employers, and technical experts from relevant fields.

The ESC advised the program directors on all program decisions and on basic components of the medical examination, eligibility criteria, and the outreach plan. An advisory council of > 100 people was created several months after the start of the program to broaden stakeholder involvement and to tap into the enthusiasm and creativity of responder organizations. Generally 40–50 responder representatives attended quarterly advisory council meetings. The ESC and advisory council helped maintain open lines of communication with representatives of the program's diverse responder population.

Examination eligibility. To be eligible to receive an examination, a responder must have fallen into one of two categories: For the first category, the responder must have been a rescue, recovery, debris-cleanup and related support services worker, or volunteer in *a*) lower Manhattan (south of Canal St.), *b*) the Staten Island Landfill, and/or *c*) the barge loading piers, and must have worked and/or volunteered on-site for 4 hr on 11–14 September 2001, for at least 24 hr during the month of September, or for at least 80 hr during the months of September, October, November, and December combined.

To fall into the second category, the responder must have been an employee of the Office of the Chief Medical Examiner (OCME), involved in the examination and processing of human remains, or other morgue worker who performed similar post-September 11 functions for OCME staff; a worker in the Port Authority Trans-Hudson Corporation tunnel through 1 July 2002 for a minimum of 24 hr; or a vehicle-maintenance worker with post-September 11 functions within the requisite timeframes and exposed to WTC debris while retrieving, driving, cleaning, repairing, and maintaining contaminated vehicles.

Development of the examination protocol. The clinical consortium partners, supplemented by experts in psychiatry, pulmonary medicine, otolaryngology, industrial hygiene, and epidemiology, collaborated in protocol development to provide high quality standardized occupational health screening examinations and gather information for a research database to enable scientific assessment of the full health impact of the disaster. Early in protocol planning it was decided that direct clinical services had priority where clinical protocols conflicted with collection of research data.

Standardized medical examination. Responders received a clinical screening evaluation consisting of medical, mental health, and exposure-assessment questionnaires; a standardized physical examination; and pre- and postbronchodilator spirometry, complete blood count, blood chemistries, urinalysis, and chest radiograph. Participants received both immediate and final letters with examination results and a face-to-face physician consultation at the end of the examination day. Participants were provided referrals for evaluation and treatment for physical or mental health conditions identified in the screening examination.

A trained health care practitioner administered a medical questionnaire on selected diagnoses and prior upper and lower respiratory conditions (e.g., chronic sinusitis and asthma),

occurrence of symptoms in the year before 11 September 2001, during the period the subject worked at the WTC site, for the month before the screening examination, and whether preexisting symptoms and diagnoses worsened during their WTC work. A questionnaire also asked about smoking history. Where possible, questions were adapted from standardized instruments (e.g., Burney et al. 1989; European Community Respiratory Health Survey 1994; Miller et al. 2005; National Center for Health Statistics 1996; NIOSH 2006; Piccirillo et al. 2002).

We used an interviewer-administered survey instrument to obtain pre- and post-September 11 occupational and environmental exposure histories, including dates that responders reported for first working or volunteering for September 11–related duties and, for those present on September 11, whether they were exposed to the cloud of dust from the building collapses. We constructed the ordinal date-related categories shown in the tables as a rough measure of relative dust exposures, and also categorized workers by location where they spent the majority of their time when first working at Ground Zero. We also obtained data on respirator type and use during the first week of the WTC recovery; those data will be reported in subsequent analyses.

Eligible responders were invited for clinical examinations irrespective of their willingness to provide consent to have data aggregated. Only data from responders providing institutional review board consent and HIPAA authorization (on or after 14 April 2003) are included in data analyses.

Spirometry. Spirometric examination employed the EasyOne spirometer (ndd Medical Technologies, Chelmsford, MA) using standard techniques (Miller et al. 2005). We compared spirometry results to age-, sex-, and ethnic-specific reference values derived from the third phase of the National Health and Nutrition Examination Survey (NHANES III) (Hankinson et al. 1999). Interpretation followed the recently combined American Thoracic Society and European Respiratory Society guidelines (Pellegrino et al. 2005). Only spirometry of acceptable quality, as defined by international guidelines (Miller et al. 2005), was included in the analysis (n = 8,384). Airway obstruction was defined as forced expiratory volume/forced vital capacity (FEV_1/FVC) below the lower limit of normal (LLN) with a normal FVC. Spirometry with FVC < LLN but FEV_1/FVC ≥ LLN was categorized as "low FVC." Obstruction and low FVC was defined as FEV_1/FVC < LLN and FVC < LLN. A significant bronchodilator response was defined as an increase in FEV_1 or FVC of < 12% and 200 mL. Comprehensive spirometry quality assurance was an integral aspect of this program.

Data analysis. We used SAS software (version 9.1; SAS Institute, Inc., Cary, NC) for all analyses. Categorization of occupational sector was based on the union and/or organization to which the responder reported belonging during work on the WTC effort. We categorized prevalence of specific health outcomes by date of arrival and exposure to the dust cloud and used the Cochrane-Armitage trend test to assess significance of trends in prevalence across exposure categories.

Results

The MSP began examining responders in July 2002, 3 months after receipt of federal funding. Of the 16,528 responders meeting eligibility criteria, we examined 11,095 responders in the New York/New Jersey regional clinical consortium and 645 elsewhere between 16 July 2002 and 16 April 2004. In the New York/New Jersey consortium, 9,442 of these responders provided appropriate consent to be included in this report.

Demographics. The responders screened in this program were predominantly male (87%) and white (66%), with a median age of 42 years (range, 18–82 years) (Table 1). More than 92% lived in the tristate (New York, New Jersey, Connecticut) area, 54% from New York City and 15% on Long Island; 86% were union members; 34% were construction workers; and 29% worked in law enforcement. We conducted > 14% of the examinations in languages other than English.

Time of arrival and location. Of the > 40% of the responders who first arrived for work at the site on September 11, 49% reported having been engulfed in the building-collapse dust cloud (Table 1). Another 30% first arrived on 12 or 13 September. Irrespective of date of arrival, 35% of responders began working on the pile or in the pit at Ground Zero; another 55% worked adjacent to the pile; and the remaining 10% worked at other sites. The reported average duration of exposure (the time between the first and last days of work on the WTC effort) was 171 days (range, 1 day to ≥ 2.5 years). The average time between first work day and the MSP examination was 20 months.

Symptoms. Most of the 9,442 responders examined reported being asymptomatic in the year prior to September 11 for lower respiratory tract symptoms (85%), and a large majority (66%) were asymptomatic for upper respiratory tract symptoms (Table 2). In the previously asymptomatic group, 44% reported developing lower respiratory symptoms and 55% developed upper respiratory symptoms while engaged in WTC-related work. These new symptoms were persistent in many; at the time of exam, 32% reported current lower respiratory symptoms and 44% reported current upper respiratory symptoms (Table 2). Fully 69% of all responders reported having had at least one worsened or newly incident respiratory symptom while performing WTC response work (63% upper airway and 47% lower airway symptoms, with overlap between the groups) (Table 3). Respiratory symptoms persisted to the time of examination in 59% of the population.

Early arrival at the WTC site was significantly associated with an increased reported prevalence of both newly incident and worsened respiratory symptoms (Table 3). We observed the highest prevalence among those who arrived on September 11 and were exposed to the dust cloud (54% lower respiratory and 66% upper respiratory symptoms). Those who began work on September 11 but who were not directly exposed to the dust cloud had the next highest prevalence (47% lower respiratory and 62% upper respiratory

Table 1. Demographic and exposure characteristics of the WTC MSP study population (n = 9,442).

	No. (%)
Sex	
Male	8,186 (86.7)
Female	1,256 (13.3)
Race	
White	6,203 (65.7)
Black	1,060 (11.2)
Asian	121 (1.3)
Other	253 (2.7)
Unknown	1,805 (19.1)
Hispanic ethnicity	
Yes	2,249 (23.8)
Language of exam	
English	8,114 (85.9)
Spanish	984 (10.4)
Polish	311 (3.3)
Other	33 (0.3)
Union member	
Yes	8,075 (86.0)
Union/organization affiliation	
Construction	3,209 (34.0)
Law enforcement	2,776 (29.4)
Public sector (blue collar)	739 (7.8)
Technical and utilities	683 (7.2)
Transportation	516 (5.5)
Cleaning/maintenance	258 (2.7)
Volunteers	245 (2.6)
Firefighters[a]	138 (1.5)
Health care	83 (0.9)
News agencies	81 (0.9)
Office/administration/professional	50 (0.5)
Other	664 (7.0)
Time first began WTC-related work	
11 September 2001	3,812 (40.5)
In dust cloud	1,878 (20.0)
Not in dust cloud	1,934 (20.5)
12–13 September 2001	2,801 (29.8)
14–30 September 2001	2,133 (22.7)
On or after 1 October 2001	666 (7.1)
Location of majority of work	
On the pile/in the pit	3,215 (34.8)
Adjacent to pile/pit	5,074 (54.8)
Landfill	313 (3.4)
Barges/loading pier	106 (1.1)
OCME	77 (0.8)
Elsewhere south of Canal St.	466 (5.0)

[a]Does not include active-duty New York City firefighters.

symptoms). We found a continuing statistically significant downward trend (although the prevalence remained high) in the incidence of reported symptoms for later arrival dates. Even those responders who arrived at the site on or after 1 October had a 41% prevalence of lower respiratory and a 59% prevalence of upper respiratory symptoms, nearly three times the percentage who had reported lower respiratory symptoms in the year prior to September 11, and nearly twice of the percentage who reported prior upper respiratory symptoms.

Of the 8,384 participants with acceptable quality pulmonary function exams, 28% had abnormal prebronchodilator spirometry results (Table 4). A low FVC was the most common abnormality (21%), whereas obstruction occurred in 5% and a mixed pattern (obstruction and low FVC) in 2%. We also documented a significant response to bronchodilator in 910 (11%) of participants including 33% of those with obstruction, 56% with a mixed pattern, and 18% of those with a low FVC.

Compared with a U.S. general population sample of employed, adult, white males (Mannino et al. 2003), the 4,641 participants who had never smoked had a higher prevalence of abnormalities on spirometry (27% vs. 13%). The difference was mainly attributable to a higher prevalence of tests with a low FVC (20% vs. 4%).

We observed a statistically significant association between time of arrival and low FVC, with a higher prevalence of abnormality in those who arrived earlier (Table 5). There was no significant difference in the prevalence of obstruction based on onset of exposure.

Thirty-one percent of the sample reported having received medical care for WTC-related respiratory conditions. A total of 17% of examinees reported missing work because of WTC-related health problems. Of the 1,973 workers with a self-reported diagnosis of sinusitis, 40% were seen by a doctor for this condition during the 6 months after September 11, compared to only 13% in the 6 months before September 11. Similar increases were reported in the numbers of responders who sought medical help for acute bronchitis (45% vs. 18%) and pneumonia (10% vs. 1%).

Discussion

Two principal lessons emerge from our experiences with the WTC MSP. First, the prevalence rates of respiratory and other symptoms, and the prevalence of pulmonary function abnormalities in the nearly 10,000 WTC workers and volunteers whom we examined clinically between 2002 and 2004 were very high, and they are persistent. Health effects were most frequent in responders who sustained the most intense exposures. In the aftermath of future civil disasters, hospitals and health care providers will need to anticipate and prepare for the severe health consequences that inevitably result from the extreme exposures sustained by workers in these situations.

Second, in the event of future disasters, it is likely that existing health care facilities and public health programs will not be sufficiently robust or flexible to deal with the special needs and complex health problems sustained by responders and victims. It will likely be necessary to establish large, multicenter medical follow-up programs such as were needed in New York. The more rapidly such programs can be established and funded, the more quickly essential services will be provided (Rosner and Markowitz 2006).

Abnormal spirometry was still evident in almost one-third of all WTC workers and volunteers 1–2.5 years after 11 September 2001. The most common spirometric abnormality seen was a low FVC, which had also been found in the first 1,138 participants from this group (Levin et al. 2004). Low FVC was about 5 times more prevalent among nonsmokers than expected in the general U.S. population, based on NHANES III data (Mannino et al. 2003). Prevalence of low

Table 2. Prevalence of lower and upper respiratory symptoms among the WTC MSP study population (n = 9,442).

		Did not report symptoms in year before September 11	
	Reported symptoms in year before September 11 [no. (%)]	New symptoms while working at WTC site [no. (%)]	Symptoms still present in month before exam [no. (%)]
Lower respiratory symptoms			
Dry cough	362 (3.9)	2,541 (28.3)	1,534 (17.1)
Cough with phlegm	325 (3.5)	1,183 (13.1)	742 (8.2)
Shortness of breath	344 (3.7)	1,477 (16.5)	1,266 (14.1)
Wheeze	557 (6.0)	1,232 (14.1)	749 (8.6)
Chest tightness	464 (5.1)	1,258 (14.6)	933 (10.8)
Any lower respiratory symptom	1,451 (15.4)	3,486 (43.8)	2,535 (31.9)
Upper respiratory symptoms			
Sinus-related[a]	2,169 (23.1)	2,219 (30.7)	1,863 (25.8)
Nasal-related[b]	1,967 (20.9)	3,254 (43.8)	2,536 (34.1)
Throat-related[c]	887 (9.4)	3,579 (42.0)	2,450 (28.8)
Any upper respiratory symptom	3,148 (33.5)	3,453 (55.2)	2,772 (44.3)
Any respiratory symptom	3,767 (40.0)	3,443 (61.0)	2,846 (50.4)

[a]Facial pain or pressure, head or sinus congestion, or postnasal discharge. [b]Blowing your nose more than usual, stuffy nose, sneezing, runny nose, or irritation in nose. [c]Throat irritation, hoarseness, sore throat, or losing your voice (laryngitis).

Table 3. Prevalence of new or worsened respiratory symptoms among WTC workers by date of arrival for work at WTC site and by exposure to the dust cloud (n = 9,442).

		Arrived on 11 September		Arrived	Arrived	Arrived on or	
	All responders (n = 9,442) [no. (%)]	In dust cloud (n = 1,878) [no. (%)]	Not in dust cloud (n = 1,934) [no. (%)]	12–13 September (n = 2,801) [no. (%)]	14–30 September (n = 2,133) [no. (%)]	after 1 October (n= 666) [no. (%)]	Trend test p-value[a]
Lower respiratory symptoms							
Dry cough	2,688 (28.7)	640 (34.2)	587 (30.6)	777 (28.0)	538 (25.5)	140 (21.3)	< 0.001
Cough with phlegm	1,320 (14.1)	328 (17.6)	256 (13.4)	373 (13.5)	275 (13.0)	84 (12.7)	< 0.001
Shortness of breath	1,613 (17.3)	390 (20.9)	298 (15.6)	471 (17.1)	339 (16.1)	109 (16.6)	0.001
Wheeze	1,408 (15.1)	339 (18.3)	296 (15.5)	403 (14.6)	281 (13.4)	85 (13.0)	< 0.001
Chest tightness	1,393 (15.4)	334 (18.5)	268 (14.4)	384 (14.3)	311 (15.2)	91 (14.1)	0.003
Any lower respiratory symptom	4,371 (46.5)	1,017 (54.2)	912 (47.2)	1,232 (44.2)	930 (43.8)	271 (40.8)	< 0.001
Upper respiratory symptoms							
Sinus-related[b]	510 (37.3)	785 (41.9)	712 (36.9)	1,020 (36.6)	783 (37.0)	200 (30.1)	< 0.001
Nasal-related[c]	4,552 (48.4)	982 (52.4)	939 (48.6)	1,334 (47.9)	981 (46.3)	300 (45.1)	< 0.001
Throat-related[d]	4,128 (43.9)	885 (47.2)	847 (43.9)	1,199 (43.1)	923 (43.6)	264 (39.7)	0.001
Any upper respiratory symptom	5,883 (62.5)	1,233 (65.8)	1,205 (62.4)	1,719 (61.7)	1,316 (62.1)	394 (59.2)	0.001
Any respiratory symptom	6,479 (68.8)	1,376 (73.4)	1,345 (69.7)	1,878 (67.3)	1,435 (67.7)	429 (64.5)	< 0.001

[a]One-sided p-values using the Cochran-Armitage trend test. [b]Facial pain or pressure, head or sinus congestion, or postnasal discharge. [c]Blowing your nose more than usual, stuffy nose, sneezing, runny nose, or irritation in nose. [d]Throat irritation, hoarseness, sore throat, or losing your voice (laryngitis).

FVC was higher in responders who arrived at the disaster site closer to the time of the collapse of the twin towers than in those who arrived on or after 1 October.

There are several possible explanations for the high rates of low FVC observed in this group: *a*) true restriction due to parenchymal lung disease (e.g., interstitial lung diseases such as sarcoidosis, idiopathic pulmonary fibrosis, pneumoconiosis); *b*) true restriction due to physical factors such as obesity or chest wall abnormalities; *c*) "pseudorestriction" due to air trapping (e.g., airways obstruction) or submaximal inspiratory and/or expiratory effort (typically the result of chest pain/tightness or in an attempt to reduce coughing during the test); or *d*) our selection of the reference value used to define the lower limit of the normal range for FVC.

It is likely that, in some responders, the observed increase in low FVC is due to air trapping in the lungs, possibly due to inhalation of caustic dust and airborne pollutants in the course of their WTC work. A finding that supports this explanation is our observation of an increase in FVC after administration of a bronchodilator, seen in 18% of WTC workers and volunteers with this pattern.

Another possible explanation for our observed abnormalities in pulmonary function is our choice for the lower reference limit of the normal range for FVC. In our analysis we chose to use the Hankinson pulmonary reference values derived from NHANES III (Hankinson et al. 1999), because we considered them to be most appropriate for an ethnically diverse population such as this workforce. In previous studies of workers, several spirometry reference equations other than those from NHANES III have been used (Crapo et al. 1981; Knudson et al. 1983; Miller et al. 1983; Morris et al. 1973). Although the mean predicted values calculated from these five studies are very similar for whites, differences in the lower limits of the normal range provide large differences in spirometry abnormality rates when testing large, ethnically diverse groups of workers. For example, when using the equations from Crapo et al. (1981), substantially higher rates of obstruction but lower rates of spirometric restriction (low FVC) were found in whites in our cohort. It is also possible that some responders have developed true restrictive lung disease due to their WTC-related exposures. We anticipate that these issues will become clearer with continuing prospective follow-up of this cohort.

The MSP faced many challenges, and similar challenges are likely to arise in future major civil disasters. We faced organizational challenges in coordinating work at five clinical sites in the New York/New Jersey metropolitan area, as well as in the national program. There was no systematic roster of responders. We found that a broad and vigorous outreach program to systematically identify responders and persuade them of the importance of undergoing examination was essential. Most of these workers, many of whom had volunteered their services after September 11, were unable to take paid time off to be screened, and many were not in the position to forfeit a day's wages. We needed to schedule the examinations at times and in locations that respected those difficulties. The examination content needed to be relevant and acceptable to the responders and at the same time sufficiently standardized to permit interpretation of aggregated clinical data. Translation was one of the more challenging aspects of program coordination. More than 14% of responders required non-English examinations and written materials.

The need for follow-up medical treatment and for provision of social benefits in the event of future civil disasters must be anticipated, and federal funds must be provided early on to support such programs. There was substantial social and economic disruption to the lives of many of the responders, and benefits counseling became an urgent need and an integrated component of the MSP. Many responders needed follow-up treatment for physical or mental health illnesses, and many lacked health insurance. We were obliged to secure private funding from philanthropic organizations to develop and implement treatment programs for responders. Federal funding for treatment of these workers is anticipated to begin in fall 2006.

Several limitations in these data should be noted. We do not have pre-September 11 clinical information on our cohort. It may be that responders who were sicker were more likely to participate, leading to an overestimation of risk. Conversely, we may be underestimating risk because most responders were likely to have been fit workers (healthy worker effect). In this article we do not consider the psychological consequences, which we already know to be serious (Smith et al. 2004). Subsequent papers will address responder mental health.

Conclusions

The workers and volunteers who served New York City and the nation through their heroic service in the aftermath of September 11 need continuing medical surveillance and follow-up, especially because some diseases, such as cancer, are of long latency. Malignant mesothelioma resulting from exposure to asbestos, for example, may not become evident for 30–50 years. These biological facts plus the magnitude and complexity of the exposures indicate that WTC responders should be monitored for at least 20–30 years,

Table 4. Spirometry results (prebronchodilator) among the WTC MSP study population (n = 8,384).[a]

	National population[b]	WTC MSP population			
	Never smoker (%)	Never smoker [no. (%)]	Former smoker [no. (%)]	Current smoker [no. (%)]	All [no. (%)]
Normal	87.1	3,396 (73.2)	1,541 (72.8)	1,047 (67.1)	6,031 (71.9)
Obstruction[c]	8.0	237 (5.1)	97 (4.6)	114 (7.3)	451 (5.4)
Low FVC[d]	4.4	940 (20.3)	431 (20.3)	336 (21.5)	1,721 (20.5)
Obstruction and low FVC[e]	0.6	68 (1.5)	49 (2.3)	63 (4.0)	181 (2.2)
Total	NA	4,641 (55.4)	2,118 (25.3)	1,560 (18.6)	8,384 (100.0)

NA, not applicable.
[a]Only acceptable quality spirometric examinations are included, as described by Miller et al. (2005). [b]General U.S. population sample of employed, adult, white males 17–69 years of age who never smoked (Mannino et al. 2003; NHANES III). [c]FEV_1/FVC ratio less than 5th percentile of predicted value and normal FVC. [d]FVC less than 5th percentile of predicted value and a normal FEV_1/FVC ratio. [e]FEV_1/FVC ratio less than 5th percentile of predicted value and FVC less than 5th percentile of predicted value.

Table 5. Spirometry results (prebronchodilator) by date of arrival for work at WTC site and exposure to the dust cloud among the WTC MSP study population (n = 8,384).[a]

	Arrived on 11 September		Arrived	Arrived	Arrived on or	
	In dust cloud [no. (%)]	Not in dust cloud [no. (%)]	12–13 September [no. (%)]	14–30 September [no. (%)]	after 1 October [no. (%)]	Trend test p-value[b]
Normal	1,160 (68.5)	1,222 (69.9)	1,781 (71.6)	1,397 (75.3)	453 (78.6)	—
Obstructive[c]	81 (4.8)	96 (5.5)	140 (5.6)	104 (5.6)	28 (4.9)	0.418
Low FVC[d]	408 (24.1)	400 (22.9)	506 (20.3)	318 (17.1)	84 (14.6)	< 0.001
Obstruction and low FVC[e]	44 (2.6)	29 (1.7)	61 (2.5)	36 (1.9)	11 (1.9)	0.095

[a]Only acceptable quality spirometric examinations are included, as described by Miller et al. (2005). [b]One-sided p-values using the Cochran-Armitage trend test. [c]FEV_1/FVC ratio less than 5th percentile of predicted value and normal FVC. [d]FVC less than 5th percentile of predicted value and a normal FEV_1/FVC ratio. [e]FEV_1/FVC ratio less than 5th percentile of predicted value and FVC less than 5th percentile of predicted value.

so that long-term effects are detected early, when treatment would be most beneficial.

Federal leadership is needed to bring together a wide range of civilian and military experts to prepare for the complex physical and mental health issues and the environmental issues certain to arise in future disasters. Future disaster response must incorporate rapid establishment of both diagnostic and treatment programs, and state and federal leadership must make a firm commitment for the long-term follow up of exposed workers. Finally, there is a need to ensure strong and active participation by worker representatives and local citizens. Their local knowledge is unique, and it will not become available to state and federal planners unless these vital stakeholders are invited to take an active role in the planning and implementation of responses to future disasters.

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ORIGINAL CONTRIBUTIONS

Upper Respiratory Symptoms and Other Health Effects among Residents Living Near the World Trade Center Site after September 11, 2001

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The authors investigated changes in respiratory health after September 11, 2001 (“9/11”) among residents of the area near the World Trade Center (WTC) site in New York City as compared with residents of a control area. In 2002, self-administered questionnaires requesting information on the presence and persistence of respiratory symptoms, unplanned medical visits, and medication use were sent to 9,200 households (22.3% responded) within 1.5 km of the WTC site (affected area) and approximately 1,000 residences (23.3% responded) in Upper Manhattan, more than 9 km from the site (control area). Residents of the affected area reported higher rates of new-onset upper respiratory symptoms after 9/11 (cumulative incidence ratio = 2.22, 95% confidence interval (CI): 1.88, 2.63). Most of these symptoms persisted 1 year after 9/11 in the affected area. Previously healthy residents of the affected area had more respiratory-related unplanned medical visits (prevalence ratio = 1.73, 95% CI: 1.13, 2.64) and more new medication use (prevalence ratio = 2.89, 95% CI: 1.75, 4.76) after 9/11. Greater impacts on respiratory functional limitations were also found in the affected area. Although bias may have contributed to these increases, other analyses of WTC-related pollutants support their biologic plausibility. Further analyses are needed to examine whether these increases were related to environmental exposures and to monitor long-term health effects.

asthma; environmental pollution; New York City; respiratory tract diseases; terrorism

Abbreviations: CI, confidence interval; CIR, cumulative incidence ratio; WTC, World Trade Center.

Editor's note: *An invited commentary on this article appears on page 508, and the authors' response appears on page 511.*

The destruction of the World Trade Center (WTC) on September 11, 2001 (“9/11”) resulted in the release of large amounts of pollutants into the surrounding areas. These

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pollutants included particulate matter, asbestos, metals, and organic compounds (1). Initially, smoke and debris came from the fires that erupted when the planes struck the buildings, followed by the release of airborne dust and debris from the collapse of the buildings. Subsequently, the fires that burned at the site for several months and clean-up activities released particulates. In many cases, dust from the collapse infiltrated homes and apartments at a depth of up to several inches (2). As people returned to their residences, settled dust was redispersed into the air.

One of the immediate public health concerns was the effect of this intensive exposure to these air pollutants on the health of local residents. Analyses of settled dust samples collected 5–6 days after the disaster indicated that 1–4 percent by weight were particles that can be inhaled deeply into the lungs (3) and are associated with respiratory diseases. Adverse health effects could have arisen from both acute high-level exposures and prolonged low-level exposures. Moreover, it is unknown whether the adverse respiratory effects, if they existed, were transient or persistent. Studies of asthmatic Lower Manhattan residents found worse symptoms and increases in medical care utilization and asthma medication prescriptions after 9/11 (4, 5). To our knowledge, these studies of persons with asthma are the only published studies of the respiratory health of residents near the site of the former WTC (''Ground Zero''). The pollution from the WTC disaster may have also caused new disease among previously healthy residents of New York City. Additionally, local residents complained about upper respiratory and other symptoms consistent with exposure to irritants. Since there are large residential communities around Ground Zero, the potential for respiratory health effects from exposure to these agents deserves investigation.

The goals of the present study included 1) determining whether there was an increase in the incidence of new-onset and persistent upper and lower respiratory symptoms in residents living near Ground Zero as compared with residents of a control area and 2) investigating whether there was an increase in symptom exacerbation among asthmatic residents living near Ground Zero as compared with a control area. Additionally, subgroups of residents with new-onset persistent symptoms and asymptomatic persons were identified and followed for assessment of chronic respiratory health effects, including symptom persistence and physiologic abnormalities as measured by spirometry. In this paper, we discuss the results pertaining to upper respiratory symptoms.

MATERIALS AND METHODS

Study design and study population

This retrospective cohort study was started 8 months after 9/11 (May 2002). The cumulative incidence of reported new-onset and persistent new-onset upper respiratory tract symptoms and unplanned medical visits/medication use among residents living near Ground Zero (the affected area) was compared with the incidence in a control population. Potential study buildings were selected so as to include major population areas below Canal Street in Lower Manhattan. These buildings were then stratified by housing characteristics (e.g., low- or high-income rentals, cooperatives or condominiums, public housing complexes) and selected to include a range of these characteristics. Finally, 2000 US Census data were examined to ensure that the final study buildings were representative of the range of socioeconomic characteristics present in the underlying population of Lower Manhattan.

The area defined as the affected area is located within 1.5 km of the former WTC site and includes 49 buildings in Lower Manhattan with approximately 9,200 households. A control area was used for comparison, because the health histories of residents living near the WTC prior to 9/11 were not available and respiratory diseases usually have a strong seasonal component. The prevailing wind direction was considered in selecting the control area. Therefore, areas south, east, and west of the WTC that were impacted by the plume, including Brooklyn, New Jersey, and Staten Island, were excluded from the control area. Efforts were made to identify control buildings in census blocks with similar characteristics as the affected area. The control area consisted of approximately 1,000 households in five Upper Manhattan apartment buildings more than 9 km from the WTC site. To obtain a large, representative sample in the affected area, we oversampled the population of the affected area at a 9:1 ratio (affected area:control area). Figure 1 shows the study areas and the prevailing wind directions at John F. Kennedy International Airport for September 11–30, 2001.

All residents of the identified affected and control buildings were eligible to participate in the study. Up to four residents in each household were asked to complete the questionnaire. To eliminate confounding effects due to residential mobility and to minimize potential misclassification due to occupational exposure, we excluded persons meeting any of the following criteria: 1) born after 9/11; 2) temporarily moved out of the residence after 9/11 and returned on or after January 1, 2002; 3) did not reside at the current address on 9/11; or 4) lived in the control area but worked in the affected area.

Study materials and procedures

A study packet containing a cover letter, consent forms, questionnaires, and a stamped, addressed envelope was mailed to all apartments in the study buildings. The study packets also contained information about Project Liberty (a federally sponsored program providing free crisis counseling services to those affected by the WTC disaster) for persons who experienced anxiety while reviewing the materials. To accommodate the needs of the large populations of non-English speakers in the study areas, translations of the study materials were available for Spanish- and Chinese-speaking residents.

The questionnaires included a household questionnaire and four individual questionnaires. An adult resident was asked to complete the household questionnaire by providing information on the age, gender, and asthma status of all household members. The household questionnaire also asked about the condition of the apartment immediately after 9/11, the duration and frequency of odors or dust in the apartment, and any cleaning, sampling, or inspections that were performed.

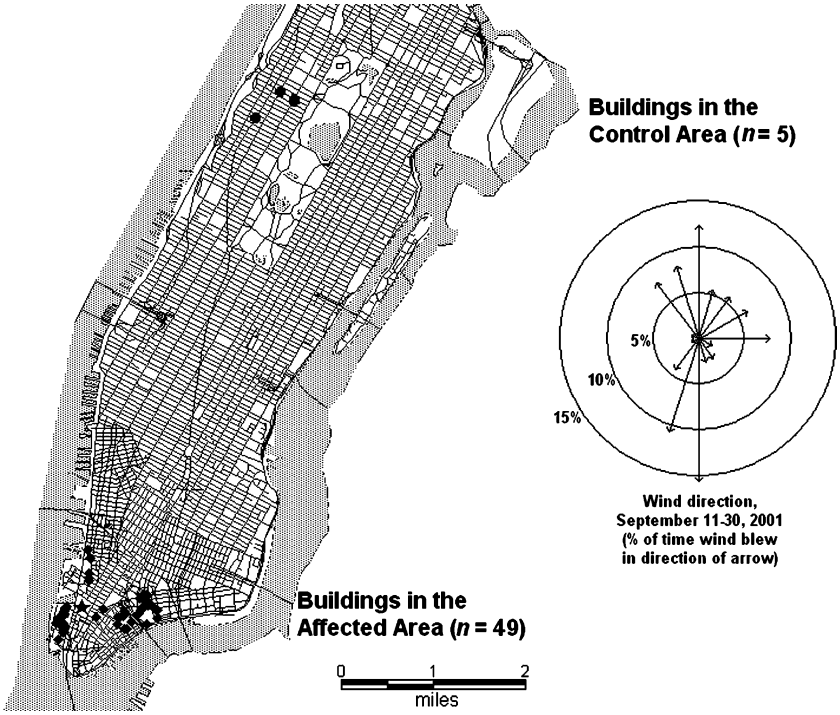

FIGURE 1. Locations of study buildings in the affected and control areas, World Trade Center Health Survey, New York City, 2002. (1 mile = 1.61 km).

In households with more than four persons, two adult residents and the two oldest residents under age 18 years were asked to complete the individual questionnaire. For children younger than age 12, a parent or legal guardian completed the questionnaire. The individual questionnaire was primarily designed to estimate the prevalence and incidence of asthma and respiratory symptoms. This questionnaire was derived from the International Union Against Tuberculosis and Lung Diseases questionnaire and the International Study of Asthma and Allergies in Childhood questionnaire, both of which have been validated and used in epidemiologic studies to detect symptoms associated with asthma and bronchial hyperresponsiveness (6–9).

For questions about upper and lower respiratory symptoms and irritation symptoms, the resident was asked whether the problem had occurred in the past 12 months, whether it started after 9/11, whether it worsened after 9/11, and, depending on the type of symptom, either the average frequency or the perceived severity of the symptom during the past 4 weeks. Additional questions assessed unplanned medical visits (outpatient visits, emergency department visits, and hospitalizations), physician diagnoses of asthma and other respiratory disorders, use of asthma medication, and respiratory functional status. The questionnaire also included questions related to sociodemographic factors, smoking history, temporary residence changes after 9/11, and employment location. After receipt of a completed questionnaire, a Metro Card with a value of $6 was mailed to the participant to acknowledge participation.

The study packets were initially distributed 1 year after 9/11 (±4 months) via bulk mail. Because of inconsistencies in the handling of this material, additional deliveries were made to each residence by hand. Where access could not be gained to make hand deliveries, the packets were left in building lobbies. Finally, in addition to the bulk mailing, a first-class mailing of the packets was made to all households, followed by a reminder postcard. After distribution of the packets, field-workers spent time in the buildings to encourage participation, provide additional copies of the study materials, and answer questions. The days and times of these outreach activities were varied to maximize the numbers and types of persons encountered. Posters advertising the study were placed in and around the buildings. Further publicity about the study was generated through notices in local newspapers and building newsletters, as well as by staff in attendance at meetings of community boards and tenant organizations and local health fairs. To estimate potential selection bias, we selected one building in the affected area (440 apartments) and two buildings in the control area (240 apartments) to receive additional outreach. These intensive outreach activities included additional mailings, advertisements, and time spent in the buildings by field-workers.

Outcome definitions

Health outcomes were defined on the basis of reported respiratory symptoms, unplanned medical visits, physician diagnoses, medication use, respiratory functional limitation, and

the time period in which symptoms occurred. ''New-onset'' symptoms were defined as upper respiratory symptoms that began after 9/11. A ''persistent new-onset'' symptom was a new-onset symptom that had bothered the respondent ''some'' or ''a lot'' in the 4 weeks prior to completing the survey.

Statistical analysis

Because of variations in the number of persons residing in each apartment and the lack of information about the number of persons in nonresponding households, the response rate was calculated using the number of responding households as a numerator. Packets that were returned marked ''vacant'' were omitted from this calculation.

The demographic characteristics of participants in the affected and control areas were compared using the χ^2 test. For new-onset respiratory health outcomes, we computed cumulative incidence by dividing the number of participants with a new-onset outcome after 9/11 by the total number of participants. However, the denominators for unplanned medical visits, new diagnoses of asthma, and medication use were based on the subgroup of participants who were ''previously healthy'' (i.e., free of a physician's diagnosis of asthma, emphysema, chronic obstructive pulmonary disease, and chronic bronchitis prior to 9/11). Cumulative incidence ratios (CIRs) comparing the affected and control areas were computed, and 95 percent confidence intervals were used to estimate the precision of the CIRs. For respiratory functional status (before and after 9/11), prevalence rates (the number of persons in a disease status category divided by the total number of participants in each area) and prevalence ratios and their 95 percent confidence intervals were computed. Finally, the χ^2 test was used to compare data for the self-described breathing statements.

Unconditional logistic regression analysis was used to compute adjusted odds ratios while controlling for potential confounders, including age, gender, education, race, and smoking. Education was used as a surrogate for socioeconomic status, because information about education was more complete (11 percent missing data) than information for income (25.3 percent missing data), and education and income were highly correlated. Because respiratory diseases are not rare events, adjusted odds ratios from logistic regression tend to consistently overestimate the CIRs. Therefore, the crude CIRs and 95 percent confidence intervals are presented in the tables, and adjusted results were used only to determine whether the results were still statistically significant after controlling for confounders.

RESULTS

A total of 9,168 survey packets were sent to residences in the affected area, and 962 packets were sent to residences in the control area. After exclusion of apartments that were definitely vacant, household response rates were 22.3 percent in the affected area and 23.3 percent in the control area. Among the buildings targeted for increased outreach, the response rates were 43.8 percent and 40.3 percent in the affected and control areas, respectively. A total of 553 respondents (17.3 percent) were excluded from the analysis on the basis of the four criteria described in Materials and Methods, giving us a total of 2,362 participants in the affected area and 291 in the control area.

TABLE 1. Demographic characteristics (%) of residents of the affected area ($n = 2,362$) and the control area ($n = 291$), World Trade Center Health Survey, New York City, 2002

Characteristic	Affected area	Control area	p value (χ^2 test)
Gender			0.35
Male	38.0	41.0	
Female	62.0	59.0	
Age (years)			<0.0001
0–34	23.4	23.8	
35–64	51.0	35.3	
≥65	25.6	40.9	
Annual household income			<0.0001
<$24,999	34.7	19.9	
$25,000–$49,999	18.8	19.9	
$50,000–$99,999	23.6	30.5	
≥$100,000	22.9	29.6	
Race/ethnicity*			
Hispanic	14.1	7.6	0.003
Asian	16.3	3.3	<0.0001
African-American	8.4	11.6	0.08
White	61.0	79.4	<0.0001
Other	4.8	4.7	0.95
Education			0.0002
Not a high school graduate	20.3	11.0	

* Race/ethnicity groups were not mutually exclusive; therefore, percentages do not add up to 100%. For calculation of p values, instead of an overall χ^2 test, paired χ^2 tests were performed for each race/ethnicity group versus the other groups combined.

Although we attempted to make the residents of affected and control areas demographically comparable, differences remained. The affected area had distributions of age and household income that were significantly different from those of the comparison area (table 1). In paired χ^2 tests, there were significantly higher proportions of Hispanics, Asians, and residents with less education (i.e., not high school graduates) but lower proportions of African Americans and Caucasians from the affected area as compared with the control area. In general, these demographic differences are similar to differences in the underlying populations according to 2000 US Census data. Since low socioeconomic status is associated with asthma, these variables were considered potential confounders and were controlled for in the multivariate analyses.

Table 2 describes the relation between residence in the affected area and upper respiratory and irritation symptoms. Rates of all new-onset symptoms were significantly higher in the affected area after we controlled for potential confounders (CIRs were 3.00–4.23). Residents of the affected area reported a significantly higher rate of at least one of

TABLE 2. Incidence of upper respiratory symptoms after September 1, 2001, and associated cumulative incidence ratios among residents of the affected area ($n = 2,362$) versus the control area ($n = 291$), World Trade Center Health Survey, New York City, 2002

Symptom(s)	New-onset				New-onset persistent			
	No.	%	CIR*	95% CI*	No.	%	CIR	95% CI
Eye irritation or burning	1,143	52.9	3.22	2.45, 4.25†	501	21.2	3.43	2.18, 5.40†
Nose irritation or burning	896	41.3	4.23	2.92, 6.11†	432	18.3	3.80	2.26, 6.38†
Nasal congestion	864	40.7	3.12	2.26, 4.31†	486	20.6	4.28	2.55, 7.17†
Hoarse throat or other throat irritation	1,142	53.1	3.41	2.56, 4.55†	543	23.0	3.34	2.18, 5.14†
Sinus congestion	719	34.2	3.11	2.18, 4.44†	425	18.0	4.76	2.65, 8.55†
Nose bleeding	310	13.7	3.47	1.92, 6.24†	101	4.3	2.49	1.02, 6.06
Recurring headaches	720	33.3	3.00	2.12, 4.26†	449	19.0	5.03	2.80, 9.03†
One or more of the above symptoms	1,696	71.8	2.22	1.88, 2.63†	1,031	43.7	3.02	2.28, 4.02†

* CIR, cumulative incidence ratio; CI, confidence interval.

† The effect was still statistically significant ($p < 0.05$) after adjustment for age, gender, education, race, and smoking.

these new-onset symptoms (71.8 percent) than did controls (32.3 percent), an increase of 121 percent (CIR = 2.22, 95 percent confidence interval (CI): 1.88, 2.63). Furthermore, the persistence of these new-onset symptoms was significantly higher in the affected area. CIRs ranged from 2.49 to 5.03, with the highest CIRs being for congestion symptoms and recurring headaches. Affected-area residents also reported a significantly higher incidence of at least one persistent new-onset symptom (43.7 percent) than did controls (14.4 percent)—a 200 percent elevation (CIR = 3.02, 95 percent CI: 2.28, 4.02).

Data on medical visits and medication use after 9/11 among previously healthy participants are presented in table 3. The incidence of unplanned medical visits for respiratory problems was significantly increased in the affected area (14.5 percent) over the control area (8.4 percent; CIR = 1.73, 95 percent CI: 1.13, 2.64) after we controlled for potential confounders. A significantly higher proportion of affected-area residents started using respiratory medication after 9/11 (18.0 percent) in comparison with controls (6.2 percent) (CIR = 2.89, 95 percent CI: 1.75, 4.76). By examining medication use in the past 4 weeks as an indication of disease persistence, we found that affected-area residents reported significantly higher rates (15.1 percent) than controls (6.2 percent) (prevalence ratio = 2.44, 95 percent CI: 1.48, 4.02). In particular, use of fast-relief (9.7 percent) and controller (10.4 percent) asthma medications was significantly higher in the affected area. The rates of new diagnosis of asthma and use of more medication after 9/11 were not statistically significantly different between two areas.

We examined three indicators characterizing different degrees of shortness of breath with exertion before and after 9/11 (table 4). Before 9/11, data for all three indicators were similar in the two areas. However, after 9/11, these indicators pointed to greater increases in the degree of shortness of breath in the affected area (prevalence ratios were 1.51–1.83). When the participants were asked to describe their breathing in the past 4 weeks (data not shown), approximately 16 percent of respondents in the affected area reported that they had ''regular trouble with breathing, but it always got

TABLE 3. Incidence of medical consultations, asthma diagnoses, and use of respiratory medication after September 11, 2001, among previously healthy* residents of the affected area ($n = 2,362$) versus the control area ($n = 291$), World Trade Center Health Survey, New York City, 2002

	Affected area		Control area		Cumulative incidence ratio	95% confidence interval
	No.	%	No.	%		
Unplanned medical visit(s) for respiratory problems in past 12 months	286	14.5	21	8.4	1.73	1.13, 2.64†
Physician diagnosis of asthma after September 11	101	18.0	6	12.0	1.50	0.69, 3.24
Started using respiratory medication after September 11	340	18.0	15	6.2	2.89	1.75, 4.76†
Used more respiratory medication after September 11	62	3.3	3	1.3	2.64	0.83, 8.34
Used respiratory medication in past 4 weeks	285	15.1	15	6.2	2.44	1.48, 4.02†
Used fast-relief‡ asthma medicine in past 4 weeks	178	9.7	9	3.8	2.55	1.32, 4.91†
Used controller§ asthma medication in past 4 weeks	191	10.4	10	4.3	2.44	1.31, 4.55†

* No diagnosis of asthma, chronic obstructive pulmonary disease, chronic bronchitis, or other lung disease before September 11, 2001.

† The effect was still statistically significant ($p < 0.05$) after adjustment for age, gender, education, race, and smoking.

‡ Asthma medication that induces rapid bronchodilation of the airways.

§ Asthma medication that can either prevent inflammation or maintain bronchodilation.

TABLE 4. Self-reported prevalence of shortness of breath with varying levels of exertion before and after September 11, 2001, among residents of the affected area ($n = 2,362$) versus the control area ($n = 291$), World Trade Center Health Survey, New York City, 2002

Level of exertion	Affected area		Control area		Prevalence ratio	95% confidence interval
	No.	%	No.	%		
Shortness of breath when hurrying on level ground or walking up a slight hill						
Before September 11	541	26.1	61	24.0	1.09	0.86, 1.37
After September 11	1,075	53.8	71	32.0	1.68	1.38, 2.05*
Shortness of breath when walking with other people of one's own age on level ground						
Before September 11	325	15.9	38	14.8	1.08	0.79, 1.47
After September 11	730	38.6	47	21.1	1.83	1.41, 2.38*
Having to stop for breath when walking at one's own pace on level ground						
Before September 11	303	14.4	39	15.1	0.95	0.70, 1.30
After September 11	653	32.9	50	21.7	1.51	1.18, 1.95*

* The effect was still statistically significant ($p < 0.05$) after adjustment for age, gender, education, race, and smoking.

completely better'' as compared with 10 percent in the control area ($p < 0.05$). Furthermore, significantly more residents of the affected area reported that their ''breathing was never quite right'' (21 percent) as compared with residents of the control area (9 percent) ($p < 0.05$).

DISCUSSION

Respiratory outcomes

In the current study, we found that incidence rates of at least one new-onset upper respiratory symptom and all individual symptoms were significantly increased by 122 percent and over 200 percent, respectively, among affected-area residents. Additionally, almost half of residents in the affected area reported persistence of these symptoms, and the rate of persistent new-onset symptoms was increased by 200 percent. Prezant et al. (10) reported that among firefighters with high or moderate levels of exposure, 54 percent had nasal congestion and 41 percent had nasal drip after 9/11. Eighty-two percent of the firefighters who had high levels of exposure experienced sore throat after 9/11. Banauch et al. (11) reported persistence of symptoms and bronchial hyperreactivity among these firefighters 6 months after 9/11.

Among previously healthy residents in the affected area, we found a 73 percent increase in unplanned medical visits and a 189 percent increase in new medication use for respiratory problems after 9/11. Moreover, there was a 144 percent increase in the use of respiratory medication in the past 4 weeks, including use of fast-relief and controller medicines, among previously healthy affected-area residents. Additionally, the self-described respiratory functional status of affected-area residents was impacted more than that of control-area residents. Shortness of breath with varying levels of exertion was significantly higher in affected-area residents than in the controls. Self-reported descriptions of breathing during the past 4 weeks also indicated significantly higher levels of breathing trouble in the affected area. Szema et al. (5) found that visits to a health clinic for asthma and prescriptions for asthma medication both increased among pediatric asthma patients after 9/11. All of these findings suggest that residents near Ground Zero experienced a significant increase in respiratory diseases related to the WTC disaster and that these symptoms were still persistent in a significant portion of the residents after 1 year.

Our study was one of the earliest of the few studies to estimate the incidence of respiratory disease among residents of Lower Manhattan after 9/11. Both Fagan et al. (4) and Szema et al. (5) studied residents of Lower Manhattan; however, their populations were restricted to persons with asthma. Although residents near Ground Zero were probably not exposed to air pollution levels as high as those of the firefighters involved in WTC rescue, recovery, and clean-up activities, we have shown that residents of the affected area did report significantly more upper respiratory symptoms than residents of the control area.

Ambient air quality after 9/11

The New York City Department of Health and Mental Hygiene (12) measured the levels and composition of outdoor and indoor surface and airborne dust from November 4 to December 11, 2001, in residential areas near Ground Zero and in a comparison area. That study found a greater percentage of synthetic vitreous fibers, asbestos, quartz, calcite, portlandite, and gypsum in settled dust in Lower Manhattan than in the comparison area. The Environmental Protection Agency collected dust samples at various locations in the immediate vicinity of the WTC site 1–2 days after 9/11 (2). The WTC samples of particulate matter less than 2.5 μm in diameter were alkaline and composed primarily of calcium-based compounds such as calcium sulfate (gypsum) and calcium carbonate (calcite). Gypsum and calcite can irritate the mucus membranes of the eyes, nose, throat, and upper airways (13), and calcium carbonate dust can cause coughing, sneezing, and nasal irritation (14).

Although smoke or debris might have contributed to the increase in adverse respiratory health outcomes in this study, psychological stress might also have played an important role in these effects (15). In the current study, we could not determine whether environmental factors, psychological distress, or both contributed to the increase in respiratory symptoms, since psychological factors were not examined.

Strengths and limitations

This study is an important first step in identifying the acute and chronic respiratory health impact of the WTC disaster. Of the few studies that have investigated respiratory health among residents of Lower Manhattan after 9/11, it is one of the largest. This study responded to local residents by examining specific symptoms of concern to the community. The design and analysis used in this study allowed for the control for seasonal and socioeconomic confounding effects. In addition, the use of a cohort design allowed for examination of multiple health outcomes.

Although intensive outreach activities were implemented as described in Materials and Methods, we obtained low response rates. This may have been due to the emotional aftermath of the disaster—residents might not have been willing to answer questions that would provoke an emotional reaction. In addition, at the time of this study, the residents of Lower Manhattan were inundated with forms from government agencies and other organizations. The amount of information requested during this time was probably overwhelming. In addition, residents may have thought they had already completed a questionnaire when in fact they had not. New York City also has a history of lower response rates. The 2000 Census only recorded a final response rate of 55 percent in New York City, despite intense advertising and door-to-door follow-up. More importantly, a significant number of residents moved out of the affected area after 9/11. For this reason, if the denominator for calculating the household response rate was overestimated (despite attempts to identify vacant households), the actual response rate would have been underestimated.

The low response rates, although similar between the two study areas, may have introduced selection bias. That is, residents who experienced symptoms, especially those who lived in the affected area, might have been more likely to participate than those who did not. This could have caused the incidence of new-onset symptoms to be overestimated, particularly in the affected area. To minimize this bias, we emphasized the importance of participation for people with and without breathing problems during recruitment activities. In addition, general terms such as ''breathing or lung problems'' rather than specific terms like ''asthma'' were used.

To examine possible selection bias due to low response rates, we compared results for the buildings targeted for increased outreach and the nontargeted buildings. Results from the targeted buildings, in which higher response rates were achieved, are assumed to be more accurate and representative. If there was selection bias, we would expect to find a weaker exposure-disease association in the targeted buildings. Instead, we found that the risk estimates for new-onset and new-onset persistent symptoms were consistently higher in the targeted buildings than in the nontargeted buildings (see appendix table 1). These results suggest that any selection bias was in the opposite direction than we would have expected (i.e., the true association may have been underestimated).

Another potential problem with this study is reporting bias. Affected-area participants may have recalled or reported more symptoms than the controls. To prevent such reporting bias, we asked symptom questions not only qualitatively but also quantitatively, by including questions on specific time frames, severity, and frequency, which are less prone to recall bias. To estimate potential reporting bias, we compared rates of self-reported physical disability (which should not have been related to WTC exposures) between the affected area and the control area. The similar rates in the two areas (14.7 percent and 13.1 percent, respectively) indicate no significant reporting bias due to residence area. A participant responding affirmatively about every symptom may have been affected by recall bias ($n = 10$). Minimal changes were observed when these persons were excluded from the analysis. We believe recall of unplanned medical visits, including emergency department visits and hospitalizations, is more likely to be accurate than recall of symptoms, since such events are more likely to be memorable, and we solicited information on the reason for and exact month and year of the visit. Among respondents reporting a specific respiratory symptom, we compared the proportions who had unplanned medical visits. We found that the proportions were similar in the affected and control areas for most symptoms. If there was overreporting in the affected area, the proportion of persons reporting a specific symptom who also had unplanned medical visits should have been lower in the affected area than in the control area. Therefore, there is no clear evidence of reporting bias on the basis of our limited assessment. In general, reporting bias can be minimized by using objective indicators (e.g., medical records) rather than self-reported information. In this study, it was not feasible to review medical records. Additionally, an analysis of medical records would probably have underestimated or completely missed the less severe symptoms included in our survey.

One final area of concern is the possibility of exposure misclassification. As described above, we excluded persons with evidence of residential mobility and exposures unrelated to their area of residence in order to minimize this bias. However, an unidentified group of affected-area residents may have altered their behavior, spending less time at home in the aftermath of 9/11. Thus, their actual exposure may have been overestimated. On the other hand, it is also possible that control-area residents were impacted by the WTC plume in unforeseen ways.

Conclusion

This study suggests that residents who lived near Ground Zero on 9/11 reported significantly more upper respiratory and irritation symptoms, unplanned medical visits, and use of respiratory medications and decreased respiratory functional status after 9/11. In a significant portion of the residents, these symptoms persisted 1 year after 9/11. Although we cannot rule out the possibility that selection and

reporting bias may have contributed to these increases, chemical analyses of WTC-related pollutants by other researchers support the biologic plausibility of these findings. Further analyses are needed to examine whether increases in reported respiratory disease can be related to differences in exposure and to monitor the potential long-term health effects of the 9/11 disaster in this population.

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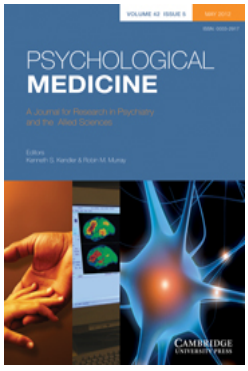
APPENDIX TABLE 1. Incidence of new-onset and persistent new-onset upper respiratory symptoms after September 11, 2001, among residents of the affected area versus the control area, by level of outreach (targeted areas and nontargeted areas), World Trade Center Health Survey, New York City, 2002

Symptom(s)	New-onset symptoms				Persistent new-onset symptoms			
	Targeted area		Nontargeted area		Targeted area		Nontargeted area	
	CIR*	95% CI*	CIR	95% CI	CIR	95% CI	CIR	95% CI
Eye irritation or burning	4.50	2.72, 7.45	2.76	1.99, 3.85	4.28	2.02, 9.10	3.22	1.81, 5.74
Nose irritation or burning	8.96	4.07, 19.73	3.19	2.11, 4.83	5.68	2.33, 13.82	3.35	1.76, 6.37
Nasal congestion	5.47	2.89, 10.38	2.50	1.72, 3.62	9.24	3.45, 24.69	3.32	1.81, 6.09
Hoarse throat or other throat irritation	4.62	2.81, 7.61	3.06	2.15, 4.36	4.22	2.19, 8.15	3.42	1.92, 6.08
Sinus congestion	6.42	3.09, 13.35	2.40	1.61, 3.59	6.53	2.70, 15.82	4.83	2.19, 10.65
Nose bleeding	10.56	2.60, 42.89	2.41	1.26, 4.59	5.09	1.20, 21.47	2.18	0.69, 6.81
Recurring headaches	5.19	2.73, 9.89	2.48	1.64, 3.75	8.16	3.04, 21.91	4.41	2.12, 9.16
One or more of the above symptoms	3.46	2.49, 4.82	1.83	1.51, 2.21	3.69	2.37, 5.74	3.01	2.07, 4.37

* CIR, cumulative incidence ratio; CI, confidence interval.



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ORIGINAL ARTICLE

Exposure, probable PTSD and lower respiratory illness among World Trade Center rescue, recovery and clean-up workers

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Background. Thousands of rescue and recovery workers descended on the World Trade Center (WTC) in the wake of the terrorist attack of September 11, 2001 (9/11). Recent studies show that respiratory illness and post-traumatic stress disorder (PTSD) are the hallmark health problems, but relationships between them are poorly understood. The current study examined this link and evaluated contributions of WTC exposures.

Method. Participants were 8508 police and 12 333 non-traditional responders examined at the WTC Medical Monitoring and Treatment Program (WTC-MMTP), a clinic network in the New York area established by the National Institute for Occupational Safety and Health (NIOSH). We used structural equation modeling (SEM) to explore patterns of association among exposures, other risk factors, probable WTC-related PTSD [based on the PTSD Checklist (PCL)], physician-assessed respiratory symptoms arising after 9/11 and present at examination, and abnormal pulmonary functioning defined by low forced vital capacity (FVC).

Results. Fewer police than non-traditional responders had probable PTSD (5.9% *v.* 23.0%) and respiratory symptoms (22.5% *v.* 28.4%), whereas pulmonary function was similar. PTSD and respiratory symptoms were moderately correlated ($r = 0.28$ for police and 0.27 for non-traditional responders). Exposure was more strongly associated with respiratory symptoms than with PTSD or lung function. The SEM model that best fit the data in both groups suggested that PTSD statistically mediated the association of exposure with respiratory symptoms.

Conclusions. Although longitudinal data are needed to confirm the mediation hypothesis, the link between PTSD and respiratory symptoms is noteworthy and calls for further investigation. The findings also support the value of integrated medical and psychiatric treatment for disaster responders.

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Key words: 9/11, disaster responders, exposure, mediate, post-traumatic stress disorder, respiratory conditions, risk factors, World Trade Center.

Introduction

The September 11, 2001 (9/11) terrorist attack on the World Trade Center (WTC) was an extraordinary environmental disaster with unprecedented physical hazards to rescue and recovery workers from the disintegrated structure and contents of the WTC buildings, the combustion of 90 000 liters of jet fuel from the hijacked planes, and the smoldering debris fire under the 'pile' (Gavett, 2003; McGee *et al*. 2003; Landrigan *et al*. 2004; Lioy & Georgopoulos, 2006). At the same time, responders were exposed to extreme trauma from the loss of colleagues and friends, witnessing

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death and destruction, handling dead bodies, body parts, fluids and personal effects, and inhaling the caustic odor of burning and decomposing bodies and debris.

As a consequence, respiratory ailments and post-traumatic stress disorder (PTSD) became the two persistent, signature health problems among WTC rescue, recovery and clean-up workers. Specifically, elevated rates of respiratory symptoms, asthma and abnormal lung function were reported from 3 months to 9 years later (Levin *et al*. 2002; Prezant *et al*. 2002; CDC, 2004; Herbstman *et al*. 2005; Tapp *et al*. 2005; Brackbill *et al*. 2006, 2009; Herbert *et al*. 2006; Wheeler *et al*. 2007; Aldrich *et al*. 2010; Niles *et al*. 2011; Wisnivesky *et al*. 2011). One year after the disaster, nearly half of the workers evaluated at the WTC Medical Monitoring and Treatment Program (WTC-MMTP) reported incident WTC-related upper (49.6%) and lower (39.5%) respiratory symptoms, and 31% of non-smokers had abnormal spirometry findings (CDC, 2004); by 9 years, the cumulative incidence of spirometric abnormalities was 41.8% (Wisnivesky *et al*. 2011). Being in the dust cloud with its airborne toxins and longer duration of time working at the site significantly elevated the risk of respiratory problems (e.g. Aldrich *et al*. 2010).

High rates of probable PTSD assessed with self-report measures such as the PTSD Checklist (PCL) have also been reported for responder cohorts (Perrin *et al*. 2007; Bills *et al*. 2008; Farfel *et al*. 2008; Stellman *et al*. 2008; Brackbill *et al*. 2009; Berninger *et al*. 2010; Niles *et al*. 2011; Wisnivesky *et al*. 2011). For example, a study of firefighters found annual rates for the first 4 years after 9/11 of about 10% per year (Berninger *et al*. 2010). Similarly, the rate for the WTC-MMTP cohort, assessed from 10 to 61 months after 9/11, was 11.1% (Stellman *et al*. 2008). Among responders in the WTC Health Registry, the rate of probable PTSD was three times higher in unaffiliated volunteers (21.2%) than in police (6.2%) (Perrin *et al*. 2007). Similar to respiratory symptoms, exposure to the dust cloud and longer duration of work were significant risk factors for PTSD (e.g. Brackbill *et al*. 2009).

Studies of combat veterans (Hoge *et al*. 2007), general population samples (Goodwin *et al*. 2003; Eaton, 2005; Scott *et al*. 2009; Spitzer *et al*. 2009; Von Korff *et al*. 2009) and primary care patients (Yellowlees & Kalucy, 1990; Üstün & Sartorius, 1995; Weisberg *et al*. 2002) have consistently found a strong relationship between physical and mental health in general, and between respiratory symptoms and PTSD specifically (e.g. Engel, 2004; Spitzer *et al*. 2009), including in two recent studies of WTC responders (Niles *et al*. 2011; Wisnivesky *et al*. 2011). There are at least three explanations for this link. First, the association between respiratory symptoms and PTSD symptoms may be coincidental, being the result of the same exposures contributing to both conditions. Second, PTSD is associated with immunologic dysregulation (McEwen & Stellar, 1993; Chrousos, 1995; Delahanty *et al*. 1997; Ironson *et al*. 1997; Boscarino & Chang, 1999; Schnurr & Jankowski, 1999), which may increase pulmonary inflammation and autonomic dysregulation resulting in respiratory abnormalities (Blechert *et al*. 2007). Furthermore, the cognitive and attentional processes associated with PTSD may increase perception and reporting of respiratory symptoms (Dales *et al*. 1989; Yellowlees & Kalucy, 1990; Üstün & Sartorius, 1995; Schnurr & Green, 2004; North *et al*. 2009). For these reasons, Spitzer *et al*. (2009) argued that PTSD can mediate the effects of trauma on chronic respiratory disease. Third, chronic respiratory symptoms could serve as recurrent reminders of the horrors of a traumatic event and elevate PTSD rates (Yellowlees & Kalucy, 1990); that is, pulmonary problems may mediate effects of trauma on PTSD.

The present study explores the associations of WTC exposures with probable PTSD, respiratory symptoms and lung function abnormality in rescue, recovery and clean-up workers participating in the WTC-MMTP. The cohort is composed of workers trained in disaster response (e.g. police; $n=8508$) and non-traditional responders in other occupations (e.g. building trades, maintenance, communications, transportation, health care, and other volunteers; $n=12\,333$). Previous research documented that professional responders to disasters report fewer mental health symptoms than volunteers with no previous disaster training (Perrin *et al*. 2007; Thormar *et al*. 2010). We thus stratified the cohort into police and non-traditional responders both to compare the rates of PTSD and respiratory symptoms and to examine the associations among these conditions. We explored three alternative hypotheses: (1) PTSD statistically mediated the association of exposure with pulmonary health; (2) respiratory problems mediated the association of exposure with PTSD; or (3) their co-morbidity was due to shared risk factors.

Method

The sample

Data come from patients evaluated at the WTC-MMTP, which comprises seven clinics in New York and New Jersey. The program is available to WTC responders who (*a*) had qualifying involvement in the WTC clean-up and recovery effort; and (*b*) were not eligible to participate in other federally funded programs offered to the New York City Fire Department or to federal or state employees (Herbert *et al*. 2006).

WTC responders were recruited to the program through an extensive outreach effort that included union meetings, mailings, media articles, and some 50 000 telephone calls in multiple languages. The data for the current study were derived from the initial examinations that took place on average 4 years after 11 September 2001, between 16 July 2002 and 11 September 2008.

Institutional Review Boards of each affiliated site approved and monitored compliance with procedures for obtaining informed consent and protecting human subjects. More than 90% of clinic patients provided written informed consent for their data to be used for research purposes ($n=22\,894$ participants). Complete data on all study variables were available for $n=20\,841$. The excluded group was within two percentage points of the analysis sample on all study variables except working in law enforcement (34.1% of excluded *versus* 40.8% of the analysis sample), long work on site (22.4% *v.* 25.1%) and probable PTSD (20.5% *v.* 16.0%).

Measures

WTC exposures

WTC exposure was assessed with two indices previously found to be significantly associated with both mental and physical health (e.g. Brackbill *et al.* 2006): dust cloud exposure (DiGrande *et al.* 2011), which occurred among responders who arrived on 11 September 2001 and worked on or near the debris pile; and long duration of work at Ground Zero, the Fresh Kills landfill (where debris from the disaster was brought), or the Office of the Chief Medical Examiner. The median duration of work was 633 h (interquartile range 191–1353 h). Long duration was defined as being in the top quartile (>1353 h).

Probable PTSD

Probable WTC-related PTSD was measured using the PCL (Weathers *et al.* 1993), a 17-item self-report measure assessing the criterion symptoms listed in DSM-IV. Participants were asked to rate problems they were bothered by in the past month 'in relation to 9/11' on a scale of '1 = not at all' to '5 = extremely'. The scale was summed, and a score of $\geqslant 50$ was used to indicate probable PTSD (Terhakopian *et al.* 2008). Item no. 5 asks about 'having physical reactions (e.g. heart pounding, trouble breathing, sweating) when something reminded you of the disaster'. To test whether this item influenced the association between PTSD and respiratory symptoms, we also scored PTSD by summing the other 16 items and applying a prorated cut-point of 47.

Lower respiratory symptoms

Lower respiratory symptoms were rated by WTC-MMTP physicians using questions selected from standard sources (Burney *et al.* 1989; National Center for Health Statistics, 1996; NIOSH, 2006). Seven lower respiratory symptoms were assessed: shortness of breath (under a variety of circumstances and times of day), wheezing, chest tightness, exercise intolerance, dry cough, hemoptysis, and productive cough. We focused on the development of one or more new symptoms after 11 September 2001 that persisted in the month before examination.

Pulmonary function

Pulmonary function was evaluated using the EasyOne™ spirometer (ndd Medical Technologies, USA) following standard techniques (Miller *et al.* 2005; Enright *et al.* 2008). Consistent with previous reports on WTC responders (Herbert *et al.* 2006; Skloot *et al.* 2009), we focused on restrictive breathing pattern as measured by tests of forced vital capacity (FVC) and forced expiratory volume in one second (FEV1). Abnormal pulmonary function was based on the trial yielding the largest sum of FVC + FEV1 and defined as scoring below *versus* within/above the age-sex-race-height-specific lower limit of normal (Hankinson *et al.* 1999).

Additional risk factors

Other established risk factors, such as body mass index (BMI) and current tobacco use (e.g. Eaton, 2005; Von Korff *et al.* 2009), were adjusted in all multivariate analyses. Current age, sex and time (in years) from 9/11 to assessment were also adjusted when the bivariate analysis indicated that they were significantly related to the health variables.

Analysis methods

We first compared police and non-traditional responders on the study variables using χ^2 tests for categorical data and t tests for continuous variables. To evaluate bivariate associations among the variables, we used polychoric correlations when continuous variables were involved and tetrachoric correlations when both variables were dichotomous to produce equivalent estimates for continuous variables, dichotomous variables, and a mix of the two. Polychoric and tetrachoric correlations have a clear interpretation, with $r=0.10$ conventionally considered a small effect, $r=0.30$ a medium effect and $r=0.50$ a large effect (Cohen, 1988).

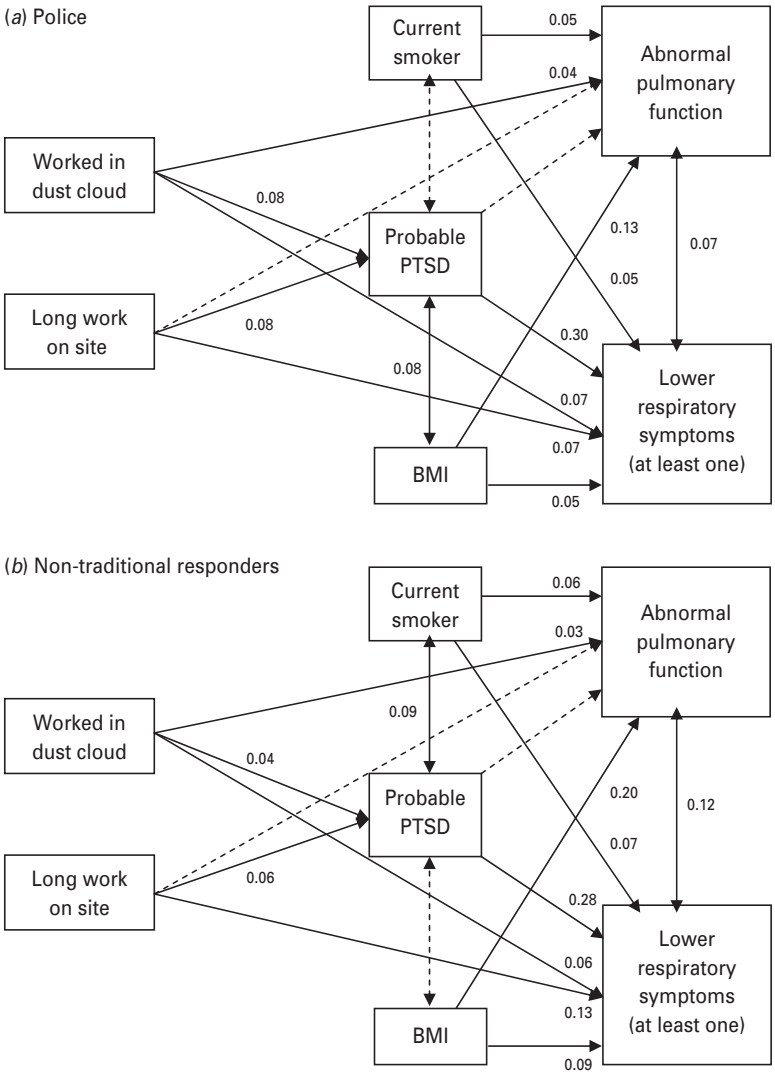

Fig. 1. Best-fitting structural equation models for (*a*) police and (*b*) non-traditional responders. Values are standardized path coefficients. Non-significant ($p > 0.05$) coefficients are not shown, and the corresponding paths are shown as broken lines. Correlations among covariates are not shown. Analyses adjusted for age, gender and time to assessment (not shown) whenever they were significantly correlated with the outcome (Table 2). Age, gender and time to assessment had paths to probable post-traumatic stress disorder (PTSD); age and gender had paths to pulmonary function; time to assessment had a path to lower respiratory symptoms. Directional arrows indicate regression paths; double-headed arrows indicate correlations. BMI, Body mass index.

Structural equation modeling (SEM), a system of multiple regressions that are estimated simultaneously (Kline, 2011), was used to explore the plausibility of the three alternative hypotheses about the pathways from exposure to PTSD and respiratory conditions. In the first model, WTC exposures were associated with PTSD and respiratory problems, and these conditions were correlated but independent. In the second model, associations between exposure and respiratory problems were statistically mediated in part by PTSD. Hence, in addition to direct paths, we included paths that went from exposures to PTSD and then from PTSD to respiratory problems (Fig. 1). In the third model, associations between exposure and PTSD were mediated in part by respiratory conditions. In the latter two analyses, we tested the statistical significance of the indirect paths. In each model, we adjusted for smoking status and BMI in addition to the other risk factors that were significantly associated with the health outcome in the bivariate analyses. The analyses were performed using Mplus version 6.1 (Muthén & Muthén, 2010). We used the maximum likelihood robust (MLR) estimator, which can handle non-normal distributions. In evaluating the model, we considered two absolute and three relative fit indices available in Mplus (Akaike, 1974;

Table 1. *Comparison of police and non-traditional responders on study variables*[a]

	Police ($n=8508$)	Non-traditional responders ($n=12\,333$)	p value
Years from 9/11 to assessment, mean (S.D.)	4.1 (1.8)	3.4 (1.9)	<0.001
Current age (years), mean (S.D.)	40.8 (6.6)	44.4 (9.9)	<0.001
Sex: female, %	15.0	13.9	<0.05
Worked in dust cloud, %	28.9	12.7	<0.001
Long work on site, %	22.8	26.8	<0.001
BMI, mean (S.D.)	30.0 (4.9)	29.3 (5.3)	<0.001
Current cigarette smoker, %	10.2	20.3	<0.001
Probable WTC-related PTSD, %	5.9	23.0	<0.001
Abnormal pulmonary function, %	23.7	22.1	<0.05
Lower respiratory symptoms, %	22.5	28.4	<0.001

BMI, Body mass index; WTC, World Trade Center; PTSD, post-traumatic stress disorder; S.D., standard deviation.
[a] Dichotomous variables were compared using the χ^2 test. Continuous variables were compared using the t test.

Kass & Raftery, 1995; Burnham & Anderson, 2002; Marsh *et al*. 2004).

Results

Sample characteristics

The police cohort differed significantly ($p<0.001$) from the non-traditional responders on most study variables (Table 1). Police were less likely to have probable WTC-related PTSD (5.9% *v*. 23.0%) and to have respiratory symptoms (22.5% *v*. 28.4%). However, the proportion with abnormal pulmonary function was similar (~23%). With regard to exposure, more than twice as many police (28.9%) compared to non-traditional responders (12.7%) were exposed to the dust cloud, but more non-traditional responders (26.8%) than police (22.8%) spent prolonged time working at the site. In addition, most of the police ($n=7898$; 92.8%) and non-traditional responders (n=10489; 85.0%) reported working during September, 2001. Among them, 40.0% of police and 33.1% of non-traditional responders reported spending the majority of their time on or in the debris pile or pit; a further 42.5% of police and 58.9% of non-traditional responders worked in adjacent areas. The remainder were at the landfill, medical examiner's office, loading piers, and elsewhere.

With respect to background characteristics, police officers were younger, had slightly higher BMI, were less likely to smoke cigarettes, and were examined somewhat later than non-traditional responders.

Bivariate associations

Table 2 shows the bivariate associations among the study variables. Overall, the associations among the health variables were similar in the two groups. Abnormal lung function was only modestly correlated with respiratory symptoms ($r=0.09$ in police and 0.13 in the non-traditional group) and was not significantly associated with probable PTSD. By contrast, lower respiratory symptoms were substantially associated with probable PTSD ($r=0.28$ and 0.27 respectively). The associations were the same to the second decimal when we substituted the revised PTSD variable that excluded PCL item no. 5.

WTC exposures showed notable associations with lower respiratory symptoms (range $r=0.14$–0.24), less so with probable PTSD ($r=0.07$–0.12), and were only weakly associated with lung function. Indeed, for PTSD and respiratory symptoms, the odds ratios (ORs) among police ranged from 1.4 [95% confidence interval (CI) 1.2–1.8] for dust cloud exposure with probable PTSD to 1.6 for dust cloud exposure and long hours worked with respiratory symptoms (95% CI 1.5–1.8 and 1.4–1.8 respectively). Among non-traditional responders, the ORs ranged from 1.2 for both dust cloud exposure and long hours worked with probable PTSD (95% CI 1.1–1.4 for each) to 2.0 (95% CI 1.8–2.2) for long hours worked with respiratory symptoms.

Among the other risk factors, higher BMI was significantly associated with pulmonary abnormality, and smoking was most strongly associated with respiratory symptoms. The other risk factors were significantly associated with at least one health variable and hence were adjusted in the multivariate models.

Path models

Each of the three models examined with SEM fit the data well (Supplementary Table S1, available online). However, the model in which associations between exposures and respiratory problems were mediated

Table 2. *Correlations among study variables in police (below diagonal) and non-traditional responders (above diagonal)*

	Time to assess-ment	Age	Female	Worked in dust cloud	Long work on site	BMI	Current smoker	Probable PTSD	Pulmonary function	Lower respiratory symptoms
Time to assessment	–	0.14	0.04	0.00	−0.14	0.06	−0.05	0.08	0.04	**−0.22**
Age	**0.17**	–	−0.03	0.04	−0.05	0.06	−0.14	0.02	0.13	0.00
Female	0.06	−0.01	–	−0.08	−0.06	**−0.18**	**−0.16**	**0.19**	**−0.15**	0.01
Worked in dust cloud	−0.14	0.01	−0.06	–	0.09	0.07	−0.01	0.07	0.08	0.14
Long work on site	−0.06	−0.01	0.03	**0.18**	–	0.03	0.11	0.07	−0.02	**0.24**
BMI	0.04	0.06	**−0.26**	0.02	0.05	–	−0.08	−0.02	**0.21**	0.07
Current smoker	−0.08	−0.04	0.13	0.00	0.00	**−0.15**	–	0.12	0.07	**0.15**
Probable PTSD	0.11	0.14	0.05	0.11	0.12	0.08	0.06	–	0.03	**0.27**
Pulmonary function	−0.02	0.02	**−0.22**	0.06	0.01	**0.15**	0.05	0.03	–	0.13
Lower respiratory symptoms	**−0.17**	0.04	0.06	**0.17**	**0.16**	0.08	0.11	**0.28**	0.09	–

BMI, Body mass index; PTSD, post-traumatic stress disorder.

Correlations involving continuous variables are polychoric; all others are tetrachoric. Correlations >0.03 are significant at $p<0.05$ level.

Noteworthy associations ($r \geqslant 0.15$) are shown in bold.

in part by PTSD showed better absolute fit in both responder groups. The relative fit indices indicated that support for this pathway was much stronger (odds in favor of it were over 100:1) than for the alternatives. This model is presented in Fig. 1; significant paths are shown with solid lines, along with the coefficients, and non-significant paths are given with dashed lines, without coefficients. Time to assessment, age and sex were adjusted in these models whenever these variables were significantly correlated with the outcome (paths not shown). The results were similar for the two occupational groups except that, in police, BMI but not smoking was associated with probable PTSD, whereas among the non-traditional responders, smoking but not BMI was associated with PTSD. Overall, both WTC exposures were associated modestly but significantly with probable PTSD (range $\beta=0.04$–0.08), which in turn was substantially associated with respiratory symptoms ($\beta=0.28$ and 0.30). Independent of this pathway, WTC exposures contributed directly to respiratory symptoms ($\beta=0.06$–0.13), and smoking and BMI also showed weak but significant associations. We tested the indirect contributions of each WTC exposure to lower respiratory symptoms and found all of them to be significant ($p<0.002$), indicating that these associations were partially mediated by PTSD. With regard to lung function, the exposures were weakly associated in both groups, and none of the indirect associations was significant, indicating that the links of exposures to lung function abnormality were independent of PTSD.

Discussion

Consistent with prior studies of WTC responder cohorts, abnormal pulmonary function, lower respiratory symptoms, and probable WTC-related PTSD were common an average of 4 years after the disaster. Specifically, nearly one-quarter of police and one-third of non-traditional responders had lower respiratory symptoms that emerged after 9/11 and were present in the month prior to examination, and 22–24% had abnormal lung function findings. As expected, the prevalence of probable WTC-related PTSD in non-traditional responders without emergency response training (23.0%) was considerably higher than among police responders (5.9%). Consistent with prior studies (e.g. Perrin *et al*. 2007; Brackbill *et al*. 2009), dust cloud exposure and greater number of hours worked were associated with PTSD, and there was a significant association between probable PTSD and respiratory symptoms. Most importantly, our results suggested an indirect association of exposure with respiratory problems through PTSD, a finding that mirrors research conducted with Vietnam veterans (Schnurr & Jankowski, 1999). Moreover, the associations observed in the final model were similar in both police and non-traditional responders. Thus, the current results both extend our understanding of the health of WTC-MMTP responders and add to a growing body of data on the link between PTSD and respiratory problems.

This study cannot determine whether PTSD mediates the direct effects of WTC exposures on

respiratory symptoms or if it serves to mediate the chronicity, rather than the onset, of respiratory symptoms. Longitudinal data and a rigorous diagnosis of PTSD are needed to disentangle these possibilities. Future studies should also include direct measures to test possible biological (e.g. immunologic dysregulation) and cognitive (e.g. increased attention to somatic symptoms) mechanisms underlying the observed link.

There are other limitations that should be noted when drawing inferences from the results. The current sample is composed of volunteers, and prevalence estimates from this and responder cohorts in previous reports must be treated with caution (Savitz *et al*. 2008). It is also possible that PTSD increased the participation of individuals with respiratory symptoms and WTC exposures. Longitudinal research using data from subsequent visits will determine whether PTSD increased retention of individuals with these symptoms and exposures, but we have no way of assessing this bias with data from the initial visit. To enhance reliability, we focused on incident respiratory symptoms that appeared after 9/11 rather than symptoms that started before 9/11. Thus the rates reported here are lower than those in studies combining incident and prevalent cases (e.g. Farfel *et al*. 2008). We also limited the analysis to two reasonably independent exposures based on prior WTC findings. Future research should also consider other specific exposures. With regard to probable PTSD, the analysis sample had a somewhat lower rate than the excluded sample. Thus the prevalence estimates are conservative. As noted elsewhere, police officers may have underreported PTSD symptoms because of concerns about retaining their employment. Despite these limitations, our results clearly confirm that respiratory and PTSD conditions were common and co-morbid, and suggest that PTSD may be mediating the exposure–respiratory symptom relationship in both professional and non-traditional WTC responders.

Shortly after 9/11, WTC rescue and recovery workers began to report a variety of symptoms involving the lower respiratory system, including dyspnea, chest discomfort, and chronic cough. These reports were first noted among New York City Fire Department workers who developed cough and bronchial hyperactivity (WTC cough; Prezant *et al*. 2002). These findings were predominantly attributable to airway abnormalities. Intense exposure and early development of bronchial hyperactivity predicted persistence of reactive airway dysfunction 6 months later. Physiologically, there was a bronchodilator response and hyper-reactivity; radiographically, there was air trapping and thickening of the bronchial wall without evidence of parenchymal changes (Izbicki *et al*. 2007; Prezant, 2008). However, the protean nature of the respiratory symptoms and the lack of physical or physiologic correlates of disease in some patients raised the possibility that the symptoms resulted from multiple etiologies. This notion received support in the present study, as we found that lower respiratory symptoms had a weak association with pulmonary function, and, consistent with Niles *et al*. (2011), their associations with probable PTSD were much stronger.

We initially expected that responders with intense and extensive exposure would display more severe pulmonary illness and higher levels of PTSD symptoms. We were therefore surprised not to find a correlation between abnormal spirometry results and PTSD. However, a one-time spirometry assessment is known to have low sensitivity and specificity for episodic respiratory illnesses. The link between respiratory symptoms and PTSD, although well documented in general, clinical and veteran populations, is not well understood. Further studies are needed to elucidate the precise biological and psychological mechanisms involved in populations with different exposure experiences. The stratification of our analysis by occupational status revealed that the police and the non-traditional responders differed with respect to WTC exposures and prevalence of probable PTSD. The latter may be explained by the characteristics of police officers, including the selection, training, previous exposure to traumatic events, 9/11 exposure differences and reporting biases, in addition to the availability of social support and mental health services during and after the disaster. Although PTSD was less common in police than non-police, the link between probable PTSD and lower respiratory symptoms (and the absence of an association with abnormal spirometry results) was similar in the two groups.

The results have important implications for understanding illness burden on responders following large-scale disasters. Respiratory illness, in particular, is multi-faceted and can be attributed to structural abnormalities, functional syndromes and somatization. The presence of probable PTSD may provide an important signal for clinicians regarding the etiology or persistence of such symptoms presented by the responders. As shown here, there is a substantial association between PTSD and respiratory symptoms. Regardless of which came first, PTSD or respiratory symptoms, our findings emphasize that mental health screening is as essential as screening for respiratory symptoms. Of course, a clinical diagnosis of PTSD and objective testing for physical conditions provide the most crucial evidence about co-morbidity, and longitudinal data are needed to validate the mediation results. Nonetheless, the current findings support

treatment strategies that integrate physical and mental health targets (Von Korff *et al*. 1997).

The current results also support previous findings that the health and mental health effects of the WTC disaster are enduring (Wisnivesky *et al*. 2011). Understanding why some responders are at higher or lower risk for developing persistent health problems following a large-scale disaster is important for designing disaster preparedness and long-term treatment programs for health problems that may develop into more chronic conditions. The health consequences of disaster recovery and clean-up could be improved by a better understanding of the prior training and experiences of the responders who altruistically assist under the worst possible conditions and by providing non-traditional responders with some level of preparation before they go on site. A qualitative study by Johnson *et al*. (2005) found that non-traditional WTC responders felt ill-prepared for the recovery and clean-up work. Specifically, they felt overwhelmed by the clean-up duties and did not feel that they had proper protective equipment. In our study, this group reported significantly higher rates of probable PTSD than police. This finding suggests that better preventive interventions must be put in place for non-traditional responders who volunteer to participate in disaster-related activities (Reissman & Howard, 2008). Providing psychological first-aid soon after the exposure is recommended to protect against the development of chronic stress-related disorders (Ursano *et al*. 2007).

In our age, the number of toxic events in which relatively large populations are exposed to concomitant physical and psychological traumas has increased dramatically. In the sample of WTC responders who participated in this study, there was a striking correlation between PTSD and respiratory symptoms, with evidence that PTSD might play a mediating role in the exposure–symptom relationship. The associations reported in this paper have set the stage for further research to elucidate the pathways for the development and maintenance of respiratory problems using a longitudinal design, a diagnostic measure of PTSD, and additional risk and protective factors. Scott *et al*. (2009) demonstrated that mental–physical comorbidity has both additive and synergistic effects on disability, underscoring the importance of disentangling the association of PTSD and respiratory symptoms in addition to the provision of integrated general medical and psychiatric care for disaster responders.

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Note

Supplementary material accompanies this paper on the Journal's website (http://journals.cambridge.org/psm).

Declaration of Interest

None.

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Trends in Respiratory Symptoms of Firefighters Exposed to the World Trade Center Disaster: 2001–2005

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Background: Respiratory symptoms, either newly reported after the World Trade Center (WTC) disaster on 11 September 2001 (9/11) or increased in severity, have been well documented in WTC-exposed workers and New York City residents. However, considerable uncertainty exists over the persistence of symptoms.

Objectives: In this study, our goals were to describe trends in post-9/11 respiratory and gastroesophageal reflux disease (GERD) symptoms in WTC-exposed firefighters and to examine symptom progression in the cohort that completed both year 1 and year 4 questionnaires.

Methods: We analyzed questionnaire responses from 10,378 firefighters in yearly intervals, from 2 October 2001 to 11 September 2005, defining exposure based on arrival time at the WTC site. For the cohort of 3,722 firefighters who completed the two questionnaires, we also calculated exposure duration summing months of work at the site.

Results: In cross-sectional analyses, the prevalence of dyspnea, wheeze, rhinosinusitis, and GERD remained relatively stable, whereas cough and sore throat declined, especially between 1 and 2 years post-9/11. We found a dose–response relationship between arrival time and symptoms in all years ($p < 0.01$). Logistic models of symptoms at year 4 in the cohort demonstrated independent effects of earlier arrival and longer work duration: each additional month of work increased the odds of symptoms 8–11%.

Conclusions: Protracted work exposures increased the odds of respiratory and GERD symptoms 4 years later. In most large disasters, exposures may be unavoidable during the rescue phase, but our data strongly suggest the need to minimize additional exposures during recovery and cleanup phases.

Key words: disaster medicine, firefighters, gastroesophageal reflux disease (GERD), occupational medicine, rescue workers, respiratory symptoms, World Trade Center. *Environ Health Perspect* 117:975–980 (2009). doi:10.1289/ehp.0800291 available via *http://dx.doi.org/* [Online 11 February 2009]

The collapse of the World Trade Center (WTC) on 11 September 2001 (9/11) and subsequent recovery efforts released large amounts of particulate dust, combustion particles, gases, fumes, and other noxious materials, some of which will remain incompletely characterized [Banauch et al. 2006; Centers for Disease Control and Prevention (CDC) 2002a; Edelman et al. 2003; Landrigan et al. 2004; Lioy et al. 2002; McGee et al. 2003; Mendelson et al. 2007], particularly the gaseous component (Lioy et al. 2002). After the initial dust cloud settled, fires continued to be a major source of ongoing airborne contamination for months after the attack. The Fire Department, City of New York (FDNY), operated a continuous rescue/recovery effort at the site that lasted until July 2002 (Fireman et al. 2004; Prezant et al. 2002) and involved > 15,000 rescue workers [firefighters and emergency medical service (EMS) workers].

In the first 6 months after 9/11, the Bureau of Health Services (BHS) of FDNY identified 332 firefighters with "World Trade Center cough," defined as a persistent cough that developed after exposure to the site and that was severe enough to require extensive medical leave (Prezant et al. 2002). In the same report, a range of frequent coexistent symptoms were identified, including dyspnea, wheeze, nasal congestion/drip, and acid reflux, that were consistent with asthma, rhinosinusitis, and gastroesophageal reflux disease (GERD). Increased bronchodilator responsiveness and bronchial hyperreactivity were often noted in this and other studies (Banauch et al. 2003, 2005a; Prezant et al. 2002). A later study involving 12,079 FDNY rescue workers documented a decline in pulmonary function during the first year post-9/11 that was 12 times that found pre-9/11 (Banauch et al. 2006). An exposure–response gradient, based on arrival time at the WTC (Prezant et al. 2002), was consistently demonstrated for symptoms, bronchodilator responsiveness, bronchial hyperreactivity, and declines in pulmonary function. Respiratory symptoms, either newly reported post-9/11 or increased in severity, have also been documented in other exposed workers (Herbert et al. 2006; Herbstman et al. 2005; Salzman et al. 2004; Tao et al. 2007; Wheeler et al. 2007) and residents (CDC 2002b; Lin et al. 2005; Reibman et al. 2005; Szema et al. 2004).

Considerable uncertainty exists over the persistence of respiratory symptoms among WTC-exposed individuals because of a lack of long-term follow-up data. One earlier study reported on respiratory symptoms at three time points (pre-9/11, while working at the site, and 10–31 months post-9/11), but the first two time points were collected retrospectively and therefore were potentially subject to recall bias (Herbert et al. 2006). Another study evaluated symptom persistence at 1 and 20 months post-9/11 but focused exclusively on lower respiratory symptoms (LRS) in a convenience sample of 471 police officers (Buyantseva et al. 2007). The present study is the first to report the evolution of WTC respiratory symptoms in a large, highly exposed, homogeneous (similar firefighting job tasks) group (n = 10,378), with prospective follow-up over the first 4 years. We describe temporal trends in the prevalence of post-9/11 aerodigestive symptoms [upper respiratory symptoms (URS), LRS, and GERD] through 11 September 2005. We further analyzed the progression of symptoms in those firefighters (n = 3,722) that completed questionnaires during both the first and fourth years, thereby enabling assessment of four symptom patterns: early onset/resolved, early onset/persistent, delayed onset, and asymptomatic initially and after 4 years (Buyantseva et al. 2007).

Methods

Since 1997, the FDNY BHS has performed periodic health evaluations on FDNY members approximately every 18 months; these evaluations include physician examinations and, since 2001, self-administered health questionnaires. The questionnaires are programmed on touch-screen computers, with trained personnel available to answer questions. Participation in the study required written informed consent and was

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Study participants. The original sample consisted of 14,380 firefighters and EMS workers who were hired before 25 July 2002 (the date the WTC site closed). We excluded 1,636 firefighters who arrived after day 14 or were never present (because of demographic differences between them and earlier arrivals); 369 who did not complete questionnaires; and 1,997 EMS workers (because of differences in their job tasks and because they had less stringent preemployment health requirements). The final sample for cross-sectional analysis consisted of 10,378 firefighters.

Data sources. We obtained demographics from the FDNY employee database. Symptoms, exposure status, mask/respirator use, and smoking history were collected from the questionnaires.

Symptom prevalence. The questionnaire asked participants about LRS and URS: "Since the disaster, have you had any of the following new or worsening respiratory symptoms?" For LRS, possible answer choices included "no respiratory symptoms," "wheezing," "shortness of breath," and "daily cough"; for URS, possible answers included "no nose or throat symptoms," "nasal drip," "nasal congestion," "sore throat," and "hoarse throat with change or loss of voice." Multiple answers were allowed. We estimated GERD symptoms based on a positive response to "chest tightness or pain" or "stomach upset or heartburn." Follow-up questionnaires asked participants if they had any of the above symptoms, and affirmative answers were qualified as to their presence during "the last 4 weeks." We obtained information on symptoms pre-9/11 from the participant's first post-9/11 questionnaire, which asked: "Prior to the disaster did you commonly suffer from any of the following: daily cough, nasal congestion or drip, wheeze, shortness of breath, chest tightness or pain." Multiple answers were allowed.

WTC exposure. The FDNY-WTC exposure intensity index (Prezant et al. 2002) categorized exposure based on first arrival at the WTC site as follows: group 1 (the most severely exposed) arrived on the morning of 9/11 and were present during the tower collapses; group 2 arrived during the afternoon of 9/11; group 3 arrived on day 2 (12 September 2001); and group 4 (least exposed) arrived on days 3–14.

In addition to arrival group, we created two duration variables. The first used information from questions in which participants reported which months they worked at the site, on or off duty, from September 2001 through July 2002. We used the sum of the number of months participants worked on the site as a continuous variable in multivariate models. We created the second variable, based on both work duration and mask/respirator use, by multiplying each month the participant reported working at the site by 1.0, 0.75, or 0.25, depending on the reported mask/respirator use frequency of "never," "rarely," or "mostly" during that month (Wheeler et al. 2007). The sum of the number of mask-use–weighted months was tested as a continuous variable in multivariate models.

Smoking history. "Current smokers" reported smoking cigarettes during any year post-9/11. "Former smokers" reported smoking before 9/11 but did not report current smoking in any post-9/11 questionnaire. "Never smokers" consistently reported not smoking pre- and post-9/11.

Time periods. In this study we include data from 17,447 questionnaires analyzed cross-sectionally in 1-year periods based on the date administered: year 1, 2 October 2001 to 11 September 2002; year 2, 12 September 2002 to 11 September 2003; year 3, 12 September 2003 to 11 September 2004; and year 4, 12 September 2004 to 11 September 2005. Within each year, if persons completed more than one questionnaire, we used data only from the earliest one.

Cohort for analysis of symptom patterns over time. To identify symptom patterns and their relative frequency, we also analyzed a cohort (n = 3,722) that completed questionnaires during both the first and fourth years according to four reported symptom patterns: early onset/resolved, early onset/persistent, delayed onset, and asymptomatic initially and at 4 years (Buyantseva et al. 2007).

Statistical analyses. Bivariate analyses of categorical variables used the chi-square test with odds ratios (ORs) and 95% confidence intervals (95% CIs). We assessed continuous variables using the t-test or analysis of variance. In cross-sectional analyses, we used marginal logistic regression models fitted with generalized estimating equations to assess differences in the annual prevalence of symptoms by arrival group, and McNemar's test for trend to assess the relation of arrival group to symptoms.

In the cohort, we tested the linear trend of symptom prevalence over time by arrival group using the Cochran-Armitage test for trend. We used multiple logistic regression analyses with backward elimination to predict outcomes of any LRS, URS, or GERD at follow-up. Variables tested in all models included age and years of FDNY service on 9/11, arrival group, duration of work at the WTC site in months and weighted for mask/respirator use, symptoms before 9/11, symptoms reported on initial questionnaire, smoking status (current, former, or never), and elapsed time between initial and follow-up questionnaires. We individually tested three interaction terms in each model: arrival group and smoking history, arrival group and months of work, and mask/respirator use and months of work. Variables remained in the model based on a p-value of ≤ 0.05 and assessment of their impact on other variables in the model. Goodness of fit was assessed using the Hosmer-Lemeshow test. Data were analyzed using SAS, version 9.1 (SAS Institute Inc., Cary, NC).

Results

We collected 17,447 questionnaires from 10,378 WTC-exposed firefighters over the 4-year period from 2 October 2001 to 11 September 2005. During the study, firefighter compliance with scheduled periodic evaluations every 18 months, including questionnaire completion, was 85%. Most participants were male (99.8%), were white (93.6%), and never smoked (73.1%). The number of participants in each year of the serial cross-sectional analyses was 8,920 in year 1; 1,197 in year 2; 2,889 in year 3; and 4,441 in year 4. By arrival group, 16.2% (1,683) arrived during the morning on 9/11, 63.7% (6,611) during the afternoon of 9/11, 11.7% (1,215) on day 2, and 8.4% (869) on days 3–14. The overall mean (± SD) duration of work at the WTC site was 4.4 ± 2.8 months, which differed significantly by arrival group: 4.7 ± 3.0, 4.4 ± 2.8, 3.9 ± 2.5, and 3.3 ± 2.3 months for arrival groups 1–4, respectively ($p < 0.0001$). Comparing the group of 10,378 with the cohort of 3,722, we found small statistically significant differences in mean age (39.2 years vs. 37.3 years; $p < 0.01$) and percent Caucasian (93.6% vs. 94.7%; $p < 0.01$), whereas percent male (99.8%) and percent arrival group 1 (16.2%) were the same.

Prevalence of symptoms in cross-sectional analyses. Before 9/11, participants had rarely reported LRS: frequent cough was reported by 4.1%, dyspnea by 2.5%, and wheeze by 1.2%. In the first year (2 October 2001 to 11 September 2002), the most common LRS was frequent cough, reported by 54.2%. By year 2, the rate of frequent cough declined to 16.9%, remaining close to that level to affect 15.7% during year 4. In contrast, dyspnea and wheeze showed little change: dyspnea was reported by 40% during year 1 and 38.8% during year 4, and wheeze was reported by 34% throughout all 4 post-9/11 years.

Before 9/11, reports of URS were also rare, with frequent sore throat reported by 3.2% and frequent rhinosinusitis by 4.4%. During year 1, the most common respiratory symptom was sore throat, reported by 62.4%. By year 2, the rate of sore throat declined to 36.0%, plateauing to affect 37.0% in year 4. In contrast, rhinosinusitis showed little change, varying from 45.1% to 47.8% during years 1 and 4, respectively. Before 9/11, symptoms consistent with GERD were reported by 5.2%. GERD symptoms were reported by 41.8% during

year 1 and remained between 40% and 45% during all 4 post-9/11 years (Figure 1).

Prevalence by arrival group in cross-sectional analyses. For all symptoms, earlier arrival was associated with higher prevalence in all years (all $p < 0.01$). For cough, dyspnea, wheeze, sore throat, and rhinosinusitis, those in arrival groups 3 and 4 experienced a greater proportion of decline over time compared with changes in earlier arrival groups (Table 1, Figure 2).

Symptom progression in the cohort. A total of 3,722 firefighters completed both year 1 and year 4 questionnaires. In year 1, the mean (± SD) number of reported symptoms per person was 2.6 ± 2.0, which significantly declined to 2.2 ± 2.0 ($p < 0.0001$) in year 4.

On the initial questionnaire, 64.1% reported one or more LRS, 69.7% one or two URS, and 38.4% GERD. At year 4, the prevalence of any LRS declined significantly to 49.5%, largely attributable to the 69.0% decline in cough, because both dyspnea and wheeze significantly increased from 35.2% to 39.4% and from 28.9% to 34.6%, respectively ($p < 0.001$ for both). Similarly, we found a significant decline ($p < 0.001$) in any URS to 57.3%, primarily attributable to a 37.4% decline in sore throat, because rhinosinusitis significantly increased from 44.1% to 48.7% ($p < 0.001$). The prevalence of GERD also increased from 38.4% to 43.8% ($p < 0.001$).

Factors associated with symptom patterns in the cohort. We explored the relationship between arrival group and symptom patterns in the cohort with year 1 and year 4 questionnaires (n = 3,722). Earlier arrival group was consistently related to symptom persistence for LRS, URS, and GERD. Comparing earliest arriving participants (arrival group 1) with all others, arrival group 1 members were more likely to have LRS (OR = 1.8; 95% CI, 1.5–2.2), URS (OR = 1.5; 95% CI, 1.3–1.8), and/or GERD (OR = 1.9; 95% CI, 1.5–2.2) at year 4. This held true for each individual symptom as well. For LRS, persistent cough (OR = 1.7; 95% CI, 1.3–2.1), persistent dyspnea (OR = 2.0; 95% CI, 1.7–2.4), and persistent wheezing (OR = 1.8; 95% CI, 1.5–2.3) were all more likely among arrival group 1 members. A similar pattern was apparent for those with persistent URS: persistent rhinosinusitis (OR = 1.3; 95% CI, 1.1–1.6) and persistent sore throat (OR = 1.6; 95% CI, 1.3–1.9). In contrast, asymptomatic status was consistently related to later arrival status ($p < 0.0001$; Table 2).

The prevalence of smoking in the cohort was 13.5%, 11.1%, and 75.4% for current, former, and never smokers, respectively. Current and former smokers were generally overrepresented among those with persistent symptoms. We also carried out analyses comparing persons with persistent symptoms with those who recovered. We found that current smoking compared with never smoking was associated with persistent wheeze (OR = 1.5; 95 CI, 1.1–2.1), cough (OR = 1.5; 95% CI, 1.1–2.0), and GERD (OR = 1.6; 95% CI, 1.2–2.3). Former smoking compared with never smoking was not significantly associated with individual symptoms but was associated with persistent LRS (OR = 1.3; 95% CI, 1.0–1.8) and URS (OR = 1.3; 95% CI, 1.0–1.7).

Table 1. Annual prevalence of symptoms in 10,378 firefighters by arrival group (%).[a]

Symptom	Arrival group	Year[b] 1 (n = 8,920)	2 (n = 1,197)	3 (n = 2,889)	4 (n = 4,441)	Percent change, years 1–4[c]	p-Value[d]
Cough	1	64.3	25.9	24.3	20.0	–68.9	< 0.0001
	2	54.8	16.1	16.9	16.1	–70.6	< 0.0001
	3	48.4	13.7	12.6	12.7	–73.8	< 0.0001
	4	37.4	8.4	10.7	6.0	–84.0	< 0.0001
Dyspnea	1	54.4	57.7	54.3	50.1	–7.9	0.554
	2	39.2	42.3	43.2	39.6	1.0	0.002
	3	32.5	31.3	34.9	28.7	–11.9	0.273
	4	25.0	20.0	26.6	19.2	–23.2	0.269
Wheeze	1	44.2	51.2	48.4	43.5	–1.5	0.090
	2	33.7	36.5	38.7	35.5	5.6	< 0.0001
	3	29.7	31.3	32.7	23.2	–21.9	0.034
	4	21.5	22.1	23.7	17.9	–16.7	0.514
Rhinosinusitis	1	50.6	50.2	53.9	54.4	7.4	0.193
	2	45.5	41.8	48.4	49.1	7.9	< 0.0001
	3	42.4	37.4	40.9	39.6	–6.6	0.416
	4	35.5	24.2	31.6	32.5	–8.5	0.079
Sore throat	1	70.4	48.8	48.9	45.6	–35.1	< 0.0001
	2	63.2	35.5	39.2	38.2	–39.6	< 0.0001
	3	58.5	32.1	28.6	26.3	–55.1	< 0.0001
	4	45.9	18.9	26.6	21.5	–53.1	< 0.0001
GERD	1	53.7	51.2	53.6	53.9	0.4	0.645
	2	41.5	39.4	45.9	43.2	4.1	< 0.0001
	3	35.6	39.7	35.5	35.0	–1.7	0.847
	4	28.3	30.5	27.7	28.5	0.7	0.781

[a] p-Values all < 0.01, by McNemar's test for trend between symptom prevalence and arrival group. [b] Individuals in each year may not be the same. [c] Calculated as (year 4 – year 1)/(year 1) × 100. [d] p-Values from marginal logistic regression model fitted with generalized estimating equations, with an exchangeable within-individual correlation.

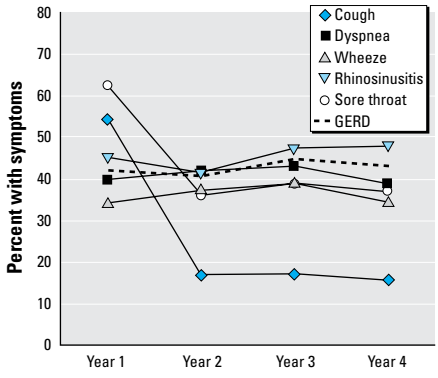

Figure 1. Trends in the prevalence of symptoms in 10,378 firefighters from 2001 through 2005.

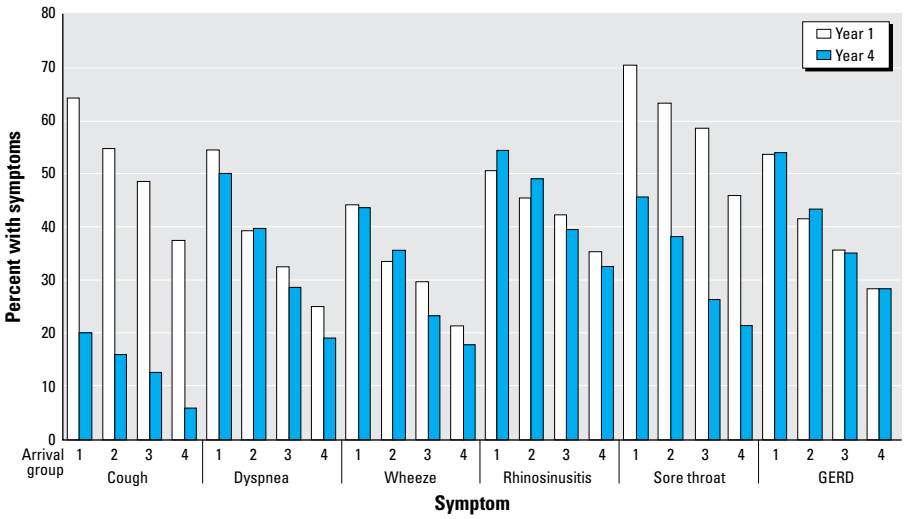

Figure 2. Trends in the prevalence of symptoms in 10,378 firefighters during year 1 (2001–2002) and year 4 (2004–2005) by arrival group.

Multivariate analyses. Multivariate logistic regression models in the cohort predicting symptoms at year 4, either persistent or delayed onset were carried out separately for LRS, URS, and GERD outcomes. Arrival group, initial symptoms, age on 9/11, and months of work (either modified by mask/respirator use or unmodified) were independently associated with symptoms at follow-up in all models. We used the unmodified duration variable because results did not differ from those using the modified variable. Elapsed time between year 1 and year 4 questionnaires remained significant only in the LRS model. Three interaction terms—months of work and arrival group, smoking and arrival group, and months of work and mask/respirator use—were not statistically significant (all $p > 0.05$). The overlap between LRS, URS, and GERD was apparent, especially in the model predicting GERD, where the addition of terms for initial LRS and rhinosinusitis symptoms greatly improved the model fit. All models satisfied Hosmer-Lemeshow goodness of fit tests (Tables 3–5).

Discussion

In this study we describe the prevalence of respiratory symptoms in a well-characterized group of 10,378 WTC-exposed firefighters who worked, on average, four times longer at the WTC site (Wheeler et al. 2007) and were followed more than twice as long (4 years) as workers in most previous reports (Buyantseva et al. 2007; Tao et al. 2007; Wheeler et al. 2007). We found that cough, previously characterized in air pollution studies as the most sensitive indicator of lower respiratory insult (Dockery and Pope 1994), similarly served as a sentinel indicator in WTC-exposed firefighters. In our study, cough was one of the earliest-appearing and earliest-resolving symptoms, declining sharply between 1 and 2 years post-9/11 to affect 16% of firefighters by the study's end. Despite this sharp decline, cough rates during the final period were approximately four times their pre-9/11 rate. Other LRS rates after 9/11 remained relatively constant, and by study's end, wheeze and dyspnea were reported at 28.6 and 15.5 times their pre-9/11 rates, respectively.

For URS, the prevalence of sore throat declined by 41%, whereas rhinosinusitis symptoms increased by 6%. The final rates were 10.7 and 10.6 times their pre-9/11 rates, respectively. GERD symptoms increased by 3.2% during the study, with a final rate 8.2 times its pre-9/11 prevalence. We are confident that comparing rates during the final study period with pre-9/11 rates is valid even though the latter were collected retrospectively at the first post-9/11 questionnaire, because these data are comparable with information collected during FDNY periodic medical evaluations obtained pre-9/11.

Analyses of the cohort of 3,722 enabled us to examine reported-symptom progression in the group of firefighters who completed questionnaires in both the first and

Table 2. Symptom progression [no. (%)] by arrival group in the cohort ($n = 3,722$) at year 4.

	Arrival group					
Symptom pattern	1 ($n = 603$)	2 ($n = 2,504$)	3 ($n = 384$)	4 ($n = 231$)	Total ($n = 3,722$)	p-Value[a]
Cough						
Early onset /recover	260 (43.1)	1,014 (40.5)	136 (35.4)	67 (29.0)	1,477 (39.7)	< 0.0001
Persistent	104 (17.3)	297 (11.9)	39 (10.2)	9 (3.9)	449 (12.1)	< 0.0001
Delay onset	20 (3.3)	105 (4.2)	13 (3.4)	7 (3.0)	145 (3.9)	0.77
Asymptomatic	219 (36.3)	1,088 (43.5)	196 (51.0)	148 (64.1)	1,651 (44.4)	< 0.0001
Wheeze						
Early onset /recover	64 (10.6)	284 (11.3)	48 (12.5)	25 (10.8)	421 (11.3)	0.64
Persistent	156 (25.9)	446 (17.8)	42 (10.9)	11 (4.8)	655 (17.6)	< 0.0001
Delay onset	103 (17.1)	445 (17.8)	51 (13.3)	35 (15.2)	634 (17.0)	0.15
Asymptomatic	280 (46.4)	1,329 (53.1)	243 (63.3)	160 (69.3)	2,012 (54.1)	< 0.0001
Dyspnea						
Early onset /recover	81 (13.4)	319 (12.7)	43 (11.2)	22 (9.5)	465 (12.5)	0.09
Persistent	207 (34.3)	558 (22.3)	63 (16.4)	19 (8.2)	847 (22.8)	< 0.0001
Delay onset	95 (15.8)	441 (17.6)	54 (14.1)	31 (13.4)	621 (16.7)	0.23
Asymptomatic	220 (36.5)	1,186 (47.4)	224 (58.3)	159 (68.8)	1,789 (48.1)	< 0.0001
Any LRS						
Early onset /recover	138 (22.9)	602 (24.0)	107 (27.9)	50 (21.7)	897 (24.1)	0.58
Persistent	315 (52.2)	1,016 (40.6)	112 (29.2)	45 (19.5)	1,488 (40.0)	< 0.0001
Delay onset	40 (6.6)	245 (9.8)	42 (10.9)	29 (12.6)	356 (9.6)	0.004
Asymptomatic	110 (18.2)	641 (25.6)	123 (32.0)	107 (46.3)	981 (26.4)	< 0.0001
Rhinosinusitis						
Early onset /recover	91 (15.1)	395 (15.8)	63 (16.4)	36 (15.6)	585 (15.7)	0.71
Persistent	202 (33.5)	722 (28.8)	95 (24.7)	39 (16.9)	1,058 (28.4)	< 0.0001
Delay onset	126 (20.9)	520 (20.8)	63 (16.4)	44 (19.1)	753 (20.2)	0.17
Asymptomatic	184 (30.5)	867 (34.6)	163 (42.5)	112 (48.5)	1,326 (35.6)	< 0.0001
Sore throat						
Early onset /recover	184 (30.5)	771 (30.8)	128 (33.3)	60 (26.0)	1,143 (30.7)	0.60
Persistent	229 (38.0)	748 (29.9)	80 (20.8)	36 (15.6)	1,093 (29.4)	< 0.0001
Delay onset	49 (8.1)	208 (8.3)	26 (6.8)	22 (9.5)	305 (8.2)	0.93
Asymptomatic	141 (23.4)	777 (31.0)	150 (39.1)	113 (48.9)	1,181 (31.7)	< 0.0001
Any URS						
Early onset /recover	132 (21.9)	583 (23.3)	104 (27.1)	51 (22.1)	870 (23.4)	0.35
Persistent	332 (55.1)	1,182 (47.2)	148 (38.5)	61 (26.4)	1,723 (46.3)	< 0.0001
Delay onset	57 (9.5)	272 (10.9)	44 (11.5)	38 (16.5)	411 (11.0)	0.008
Asymptomatic	82 (13.6)	467 (18.7)	88 (22.9)	81 (35.1)	718 (19.3)	< 0.0001
GERD						
Early onset /recover	80 (13.3)	335 (13.4)	42 (10.9)	28 (12.1)	485 (13.0)	0.35
Persistent	217 (36.0)	628 (25.1)	71 (18.5)	27 (11.7)	943 (25.3)	< 0.0001
Delay onset	110 (18.2)	461 (18.4)	70 (18.2)	47 (20.4)	688 (18.5)	0.59
Asymptomatic	196 (32.5)	1,080 (43.1)	201 (52.3)	129 (55.8)	1,606 (43.2)	< 0.0001

[a] p-Values from Cochran–Armitage test for trend.

fourth postexposure years, thereby allowing differentiation between symptom patterns of persistence, delayed onset, resolution, and never symptomatic at year-4 follow-up. It also allowed us to explore the evolution of symptoms within individuals, as opposed to tracking change over time in the larger population. Multivariate analyses of the cohort data yielded one of our major findings. After adjusting for other variables in the model, we found that each month worked at the WTC site increased the odds of symptoms at follow-up by 11% for both LRS and GERD and by 8% for URS. At the maximum duration of 10 months, the odds of symptoms in year 4 were 2.8 times greater for LRS and GERD and 2.2 times greater for URS. In fact, 10 months of work at the site was much more strongly associated with year 4 symptoms than even the earliest arrival time. Most studies have not reported on work duration (Banauch et al. 2005a; Buyantseva et al. 2007; Fireman et al. 2004; Landrigan et al. 2004; Oppenheimer et al. 2007). Of those that did, one found an association with new-onset asthma (Wheeler et al. 2007); another reported associations with respiratory symptoms at 20 months (Buyantseva et al. 2007), although it did not control for early arrival at the WTC site; and a third found no association with post-9/11 symptoms (de la Hoz et al. 2008). Our data strongly suggest that the impact of protracted WTC work exposure was of critical importance and should be considered in future disaster plans.

Another important finding of the cohort analyses was that cough resolution did not mean that persons were free of LRS. Of those with resolved cough, half (50.9%) reported persistent or delayed-onset dyspnea, wheeze, or both at follow-up. Furthermore, because cough may arise from either lower or upper respiratory problems, we looked at URS in those with resolved cough and found that 61.3% of former coughers reported sore throat, rhinosinusitis symptoms, or both at follow-up. Thus, our data confirm our clinical impression that persons with resolved cough should not be considered symptom-free (Buyantseva et al. 2007). Similarly, among persons with URS, those with resolved sore throat had a 36.3% prevalence of rhinosinusitis symptoms, persistent or delayed in onset, during year 4.

Consistent with initial reports by this group (Banauch et al. 2005a, 2005b; Prezant et al. 2002) and others (de la Hoz et al. 2008; Herbert et al. 2006), we found considerable overlap of LRS, URS, and GERD symptoms. Adding terms for symptoms of the other respiratory groups at the initial period improved all multivariate models. Describing cough as an LRS simplifies analyses but may misclassify cough, which can also be due to rhinosinusitis symptoms (congestion/drip), sore throat, and/or GERD (Irwin et al. 1993). In fact, we found that about 30% of the cohort reported at least one LRS, one URS, and GERD symptoms during both initial and follow-up times (data not shown).

Cigarette smoking is a modifiable risk factor increasing the likelihood of LRS and GERD by approximately 50% at follow-up. This is but one of many reasons for supporting aggressive efforts to promote nonpunitive tobacco cessation programs and counseling services, available without cost at FDNY since 9/11 (Bars et al. 2006).

This study's primary limitation was its lack of access to information about treatment, which precluded estimating the effects of treatment on reported symptoms over time. We also acknowledge that both arrival group and months of work are only crude measures of exposure to the WTC site, which would better be measured by knowing specific hours and days an individual worked on-site. However, our arrival group measure was independently corroborated by others who described the intensity of outdoor exposures based on days post-9/11 (Lioy et al. 2002). Symptom reporting could have been biased because of issues related to workers' compensation, retirement disability, and civil litigation; it could also have been affected by recall bias or by the wording of our questions, which asked about symptoms since 9/11. However, in a previous study (Banauch et al. 2006) we reported that objective spirometric measurements correlated with clinical complaints, and each additional respiratory symptom was associated with an additional decrement in forced expiratory volume in 1 sec. Despite potential limitations, we found significant exposure–response gradients for symptoms at all time points. We believe the strengths of this study outweigh its limitations. First, we examined secular trends in > 10,000 firefighters and were able to study symptom progression in the cohort of 3,722 based on their questionnaire responses at both years 1 and 4. Compared with other published studies, this represents a larger group of highly exposed individuals, all with similar firefighting job tasks, and the most years of follow-up. Second, we asked about the prevalence of symptoms pre-9/11, which enabled us to compare pre- and post-9/11 symptoms in individuals whom we knew to be extremely healthy pre-9/11. Finally, we explored the data in several ways. For example, we initially selected the cohort based on persons with two or more visits at least 1 year apart to increase the number of participants, but ultimately selected only those with first- and fourth-year questionnaires to allow the maximum time for symptoms to resolve, either spontaneously or through treatment. Using either cohort did not change findings.

Conclusion

We found that cough and sore throat were the most sensitive indicators of initial respiratory insult early after 9/11, but that the other symptoms (wheeze, dyspnea, rhinosinusitis, and GERD) were more sensitive indicators at follow-up. In year 4, even cough, the symptom with the greatest decline rate, was still reported at four times the pre-9/11 level, and the other symptoms were reported at levels from 8.2 to 28.6 times their pre-9/11 rates. We found a significant exposure–response gradient based on arrival time for all symptoms. In the cohort we found that each month worked at the site conferred a substantial and highly significant increase in the odds of symptoms at follow-up. For LRS,

Table 3. Multiple logistic regression models in the cohort of 3,722 firefighters [OR (95% CI)] for LRS at year 4.

Variable	OR (95% CI)
Any URS, year 1 questionnaire	1.45 (1.21–1.73)
GERD, year 1 questionnaire	1.27 (1.07–1.51)
Cough, year 1 questionnaire	1.62 (1.38–1.90)
Dyspnea, year 1 questionnaire	2.34 (1.94–2.82)
Wheeze, year 1 questionnaire	1.91 (1.59–2.30)
Current smoking	1.56 (1.26–1.93)
Age on 9/11 (years)	1.03 (1.02–1.04)
Arrival group 1[a]	1.66 (1.16–2.37)
Arrival group 2[a]	1.49 (1.08–2.04)
Arrival group 3[a]	1.13 (0.77–1.64)
Months of work at WTC site	1.11 (1.08–1.14)
Days between questionnaires	0.999 (0.998–1.00)

[a]Reference is arrival group 4 (arrival at WTC site 3–14 days post-9/11).

Table 4. Multiple logistic regression models in the cohort of 3,722 firefighters [OR (95% CI)] for URS at year 4.

Variable	OR (95% CI)
Any LRS, year 1 questionnaire	1.53 (1.29–1.80)
Rhinosinusitis, year 1 questionnaire	2.06 (1.77–2.39)
Sore throat, year 1 questionnaire	1.73 (1.48–2.04)
Arrival group 1[a]	1.63 (1.17–2.28)
Arrival group 2[a]	1.40 (1.04–1.88)
Arrival group 3[a]	1.09 (0.77–1.55)
Age on 9/11 (years)	1.011 (1.00–1.02)
Months of work at WTC site	1.08 (1.05–1.11)

[a]Reference is arrival group 4 (arrival at WTC site 3–14 days post-9/11).

Table 5. Multiple logistic regression models in the cohort of 3,722 firefighters [OR (95% CI)] for GERD at year 4.

Variable	OR (95% CI)
Any LRS, year 1 questionnaire	1.71 (1.45–2.03)
Rhinosinusitis, year 1 questionnaire	1.20 (1.03–1.39)
GERD, year 1 questionnaire	3.48 (2.98–4.05)
Current smoking	1.49 (1.22–1.83)
Arrival group 1[a]	1.49 (1.05–2.11)
Arrival group 2[a]	1.15 (0.84–1.58)
Arrival group 3[a]	1.03 (0.71–1.49)
Age on 9/11 (years)	1.02 (1.01–1.03)
Months of work at WTC site	1.11 (1.08–1.14)

[a]Reference is arrival group 4 (arrival at WTC site 3–14 days post-9/11).

5 months of work exposure conferred a risk equivalent to arriving at the WTC site during the morning of 9/11, and 10 months of work was associated with an almost 3-fold risk of symptoms at follow-up. The importance of this finding cannot be overemphasized. In any disaster, exposures will be difficult to avoid in the first weeks when the potential for successful rescues are time-limited and the environment may be difficult to control. However, during subsequent recovery and cleanup phases, it is reasonable to expect appropriate protection from potential environmental hazards; our data strongly suggest the need to develop and implement strategies that include guidelines for respirator use to minimize additional exposures during these phases.

Correction

In the original manuscript published online, affiliations were incorrect for M.P.W. and J.K.N. They have been corrected here.

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Persistence of multiple illnesses in World Trade Center rescue and recovery workers: a cohort study

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Summary

Background More than 50 000 people participated in the rescue and recovery work that followed the Sept 11, 2001 (9/11) attacks on the World Trade Center (WTC). Multiple health problems in these workers were reported in the early years after the disaster. We report incidence and prevalence rates of physical and mental health disorders during the 9 years since the attacks, examine their associations with occupational exposures, and quantify physical and mental health comorbidities.

Methods In this longitudinal study of a large cohort of WTC rescue and recovery workers, we gathered data from 27 449 participants in the WTC Screening, Monitoring, and Treatment Program. The study population included police officers, firefighters, construction workers, and municipal workers. We used the Kaplan-Meier procedure to estimate cumulative and annual incidence of physical disorders (asthma, sinusitis, and gastro-oesophageal reflux disease), mental health disorders (depression, post-traumatic stress disorder [PTSD], and panic disorder), and spirometric abnormalities. Incidence rates were assessed also by level of exposure (days worked at the WTC site and exposure to the dust cloud).

Findings 9-year cumulative incidence of asthma was 27·6% (number at risk: 7027), sinusitis 42·3% (5870), and gastro-oesophageal reflux disease 39·3% (5650). In police officers, cumulative incidence of depression was 7·0% (number at risk: 3648), PTSD 9·3% (3761), and panic disorder 8·4% (3780). In other rescue and recovery workers, cumulative incidence of depression was 27·5% (number at risk: 4200), PTSD 31·9% (4342), and panic disorder 21·2% (4953). 9-year cumulative incidence for spirometric abnormalities was 41·8% (number at risk: 5769); three-quarters of these abnormalities were low forced vital capacity. Incidence of most disorders was highest in workers with greatest WTC exposure. Extensive comorbidity was reported within and between physical and mental health disorders.

Interpretation 9 years after the 9/11 WTC attacks, rescue and recovery workers continue to have a substantial burden of physical and mental health problems. These findings emphasise the need for continued monitoring and treatment of the WTC rescue and recovery population.

Funding Centers for Disease Control and Prevention and National Institute for Occupational Safety and Health.

Introduction

More than 50 000 people worked on the rescue and recovery effort that followed the terrorist attack on the World Trade Center (WTC) on Sept 11, 2001 (9/11).[1] This population was highly diverse; it included first responders such as firefighters, police officers, and paramedics, but also included operating engineers, iron workers, railway tunnel workers, telecommunications workers, sanitation workers, medical examiner staff, and volunteers, many of whom had no training in response to civil disasters.[2] These individuals were involved in rescue-and-recovery operations and clean-up of debris and restoration of essential services. They worked at Ground Zero, the WTC site, and also at barge-loading piers, vehicle cleaning stations, the landfill destinations for debris, and the medical examiner's office.

WTC rescue and recovery workers were exposed to a complex mix of airborne toxins.[3] Burning jet fuel from the hijacked airliners released a dense plume of black smoke containing benzene, other volatile organics, metals, and polycyclic aromatic hydrocarbons. The collapse of the towers pulverised building materials and created a dense cloud of dust that contained particulates, glass fibres, asbestos, lead, hydrochloric acid, polychlorinated biphenyls, organochlorine pesticides, and polychlorinated dioxins and furans.[4] These workers were also exposed to psychological stressors: long work shifts, fear for personal safety, and exposure to body parts.[2]

Several studies have described the health problems that developed in rescue and recovery workers in the first months and years after 9/11. These problems included sinusitis, new-onset cough, wheeze, gastro-oesophageal reflux disease, depression, post-traumatic stress disorder (PTSD), panic disorder, and other pulmonary illnesses.[2,5–10]

Despite this abundance of information on short-term and mid-term physical and mental health disorders in WTC rescue and recovery workers,[6,10,11] additional data on the long-term trajectories of these disorders are

unknown. We aimed to assess the cumulative incidence and current prevelance of physical and mental health disorders over the 9 years since the WTC attacks, examine their associations with occupational exposures, and quantify comorbidities within and between physical and mental health problems. Such information is needed to guide the care of WTC rescue and recovery workers and to plan responses to future disasters.

Methods

Study population

In this longitudinal cohort, the study population consisted of 27 449 WTC rescue and recovery workers who participated in the WTC Screening, Monitoring, and Treatment Program. Workers included in this analysis (ie, those who worked in protective services or military, construction, electrical or telecommunication repair, transportation or material moving, other occupations, or were unemployed or retired) were enrolled between July 16, 2002, and Sept 11, 2010. Eligible WTC responders were those who had worked or volunteered in lower Manhattan, or the Staten Island landfill or barge-loading piers for 4 h or more from 9/11 to Sept 14, 2001, 24 h or more during September, 2001, or 80 h or more from September, 2001, to December, 2001. Members of the Office of the Chief Medical Examiner who processed human remains were also eligible, as were workers from the Port Authority Trans Hudson Corporation who were engaged in cleaning tunnels for 24 h or more from 9/11 to July 1, 2002 (additional details of the programme have been described previously).[12] Members of the Fire Department of the City of New York (FDNY) were assessed by a parallel programme[13] and thus, not represented in our cohort. Similarly, the New York City Department of Health established a registry with interview data gathered from rescue and recovery workers and lower Manhattan residents, schoolchildren, building occupants, and passers-by; these data are not included in our study.[14] Although New York City firefighters and local residents are not represented in our cohort, the WTC Screening, Monitoring, and Treatment Program is unique in that it contains interview and physical examination data for a large and diverse group of non-firefighter rescue and recovery workers.

Procedures

Recruitment into our cohort was done by extensive outreach and publicity in partnership with organised labour, community, and volunteer organisations, legislative and governmental agencies, and public media outlets. Participation was voluntary and involved a comprehensive baseline examination, including medical, mental health, and exposure-assessment questionnaires, and a standardised physical examination plus spirometry. Follow-up assessments were offered every 12 to 18 months.

Presence of asthma, sinusitis, and gastro-oesophageal reflux disease was established by rescue and recovery workers' self-report of physician diagnosis. Workers also reported the date of diagnosis and, for pre-existing disorders, whether these disorders had recurred after 9/11. Mental health screening was undertaken with standardised methods to assess for symptoms of depression (patient health questionnaire [PHQ]), PTSD (PTSD symptom checklist-specific version, which includes questions about symptoms in reference to the 9/11 attacks) and panic disorder (PHQ).[15,16] Rescue and recovery workers were classified as having symptoms consistent with depression, PTSD, or panic disorder with validated algorithms.[15–17]

To assess lung function, rescue and recovery workers underwent spirometric examination at each visit done at different sites by uniformly trained technicians and with standard techniques.[18] Spirometric results were compared with reference values dependent on age, sex, race and ethnic origin, and interpreted with established guidelines.[19] Pulmonary obstruction was defined as forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) below the lower limit of normal. Spirometry with FVC lower than the lower limit of normal but FEV_1/FVC at the lower limit of normal or higher was categorised as low FVC. Rescue and recovery workers with pulmonary obstruction and low FVC were classified as having mixed airway disease.

Four exposure groups were created: very high, high, intermediate, and low. Group assignment of rescue workers was based on the total time spent working at the WTC site, exposure to the cloud of debris from the collapse of the WTC buildings, and work on the pile of debris. The very high exposure group consisted of those who worked more than 90 days, were exposed to the dust cloud, and worked at least some time on the pile. The high group was comprised of rescue workers who were exposed to the dust cloud but either worked less than 90 days or did not work on the pile. The intermediate group was comprised of workers not exposed to the dust cloud and who either worked between 40 days and 90 days or did not work on the pile. The lowest exposure group included those who worked less than 40 days, were not exposed to dust from the collapse, and did not work in the debris pile.

Statistical analysis

We used Kaplan-Meier estimates to calculate the cumulative incidence and number of individuals at risk for asthma, sinusitis, and gastro-oesophageal reflux disease. On the basis of the Kaplan-Meier curves, we estimated time from 9/11 to the first date that the responder reported a physician diagnosis of each disorder. Results were censored at the date of the last follow-up visit before Sept 11, 2010. Cumulative incidence of these disorders before 9/11 is shown at the intercept of the cumulative incidence curve (figure 1).

PHQ and PTSD-symptom-checklist scores were not available before the rescue and recovery workers' first

visit to the programme. Workers were interval-censored between the visit date of their first positive screening for a particular mental health disorder and their previous visit; those who screened positive at the first visit were left-censored. Cumulative incidence was calculated with an algorithm for interval censored data.[20] Previous research has shown a lower prevalence of mental health disorders in police officers than in other rescue and recovery workers.[21,22] Thus, the cumulative incidence of these disorders was assessed separately for New York City police officers versus other workers. We also used methods for interval-censored data to assess the incidence

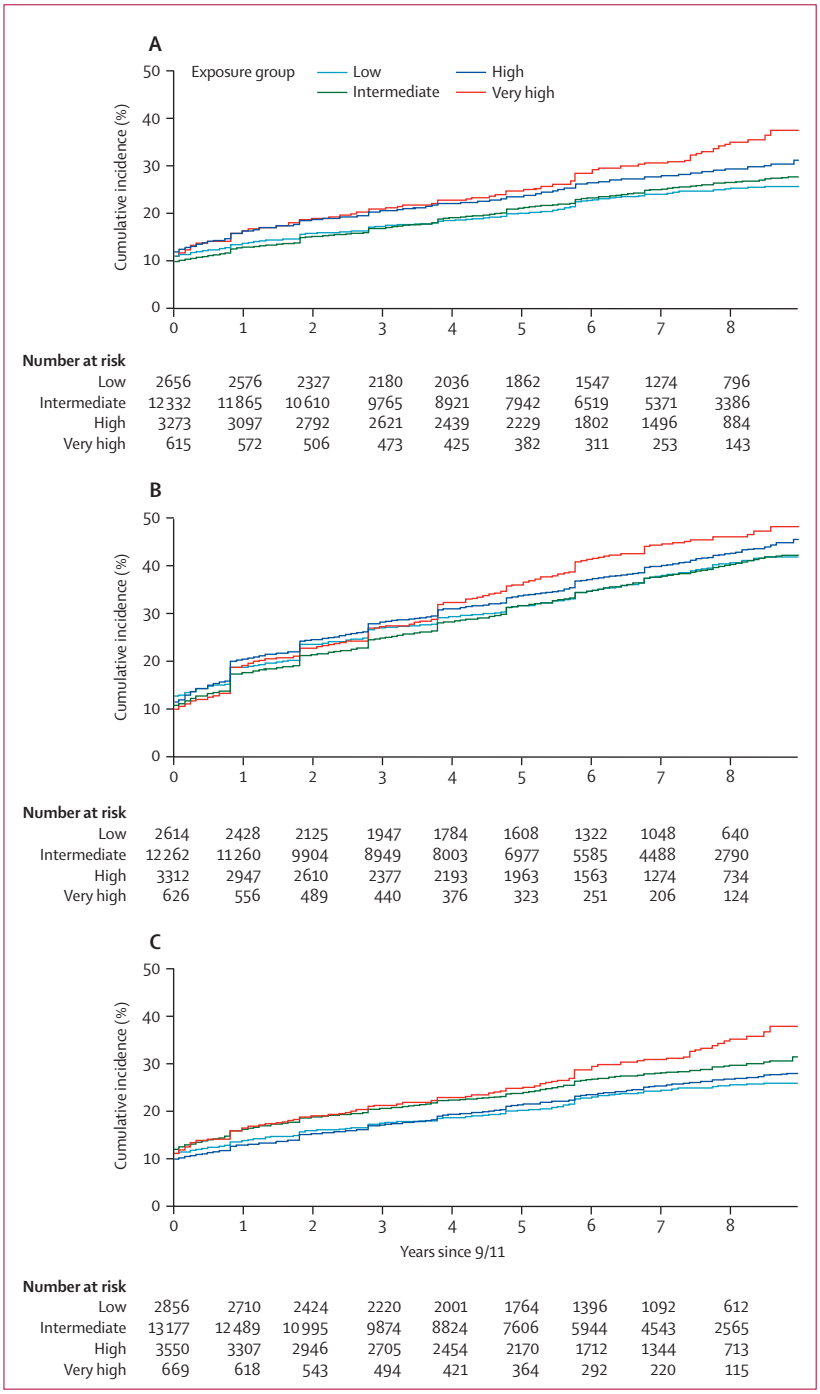

***Figure 1*: Cumulative Incidence of physical disorders in the World Trade Center Screening, Monitoring, and Treatment Program study population**
Cumulative incidence of asthma (A). Cumulative incidence of sinusitis was similar in the intermediate and low exposure groups (B). Incidence of gastro-oesophageal reflux disease incidence was increased only in the very-high-exposure group compared with other groups (C). 9/11=September 11, 2001.

	Participants (N=27 449)
Median age (years)*	38 (33–44)
Sex	
Male	23 468 (86%)
Race	
White	15 657 (57%)
Black	2963 (11%)
Asian	373 (1%)
Other	755 (3%)
Unknown	7701 (28%)
Hispanic†	6475 (31%)
Smoking‡	
Current	4054 (15%)
Former	6315 (24%)
Never	15 897 (61%)
Occupation§	
Protective services or military	12 273 (48%)
Construction	5956 (23%)
Electrical or telecommunication repair workers	1794 (7%)
Transportation or material movers	1128 (4%)
Other occupations	4025 (16%)
Unemployed or retired	477 (2%)
Union member	22 558 (83%)
Working status at the site¶	
Worker	21 287 (81%)
Volunteer	2768 (11%)
Worked and volunteer	2127 (8%)
WTC exposure category‖	
Low	3235 (14%)
Intermediate	14 769 (65%)
High	4019 (18%)
Very high	749 (3%)
Directly exposed to the dust cloud from collapse	5059 (21%)
Started working on 9/11	12 041 (44%)
Year of enrolment into the programme¶	
≤2004	11 296 (41%)
2005–07	9509 (35%)
≥2008	6643 (24%)

Data are number (%) or median (IQR). 9/11=Sept 11, 2001. WTC=World Trade Center. *Age on 9/11. †Data missing for 6206 rescue and recovery workers who did not answer the question about ethnic origin. ‡Data missing for 1183 rescue and recovery workers. §Data missing for 1796 rescue and recovery workers. ¶Data missing for 1267 rescue and recovery workers. ‖Data missing for 4677 rescue and recovery workers.

***Table 1*: Baseline demographic characteristics of the World Trade Center Screening, Monitoring, and Treatment Program study population**

of spirometric abnormalities. Rescue and recovery workers were categorised as having normal or abnormal (obstructive, low FVC, or mixed patterns) spirometric findings. This grouping is consistent with data that showed that most rescue and recovery workers with low FVC had obstructive lung disease.[23] To assess the annual risk of developing each disorder, we estimated conditional incidence rates (ie, the risk of developing a disorder in a specific year) by dividing the increment in the cumulative incidence during each year of follow-up by the cumulative incidence rate at the start of the year.

The prevalence of active asthma, sinusitis, and gastro-oesophageal reflux disease 9 years after exposure was calculated as the ratio of the number of rescue workers who reported being under physician care, taking drugs, or having had an acute episode of a specific disorder during the month before the follow-up visit, to the number of rescue workers examined during that year. The proportion of rescue and recovery workers who had symptoms consistent with depression, PTSD, panic disorder, or abnormal spirometry during the 9th year of the programme was also calculated.

To assess associations of health disorders with exposures after 9/11, we examined the cumulative incidence of each physical and mental health diagnosis and spirometric abnormality by exposure group. To assess the extent to which WTC rescue and recovery workers suffered from multiple physical or mental health problems, we constructed Venn diagrams. Analyses were done with SAS (version 9.1). The study was approved by the Institutional Review Board of Mount Sinai School of Medicine and all participants provided signed consent to use their data.

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication

Results

Most rescue and recovery workers in our cohort were male, white, and had a median age of 38 years on 9/11 (table 1). The most common occupations were protective service or military and construction (table 1). Over a tenth of rescue workers were in the low WTC exposure category, about two-thirds were intermediate category, about a fifth were in the high category, and only a few were in the very high category (table 1). The overall distribution of baseline characteristics was relatively similar across the four exposure groups; except that males and protective service or military personnel were over-represented in the very high exposure category.

Rates of rescue and recovery worker follow-up were 71% (17 224) for the first visit, 61% (9681) for the second,

	Pre-exposure	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Physical health										
Asthma	10·5% (24 985)	13·7% (22 360)	15·8% (21 496)	17·5% (19 505)	19·3% (18 227)	21·1% (16 897)	23·4% (15 317)	25·0% (12 809)	26·4% (10 744)	27·6% (7027)
Sinusitis	10·7% (25 041)	18·0% (22 357)	21·8% (20 476)	25·2% (18 238)	28·3% (16 709)	31·2% (15 204)	34·4% (13 537)	37·3% (11 100)	39·8% (9109)	42·3% (5870)
Gastro-oesophageal reflux disease	5·8% (25 539)	10·7% (24 055)	14·4% (22 741)	17·9% (20 343)	21·5% (18 603)	25·4% (16 828)	29·9% (14 796)	33·6% (11 896)	37·1% (9423)	39·3% (5650)
Mental health symptoms										
New York City police										
Depression	..	1·7% (9573)	2·0% (9467)	2·3% (8734)	3·7% (8026)	3·7% (7510)	4·2% (6999)	4·2% (6097)	6·2% (5420)	7·0% (3648)
PTSD	..	2·5% (9866)	2·5% (9679)	4·0% (9124)	4·6% (8624)	5·7% (8155)	6·3% (7597)	7·4% (6537)	8·4% (5601)	9·3% (3761)
Panic disorder	..	2·3% (9820)	2·6% (9691)	3·1% (8928)	4·4% (8186)	4·4% (7659)	5·6% (7158)	5·7% (6271)	7·0% (5591)	8·4% (3780)
Other rescue and recovery workers*										
Depression	..	10·8% (15 062)	12·7% (14 105)	15·3% (11 620)	17·0% (9855)	17·4% (8847)	19·0% (8205)	22·3% (7138)	24·6% (6229)	27·5% (4200)
PTSD	..	12·8% (16 054)	13·5% (14 641)	17·1% (12 306)	19·8% (10 762)	22·6% (9785)	24·2% (8956)	27·2% (7682)	29·7% (6473)	31·9% (4342)
Panic disorder	..	5·0% (15 995)	5·7% (15 302)	8·1% (12 880)	12·8% (10 964)	12·8% (10 083)	13·7% (9446)	14·2% (8302)	18·5% (7349)	21·2% (4953)
Abnormal spirometry	..	23·7% (24 566)	24·9% (22 174)	27·1% (19 105)	28·5% (16 542)	29·1% (14 378)	32·4% (12 700)	34·9% (10 883)	37·9% (8949)	41·8% (5769)

Data are % (number at risk). Number of individuals at risk is estimated from cumulative incidence curves. PTSD=post-traumatic stress disorder. *All workers except New York City police officers.

***Table 2*: Cumulative incidence before and after 9/11 of physical disorders, mental health symptoms, and spirometric abnormalities in the World Trade Center Screening, Monitoring, and Treatment Program study population**

and 55% (4410) for the third. Cumulative incidence of asthma increased from 10·5% (number at risk: 24985) at baseline to 13·7% (22360) at year 1, 21·1% (16897) at year 5, and 27·6% (7027) at year 9 (figure 1 and table 2). Annual incidence was highest during the 1st year after 9/11 and then remained stable in subsequent years at about 2% (table 3). Cumulative incidence of sinusitis increased from 10·7% (number at risk: 25041) before 9/11 to 18·0% (22357) at year 1, 31·2% (15204) at year 5, and 42·3% (5870) at year 9. (table 2). Highest incidence of sinusitis occurred during the first year after WTC exposure, and thereafter, was about 4% (table 3). For gastro-oesophageal reflux disease, cumulative incidence was 5·8% (number at risk: 25539) at baseline and cumulatively increased to 10·7% (24055) at year 1, 25·4% (16828) at year 5, and 39·3% (5650) at year 9 (table 2). Annual incidence ranged from 4–6% in all follow-up years. At year 9, prevalence of active asthma was 18·1% (1893), of sinusitis was 20·0% (2042), and of gastro-oesophageal reflux disease was 32·6% (3195).

Overall, 272 (1%) of rescue and recovery workers reported a history of physician diagnosed PTSD before 9/11 and 696 (3%) reported a previous diagnosis of depression. Cumulative incidence of PTSD, depression, and panic disorder was substantially lower in New York City police officers than in other rescue and recovery workers (table 2). PTSD was the mental health disorder with the highest cumulative incidence in both groups at all time intervals (table 2). Among police officers, annual incidence of PTSD peaked in the 4th year after 9/11 and then stabilised at about 1–2% per year (table 3). The annual incidence of PTSD for other rescue workers also peaked in the 4th year of follow-up and remained at about 3–4% in subsequent years (table 3).

Cumulative incidence of depression in New York City police officers was 1·7% (number at risk: 9573) at year 1, 3·7% (7510) at year 5, and 7·0% (3648) at year 9; in other rescue and recovery workers cumulative incidence was 10·8% (15062) at year 1, 17·4% (8847) at year 5, and 27·5% (4200) at year 9 (table 2). Cumulative incidence of panic disorder in police officers was 2·3% (number at risk: 9820) at year 1 and increased to 4·4% (7659) at year 5 and 8·4% (3780) at year 9. For other rescue and recovery workers, cumulative incidence rates of panic disorder were 5·0% (number at risk: 15995) at year 1, 12·8% (10083) at year 5, and 21·2% (4953) at year 9 (table 2). At year 9, prevalence of depression in police officers was 4·5% (171), PTSD 5·0% (198), and panic disorder 4·8% (191); in other rescue workers, prevalence of depression was 17·9% (953), PTSD 19·2% (1141), and panic disorder 12·3% (727).

Cumulative incidence rates of abnormal spirometry were 23·7% (number at risk: 24566) at year 1, 29·1% (14378) at year 5, and 41·8% (5769) at year 9

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Physical health									
Asthma	3·4% (22360)	2·5% (21496)	2·0% (19505)	2·2% (18227)	2·2% (16897)	2·9% (15317)	2·1% (12809)	1·8% (10744)	1·8% (7027)
Sinusitis	8·0% (22357)	4·7% (20476)	4·2% (18238)	4·2% (16709)	4·0% (15204)	4·6% (13537)	4·4% (11100)	4·0% (9109)	4·3% (5870)
Gastro-oesophageal reflux disease	5·0% (24055)	4·3% (22741)	4·0% (20343)	4·4% (18603)	4·9% (16828)	6·0% (14796)	5·3% (11896)	5·0% (9423)	4·1% (5650)
Mental health symptoms									
New York City police									
Depression	..*	0·3% (9467)	0·3% (8734)	1·4% (8026)	0·0% (7510)	0·5% (6999)	0·0% (6097)	2·0% (5420)	0·9% (3648)
PTSD	..	0·1% (9679)	0·0% (9124)	1·8% (8624)	0·8% (8155)	1·3% (7597)	0·4% (6537)	1·8% (5601)	1·0% (3761)
Panic disorder	..	0·2% (9691)	0·4% (8928)	1·5% (8186)	0·0% (7659)	0·7% (7158)	0·5% (6271)	1·3% (5591)	1·7% (3780)
Other rescue and recovery workers									
Depression	..	3·6% (14105)	2·9% (11620)	2·0% (9855)	0·4% (8847)	1·9% (8205)	4·2% (7138)	2·9% (6229)	3·9% (4200)
PTSD	..	0·3% (14641)	3·5% (12306)	4·4% (10762)	3·3% (9785)	2·3% (8956)	4·0% (7682)	2·8% (6473)	3·7% (4342)
Panic disorder	..	1·3% (15302)	1·4% (12880)	3·9% (10964)	2·3% (10083)	0·9% (9446)	0·6% (8302)	4·9% (7349)	2·9% (4953)
Abnormal spirometry	..	1·6% (22174)	1·0% (19105)	3·9% (16542)	0·8% (14378)	2·5% (12700)	5·8% (10883)	4·7% (8949)	6·2% (5769)

Data are % (number at risk). Number of individuals at risk estimated from cumulative incidence curves. PTSD=post-traumatic stress disorder. *No rate was estimated for year 1 because no data on mental health symptoms was available before 9/11. 9/11=Sept 11, 2001.

***Table 3*: Annual conditional incidence after 9/11 of physical disorders, mental health symptoms, and spirometric abnormalities in the World Trade Center Screening, Monitoring, and Treatment Program study population**

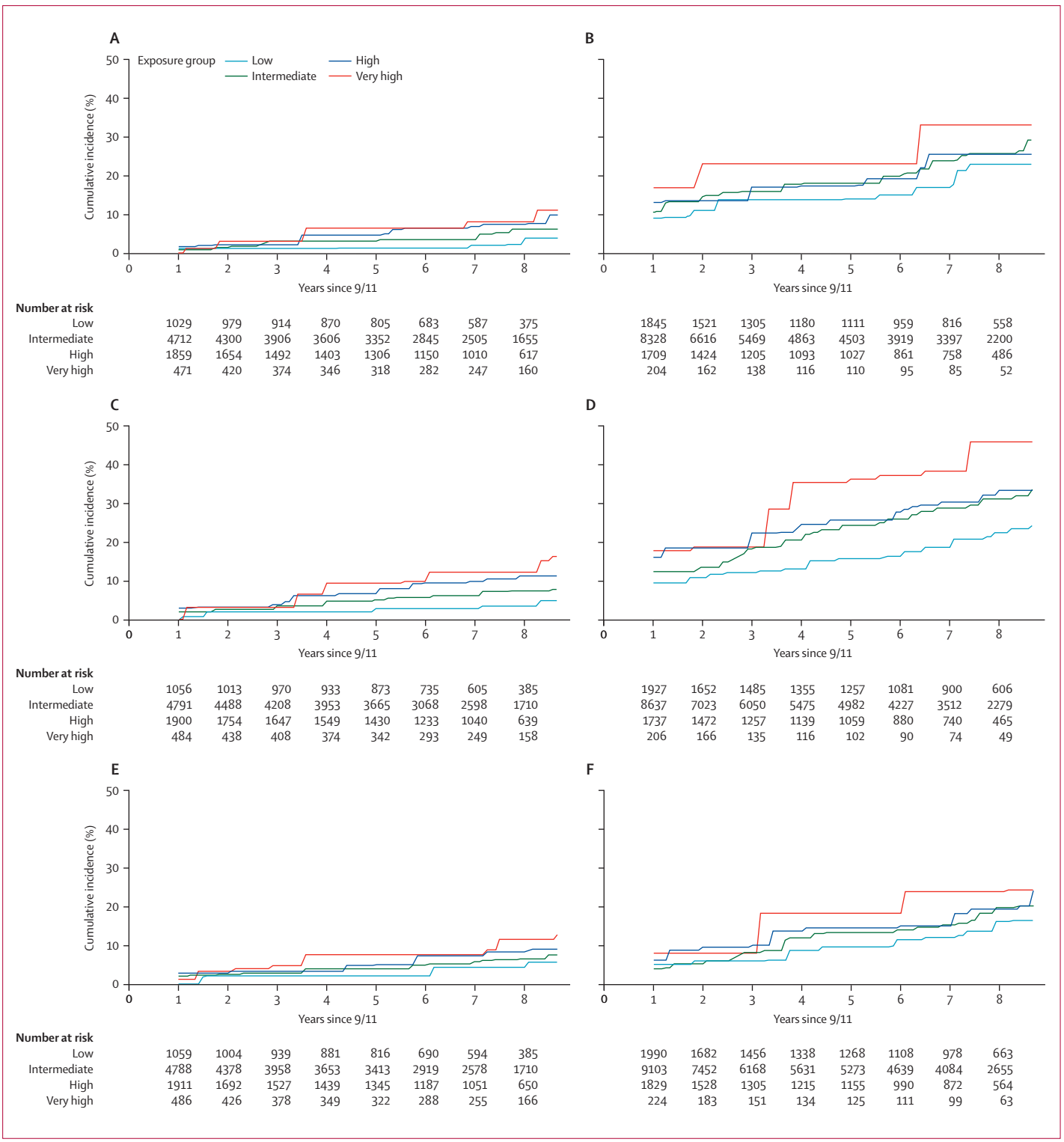

Figure 2: **Cumulative incidence of mental health disorders in New York City police officers and other rescue and recovery workers in the World Trade Center Screening, Monitoring, and Treatment Program study population**

Symptoms of depression in police officers were similar in the very-high and high-exposure categories (A). Symptoms of depression in other rescue and recovery workers were similar in the high and intermediate exposure categories (B). Symptoms of post-traumatic stress disorder (PTSD) were more common in police officers with higher exposure (C). Higher levels of exposure were associated with increased rates of PTSD symptoms in other responders (D). Symptoms of panic disorders were more common in police officers with higher levels of exposure (E). High exposure levels were associated with increased rates of panic-disorder symptoms in other rescue and recovery workers (F). 9/11=September 11, 2001.

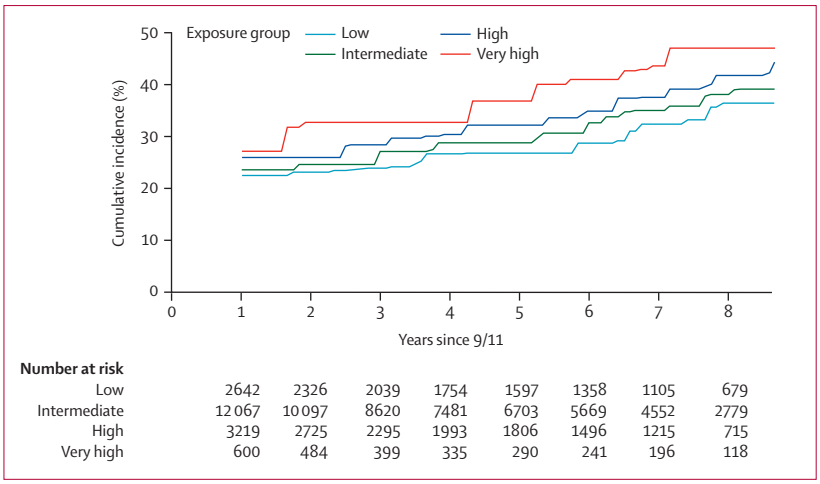

***Figure 3*: Cumulative incidence of abnormal spirometry in the World Trade Center Screening, Monitoring, and Treatment Program study population**
9/11=September 11, 2001.

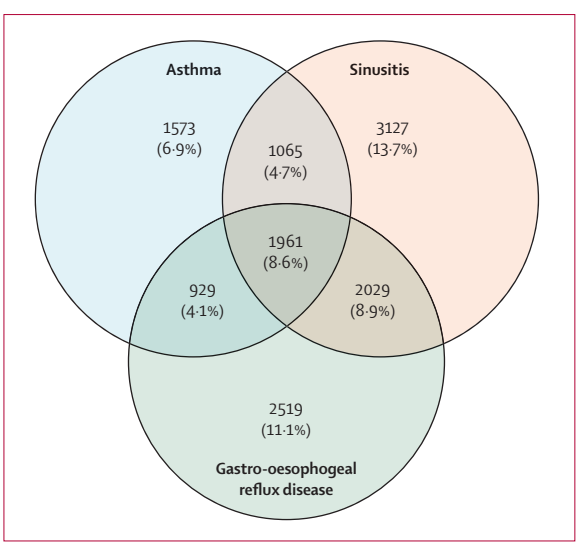

***Figure 4*: Physical comorbidities in the World Trade Center Screening, Monitoring, and Treatment Program study population**
The Venn diagram shows the extent of comorbidity in World Trade Center rescue and recovery workers who reported ever having asthma, sinusitis, or gastro-oesophageal reflux disease.

(table 2). Annual incidence of new abnormalities in lung function was about 1–2% in the initial years after exposure and then increased to 5–6% in the latter years of follow-up. At year 9, prevalence of obstructive pulmonary disease in rescue and recovery workers was 4·4% (399), low FVC 21·8% (1992), and mixed abnormalities 2·1% (188).

In analyses of exposure-stratified cumulative incidence rates, we noted that risk of asthma, sinusitis, and gastro-oesophageal reflux disease was greatest in workers with the highest levels of exposure (figure 1A–C). Overall, we reported similar findings for mental health disorders (figure 2A–F) and spirometric abnormalities (figure 3).

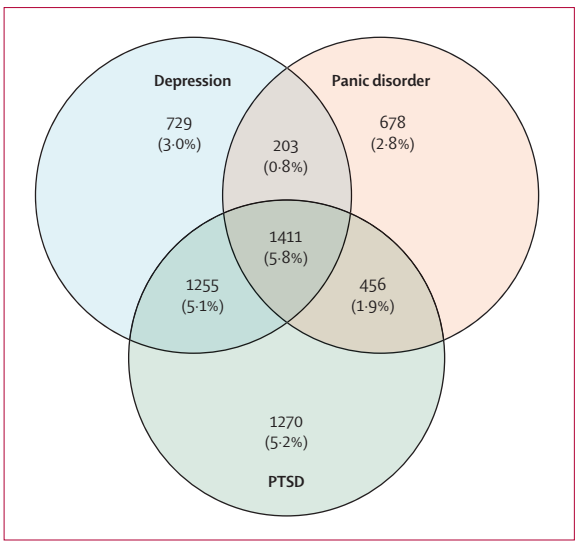

***Figure 5*: Mental health comorbidities in the World Trade Center Screening, Monitoring, and Treatment Program study population**
High number of rescue and recovery workers had symptoms consistent with several of the mental health disorders assessed during the 9 year follow-up. PTSD= post-traumatic stress disorder.

We identified extensive comorbidities associated with physical and mental health disorders. Overall, nearly a tenth of rescue and recovery workers reported physician diagnosis of three disorders: asthma, sinusitis, and gastro-oesophageal reflux disease (figure 4). About 18% of rescue and recovery workers reported diagnoses of two disorders (figure 4). The proportion of rescue and recovery workers with symptoms consistent with PTSD, depression, and panic disorder are shown in figure 5. The proportion of those with symptoms of both depression and PTSD were also reported (figure 5). Substantial comorbidity across physical and mental health disorders was also reported: 1459 (48·3%) rescue and recovery workers with asthma, 2006 (38·2%) with sinusitis, and 2348 (42·7%) with gastro-oesophageal reflux disease reported at least one mental health disorder. Similarly, 2806 (69·6%) with PTSD, 2153 (70·4%) with depression, and 1129 (72·4%) with panic disorder reported a physician diagnosis of at least one physical disorder.

Discussion

We reported that about 10–30% of rescue and recovery workers still had persistent medical disorders 9 years after the WTC attacks. More than a fifth had multiple physical and mental health problems. Most health disorders were more common in rescue and recovery workers with highest levels of exposure to dust and smoke than in those with lower levels of exposure (panel).

Our finding of upper and lower airway injury in WTC rescue and recovery workers is consistent with data from studies that have shown high rates of respiratory disease and declines in pulmonary function after exposure to WTC dust.[6,10,24] A study of New York City firefighters who

responded to WTC attack showed a striking decline in FEV_1 in the 12-month period after 9/11.[10] Airway obstruction with air trapping seemed to be the main physiological mechanism underlying this reduction in lung function.[23] Similarly, data from the WTC registry, which tracks diagnoses in rescue and recovery workers and residents of lower Manhattan, showed high rates of new onset asthma after the attacks.[6] We noted that annual incidence of abnormal spirometry in rescue and recovery workers was higher in the later years of follow-up than in earlier years. A possible explanation for this unanticipated finding is that some workers who had early subclinical loss of lung function after 9/11 crossed the threshold of abnormality only several years later as the result of further pathological or age-related decline in lung function. However, other factors, including temporal biases in the study population, cannot be excluded.

Inhalation of toxic, highly alkaline dust (pH 10–11) is the probable cause of upper and lower respiratory injury in rescue and recovery workers. The dust generated by the collapse of the WTC towers and the diesel exhaust fumes produced by rescue and recovery machinery might have caused inflammation of responders' airways, which could have led to irritant-induced rhinosinusitis, pharyngitis, and asthma. Previous studies in occupational settings have shown that comparable levels of exposure to airborne pollutants are associated with reactive airway disease.[25,26] Furthermore, animal studies have shown that exposure of the respiratory tract to high levels of fine particulate matter obtained from the WTC site has been associated with development of pulmonary inflammation and airway hyper-responsiveness.[27] Collectively, these findings underscore the importance of providing rescue workers with access to respiratory protection and enforcing its use while responding to disasters.

Previous studies have shown that New York City police officers were at lower risk than some responders for developing mental health disorders after the WTC attacks.[21,22] Possible reasons for these findings include training, previous experience in dealing with similar stressors, self-selection of individuals with high resilience during recruitment into the workforce, and possible under-reporting of psychological symptoms because of perceived job-related repercussions. We report here that PTSD and depression are the most common mental health disorders in police officers and other individuals involved with the WTC rescue and recovery efforts, a finding consistent with research showing that most WTC rescue and recovery workers with depression had comorbid PTSD.[28]

We established that rates of panic disorder remained raised up to 9 years after 9/11. These findings could have been due, in part, to anxiety symptoms that existed before WTC exposure or because some patients with generalised anxiety disorder could have been included by use of our screening method. These mental health problems occurred most commonly in rescue and recovery workers exposed to the dust cloud, which is consistent with previous findings of post-disaster psychopathological research.[6,21,29–31]

We assessed overall rates of mental health disorders in rescue and recovery workers without undertaking further analyses to stratify the sample by established risk factors such as age, sex, race or ethnic origin. Thus, our overall results might underestimate or overestimate the actual rates of mental health disorders in specific subgroups of workers. Similarly, data for ethnic origin were missing for some responders (table 1). Previous studies, for example, have shown that Hispanic WTC rescue and recovery workers have a high risk for PTSD. Consequently, the rate of PTSD seen in our study could have been underestimated, if a substantial proportion of workers with missing data for ethnic origin were Hispanics.

We do not know exactly how representative our study cohort is of the entire population of WTC first responders, because participation in our programme was voluntary. This potential shortcoming is compounded by the fact that comprehensive records of participation in the WTC rescue and recovery effort were not maintained. Therefore, neither the total number of rescue and recovery workers nor the proportion of them participating in our programme is known.

Estimates of the size of the WTC rescue and recovery worker population have varied. Calculations that need a minimal worker involvement and time undertaking rescue and recovery work suggest that the true number of workers is more than 50 000.[1] The number of WTC workers enrolled in our programme and in the parallel programme done by the FDNY is more than 40 000.[1]

Panel: Research in context

Systematic review

We searched Medline from September, 2006, to May, 2011, without language restrictions, for original studies and reviews assessing long-term illnesses in WTC rescue and recovery workers and volunteers. We used the search terms: "illnesses", "September 11", and "World Trade Center attacks". We identified five original studies and one review that summarised some of the illnesses reported by WTC rescue and recovery workers and volunteers at 5–7 years after 9/11.

Interpretation

The high prevalence of physical and mental health disorders in WTC rescue and recovery workers 9 years after the WTC disaster underscores the importance of continual provision of adequate health monitoring and treatment for these individuals. These data suggest that the clinical management of the health consequences of WTC exposures will require coordinated physical and mental health care. Planning for future disasters should anticipate the probability of persistent physical and mental illness in rescue and recovery workers.

WTC=World Trade Center. 9/11=September 11, 2001.

Hence, these two programmes combined are assessing a substantial proportion of the rescue and recovery workers. As a result of the staggered and voluntary enrolment of individuals into our programme, we do not have information from each responder at every follow-up time. However, we used robust statistical methods to estimate unbiased rates of physical and mental health disorders in the absence of complete data and to provide information on the number of rescue and recovery workers at risk at each year after 9/11. Nonetheless, self-selection of workers into our programme on the basis of WTC exposure, perceived risk, or presence of physical or mental health disorders could have occurred, which might reduce the generalisability of our findings to all WTC rescue and recovery workers.

Recruitment into our programme was staggered with some rescue and recovery workers joining in the last 3 years of the study. Although the sociodemographic characteristics of early and recent enrollees was relatively similar, we cannot exclude the possibility of recall bias or self-selection of workers at increased risk for physical or mental health disorders in late enrolees. Incidence and prevalence of most physical disorders were similar in our cohort and the FDNY cohort, which suggests that workers with medical problems have not enrolled in disproportionate numbers in our programme. By contrast with our cohort, participation in the FDNY programme was mandatory for all active duty New York City firefighters and paramedics. Therefore, the possibility of selection bias in the FDNY cohort is minimal.

We did not use an external control population to compare the rates of physical and mental health disorders in WTC rescue and recovery workers. Identification of an appropriate control group was difficult because of the unique nature of the population of workers and the possibility of a healthy worker effect in the study cohort (ie, workers commonly having lower rates of disease than the general population because severely ill and disabled individuals are less likely to be employed).[32]

We established the presence of physical disorders with self-reported information. However, objective lung function data were available from spirometry and we used validated methods to assess the presence of mental health disorders. Thus, incidence rates and prevalence of these disorders should be minimally affected by reporting bias.

We categorised each worker's level of exposure solely on the basis of three factors: exposure to the dust cloud, total time spent working at the WTC site, and work on the debris pile. These exposures have been consistently associated with risk of illnesses in WTC rescue and recovery workers and we identified positive dose–response relations in our analyses similar to those reported in other studies.[2,6] We did not, however, assess the extent to which other exposure factors, such as use of respiratory protection, personal hygiene measures, or exposure to body parts, might have influenced the observed risk of physical or mental health disorders.

Our findings show a substantial burden of persistent physical and mental disorders in rescue and recovery workers who rushed to the site of the WTC and laboured there for weeks and months 10 years ago. Many of these individuals now suffer from multiple health problems. The findings of this study emphasise the need for continued monitoring and treatment of the rescue and recovery worker population and underscore the importance of providing adequate health monitoring and treatment for these individuals. Planning for future disasters should anticipate the probability of persistent physical and mental illness in rescue and recovery workers.

Contributors

JPW and PJL had overall responsibility for the study. JPW, SLT, ACT, PJL, and SW contributed to the study design. SM, LC, REdlH, DH, RH, SL, MS, GS, JMM, LAS, IU, CK, VS, FO, and MC contributed to data collection. LS, ST, CD, CL, YJ, JK, MS, and HK contributed to data analysis. JPW, ST, AT, PB, RH, JM, RP, SS, LS, SW, and PJL contributed to the interpretation of the data. All authors wrote this Article.

Conflicts of interest

JPW is a member of the research board of EHE International. All other authors declare that they have no conflicts of interest.

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Impact of Health on Early Retirement and Post-Retirement Income Loss among Survivors of the 11 September 2001 World Trade Center Disaster

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Abstract: The health consequences of the 9/11 World Trade Center (WTC) terrorist attacks are well documented, but few studies have assessed the disaster's impact on employment among individuals exposed to the disaster. We examined the association between 9/11-related health conditions and early retirement among residents and workers who resided and/or worked near the WTC site on 9/11, and the association between such conditions and post-retirement income loss. The study included 6377 residents and/or area workers who completed the WTC Health Registry longitudinal health surveys in 2003–2004 and 2006–2007, and the 2017–2018 Health and Employment Survey. Logistic regression models were used to examine the associations. We found that 9/11-related health conditions were significantly associated with the likelihood of early retirement. Residents and/or area workers with more physical health conditions, especially when comorbid with posttraumatic stress disorder (PTSD), were more likely to retire before age 60 than those with no conditions. For retirees, having PTSD or PTSD comorbid with any number of physical conditions increased the odds of reporting substantial post-retirement income loss. Disaster-related outcomes can negatively impact aging individuals in the form of early retirement and income loss. Long-term effects of major disasters must continue to be studied.

Keywords: 9/11 impact; retirement; chronic disease; PTSD; disaster; income loss

1. Introduction

Many studies have documented the short-term health impacts of the World Trade Center (WTC) 11 September 2001 attacks, while longer-term observations of various chronic physical and mental health conditions continue to be reported among individuals exposed to the disaster [1–3]. However, relatively few studies have assessed the economic impact of the 9/11 attacks. It was noted that New York City (NYC) earnings at an aggregate level had $2.8 billion losses in the first three months post-9/11 [4]. For NYC industries, losses ranged from $3.6 to $6.4 billion in the nine months following the disaster [5]. Despite the well-established association between disaster exposure and impaired health among the 9/11-exposed population, few studies have examined the economic impact of 9/11-related poor health. One such study found that during the seven years after 9/11, nearly half of accidental disability retirements for NYC firefighters were for 9/11-related injuries or illnesses [6]. Another study conducted by the WTC Health Registry found a significant association between 9/11-related poor health and early retirement or job loss [7].

Unlike our first published work that focused on the 9/11 economic impact for non-uniformed rescue and recovery workers [7], this analysis concentrated on retirement and post-retirement well-being for residents and area workers who resided and/or worked near the WTC site on 9/11.

Previous research showed that different groups of survivors, such as rescue and recovery workers, local residents, area workers, passersby, and students and school staff, may have had different health outcomes, both physical and mental, due to their varying levels of disaster exposure [1,8,9]. Consequently, health-related retirement may also differ for different groups of survivors. Furthermore, retirement options available to rescue and recovery workers, especially uniformed workers, as compared to residents and area workers, can be a key factor in making retirement decisions and must be linked to the subsequent economic outcome [10–13].

Retirement trends were shifting during the mid-1990s into the 2000s irrespective of the effects of the 9/11 disaster, as fewer people were retiring at younger ages compared to the 1970s and 1980s [14]. Trends of employer pension plans becoming rarer, a healthier population overall, fewer labor-intensive jobs, less employer-sponsored health benefits for retirees under age 65, and an older full retirement age for Social Security have resulted in people retiring at older ages than earlier generations [15]. In tandem, retirement patterns have become more complex with many individuals transitioning from full-time to part-time work or working again after retirement [15]. Early retirement, therefore, is an important factor to consider for economic assessments, as it can strongly affect one's well-being (such as post-retirement income) for the remainder of one's life.

Poor health has been linked to early retirement in numerous studies for different population groups or countries. Self-perceived poor health was a risk factor for early exit from the labor force through early retirement, unemployment, or both [16–20]. Other studies found an association between a variety of health conditions, such as respiratory, cardiovascular, musculoskeletal diseases, cancer, and other chronic conditions, and premature labor force exit [16,17,19,21–23]. However, health problems are not the only factor that impacts decisions about early retirement; one's financial situation is another key factor in this decision-making process [24,25]. Experiencing a layoff or having a spouse who retires early increases one's likelihood of retiring early whereas being able to take a new job that requires fewer hours or offers higher pay is protective against retiring early [26]. Multiple studies have concluded, however, that health, even a subjective assessment of health, is the most important predictor of early retirement [24–26].

Previous studies of 9/11 health impact showed elevated prevalence of many chronic physical conditions, posttraumatic stress disorder (PTSD), and physical-mental comorbidity among disaster survivors [1,9,27–32]. We examined 9/11-related health conditions and PTSD comorbidity in the current analysis of health's impact on early retirement. We also went one step further and assessed whether or not those physically and/or mentally affected by the disaster continued to experience decline in their well-being after retirement in terms of substantial income loss.

In 2017–2018, the WTC Health Registry conducted an in-depth study on health and employment for a sub-sample of its enrollees. Detailed information on employment, retirement, health insurance, and other economic indicators collected from this survey, coupled with detailed health data collected from the Registry's longitudinal surveys administered in waves since 2003, provided an opportunity to further investigate the impact of 9/11-related health on retirement and post-retirement well-being. As in our previous study [7], the number of 9/11-related chronic physical health conditions and PTSD were used to measure post-9/11 health status. We hypothesized that the more 9/11-related health conditions an individual had, the more likely he or she would be to retire before age 60. Furthermore, for those who had already retired, the number of post-9/11 conditions they suffered was associated with the degree of their post-retirement income loss.

2. Materials and Methods

2.1. Study Population

The WTC Health Registry maintains a longitudinal cohort that was established in 2002 following the 11 September 2001 terrorist attacks with the aim of monitoring the long-term health outcomes in individuals exposed to the events of 9/11 in NYC. In 2003–2004, the Registry enrolled 71,426 rescue or

recovery workers, Lower Manhattan residents, area workers, passersby, and students or school staff by conducting its first health survey (Wave 1). Eligible enrollees have since been invited to participate in three additional health surveys in 2006–2007 (Wave 2), 2011–2012 (Wave 3), and 2015–2016 (Wave 4) as well as a number of in-depth studies. Previous Registry publications provide a more detailed description of this cohort [1,8].

From September 2017 to March 2018, the Registry conducted the Health and Employment Survey (HES) with a sample pool of English-speaking enrollees under 75 years of age (as of 2017) who completed at least Waves 1 and 2. Enrollees who reported retirement or unemployment due to disability/health at any of the three follow-up surveys (Waves 2–4) were invited to participate in the HES study along with a roughly equivalent number of not-yet retired age-matched enrollees. In total, 23,036 enrollees were invited to complete the HES, and the response rate reached 65%. The US Centers for Disease Control and Prevention (3793) and the NYC Department of Health and Mental Hygiene (02058) institutional review boards approved the Registry protocol and the HES protocol (17047), including the use of the data.

This study used data collected from the HES and was limited to those who lived or worked near the WTC site on 11 September 2001. During analyses, the HES data were merged with the Registry's four waves of health survey data to obtain 9/11-related health information for the study sample. We excluded 341 enrollees who had retired before the 9/11 disaster, as our focus was on the link between 9/11-related health and retirement. The final study sample was 6377 enrollees, which included 3486 retired and 2891 not-yet-retired enrollees. Of the 3486 retirees, 1234 retired before age 60, 2143 retired at or after age 60, and 109 did not report time of retirement. Additionally, 2395 enrollees reported post-retirement income loss.

2.2. Study Outcomes: Early Retirement and Post-Retirement Income Loss

In the HES, enrollees were asked if they were currently retired and, if retired, for the month and year of retirement. This information was used to calculate retirement age. In the analytical model, a dichotomous outcome variable was created for early retirement which was defined as having retired before reaching the age of 60.

Those self-reporting retirement in the HES were also asked if their total post-retirement personal income after taxes changed as compared to pre-retirement and in which direction; if they responded that their income had decreased, a follow-up question asked for the percentage of decrease (<25%, 25% to 50%, >50%). A dichotomous outcome variable for post-retirement income loss was created for those who reported substantial income loss which was defined as having over 50% of income decrease.

2.3. Chronic Physical Health Conditions and PTSD Measure

Starting in Wave 1, Registry enrollees were asked in each of the follow-up wave surveys whether they had ever been told by a doctor or other health professional that they had any of more than a dozen listed health conditions and the year of first diagnosis if diagnosed. For this study, asthma, heart disease (coronary heart disease, angina, heart attack, or other heart disease), stroke, lung disease (emphysema, chronic bronchitis, reactive airways dysfunction syndrome, sarcoidosis, pulmonary fibrosis, or other lung disease), diabetes, gastroesophageal reflux disease, and autoimmune disease (multiple sclerosis or amyotrophic lateral sclerosis, rheumatoid arthritis, or other autoimmune disease) were selected, as all have been reported to be elevated among 9/11 exposed individuals [27,33–39]. If an enrollee reported a diagnosis for any of the seven selected types of conditions in or after 2001, we categorized them as having a 9/11-related chronic physical health condition. Probable PTSD was assessed at every wave of the Registry survey via a 9/11-specific PTSD Checklist-Civilian Version (PCL-17) scale. A cut-off score of 44 or greater at any wave was used to define probable PTSD as in prior published Registry studies [1]. Co-occurrence of any of the seven selected types of physical conditions and probable PTSD was then defined as 9/11-related physical–mental comorbidity in this study.

The total number of chronic physical conditions, comorbid with PTSD or not, was used as the health indicator in the analytical models.

2.4. Sociodemographic Characteristics and Other Covariate Measures

Sociodemographic characteristics of the study sample were measured by sex, age at 11 September 2001, race/ethnicity, household income, education, and marital status. A quantitative 9/11 exposure measure was also included in the analysis as it is closely associated with PTSD [1]. The exposure measure combines disaster information, such as dust cloud exposure, injury, witnessing horror, bereavement, and home evacuation experience, collected from both Waves 1 and 2 into a 12-item score that was collapsed into four categories: 0–1 as no/low exposure, 2–3 as medium, 4–5 as high, and six or greater as very high exposure.

2.5. Statistical Analyses

Two logistic regression models were used to calculate the adjusted odds ratio (AOR) and 95% confidence intervals (95% CI) to measure the association between 9/11-related health conditions and our study outcomes. The equation for these models is

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \quad (1)$$

where p is the probability of our outcome occurring, β_0 is the intercept, $\beta_1, \ldots, \beta_k$ are the regression coefficients, and $X_1, \ldots, X_k$ are the predictors or covariates included in the model (described above). The adjusted odds ratio was estimated by taking the exponential of the regression coefficients in the model.

The first model included 4125 non-retired enrollees and early retirees, and aimed to demonstrate the relationship between poor health (measured by the number of 9/11-related health conditions with and without PTSD) and the likelihood of retiring before age 60, while adjusting for sociodemographic factors and disaster exposure.

The second model included 2395 enrollees who reported income loss after retirement and investigated the association between 9/11-related health conditions and substantial post-retirement income loss while adjusting for disaster exposure and all sociodemographic characteristics included in the first model except for age at 11 September 2001. Even though post-retirement income decreases are common and subject to lower tax rates and less work-related expenses [40], this analysis aimed to reveal that substantial income decrease (percentage of decrease larger than 50%) was associated with health.

The analyses for this study were conducted in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

3. Results

Among 4125 residents and area workers who lived or worked near the WTC site on 9/11, 1234 (29.9%) reported having retired before age 60 (Table 1). Sociodemographic characteristics that were significantly associated with early retirement included age, race/ethnicity, total household income, marital status, and education. Not surprisingly, younger enrollees were less likely to report that they had retired under age 60, as they may have not yet retired at all. Compared to non-Hispanic white residents and area workers, non-Hispanic black and Hispanic residents and area workers both had higher odds of reporting early retirement (AOR = 1.7, 95% CI: 1.3–2.1; AOR = 1.3, 95% CI: 1.0–1.7). Enrollees who were in the three higher household income groups ($50,000–<$75,000, $75,000–<$150,000, and ≥$150,000) each had higher likelihoods of experiencing early retirement. Those in the highest income group (≥$150,000) were more than twice as likely as those in the lowest income group (<$25,000) to have early retirement (AOR = 2.2, 95% CI: 1.5–3.2). On the contrary, the likelihood of reporting early retirement dropped by about 40% (AOR = 0.6, 95% CI: 0.4–0.7) and 70% (AOR

= 0.3, 95% CI: 0.3–0.4), respectively, for those with a college or post-graduate degree compared to those with high school and below education. Enrollees who were widowed had a higher likelihood of experiencing early retirement compared to those who were married or living with a partner (AOR = 1.5, 95% CI: 1.0–2.3). Sex and 9/11-related disaster exposure did not show significant association with early retirement for residents and area workers.

Table 1. Early retirement, chronic physical health conditions and post-traumatic stress disorder (PTSD) comorbidity, and other characteristics among non-retired and early retired enrollees.

Sample Characteristics	Retirement Status				Likelihood of Early Retirement	
	Not Retired (*N*, %)		Retired Early (*N*, %)			
	2891	**70.1**	**1234**	**29.9**	**AOR [a]**	**95% CI [b]**
Sex						
Female	1481	68.1	693	31.9	Ref	
Male	1410	72.3	541	27.7	1.0	0.8, 1.1
Age on 9/11						
0–24	31	93.9	2	6.1	0.1	0.0, 0.6
25–44	1089	79.1	287	20.9	0.5	0.4, 0.6
45–64	1771	65.2	945	34.8	Ref	
Race/ethnicity						
Non-Hispanic white	2085	72.1	805	27.9	Ref	
Non-Hispanic black	304	59.3	209	40.7	1.7	1.3, 2.1
Hispanic	253	64.4	140	35.6	1.3	1.0, 1.7
Non-Hispanic Asian	155	77.9	44	22.1	0.9	0.6, 1.3
Other race or multi-racial	94	72.3	36	27.7	0.9	0.6, 1.4
Total household income in 2002, $						
<25,000	167	72.3	64	27.7	Ref	
25,000 to <50,000	473	70.0	203	30.0	1.1	0.8, 1.6
50,000 to <75,000	477	68.3	221	31.7	1.6	1.1, 2.3
75,000 to <150,000	924	71.2	373	28.8	1.6	1.1, 2.3
≥150,000	564	71.4	226	28.6	2.2	1.5, 3.2
Education						
High school diploma or lower	335	54.1	284	45.9	Ref	
Some college or college graduate	1583	70.0	677	30.0	0.6	0.4, 0.7
Post-graduate	964	78.2	268	21.8	0.3	0.3, 0.4
Marital status						
Married or living with partner	1852	69.8	803	30.2	Ref	
Divorced or separated	415	69.5	182	30.5	0.9	0.7, 1.1
Widowed	57	53.8	49	46.2	1.5	1.0, 2.3
Never married	552	74.1	193	25.9	0.9	0.7, 1.2
Disaster exposure						
Low/none	630	70.6	262	29.4	Ref	
Medium	1264	70.9	520	29.1	0.9	0.8, 1.1
High	784	70.8	323	29.2	0.8	0.7, 1.1
Very high	213	62.3	129	37.7	1.1	0.8, 1.5
Number of chronic conditions [c] without PTSD						
0	1289	76.8	390	23.2	Ref	
1	527	68.7	240	31.3	1.5	1.2, 1.8
2	193	67.2	94	32.8	1.4	1.1, 1.9
≥3	61	59.8	41	40.2	1.9	1.2, 3.0
Number of chronic conditions [c] with PTSD						
0	324	73.6	116	26.4	1.2	0.9, 1.6
1	238	65.2	127	34.8	1.7	1.3, 2.2
2	153	57.1	115	42.9	2.5	1.9, 3.4
≥3	106	48.8	111	51.2	3.4	2.4, 4.7

[a] AOR: Adjusted odds ratio and was adjusted for all factors listed in this table. [b] 95% CI: 95% confidence interval. [c] Chronic physical health conditions include asthma, heart diseases, stroke, lung diseases, diabetes, gastroesophageal reflux disease (GERD), and autoimmune diseases.

Having chronic 9/11-related physical health conditions without PTSD was found to be significantly associated with early retirement in a dose-response manner with the odds of reporting early retirement increasing as the number of conditions increased (AOR = 1.5, 95% CI: 1.2–1.8; AOR = 1.4, 95% CI: 1.1–1.9; AOR = 1.9, 95% CI: 1.2–3.0 for those with one, two, and three or more conditions without PTSD, respectively) (Table 1). When chronic physical conditions were comorbid with PTSD, the likelihood of experiencing early retirement increased further and also in a dose-response manner. For example, for residents or area workers who had three or more 9/11-related physical conditions and PTSD, their odds of reporting early retirement were more than three times higher than those who did not have any of the selected conditions or PTSD (AOR = 3.4, 95% CI: 2.4–4.7). Interestingly, having PTSD alone did not significantly increase one's odds of early retirement as compared to those who did not have any physical conditions (AOR = 1.2, 95% CI: 0.9–1.6). To test the robustness of the association of 9/11-related health and early retirement, we performed a sensitivity analysis using an Ordinary Least Squares model by replacing the dichotomous early retirement outcome variable with a continuous variable measuring actual age at retirement. Our results showed findings consistent with the early retirement model results: The coefficients for enrollees who suffered one, two, or three or more physical conditions comorbid with PTSD (coefficients = −1.82, −2.89, and −2.92, respectively, and all with $p < 0.0001$) were all significant with the retirement age decreasing by an average of two to three years compared to those who did not have any 9/11-related chronic conditions (results not shown).

Approximately 73% of retirees in the study sample reported that their post-retirement income had decreased as compared to their pre-retirement income, while 19% reported no significant income changes, and 8% reported increased post-retirement income. Although post-retirement income loss seemed to be a norm for retirees regardless of their retirement age, among those who reported decreased income, a significantly higher proportion (45.9% vs. 33.7% in Table 2) of early retirees reported an income decrease of more than 50% ($p < 0.0001$). Because of the significant association of 9/11-related poor health and early retirement demonstrated in Table 1, we further tested if 9/11-related poor health was directly linked to retirees' post-retirement financial status.

Table 2. Percentage of post-retirement income loss among retirees reporting decreased income.

Retirement Age (Years)	Post-Retirement Income Loss, %		Total, *N*
	≤50% (*N* = 1437)	>50% (*N* = 889)	2326
<60	54.1	45.9	859
≥60	66.3	33.7	1467

Table 3 presents results on the association between 9/11-related health and the likelihood of having more than 50% of income decrease after retirement among enrollees who reported decreased income. Only three sociodemographic characteristics were associated with substantial post-retirement income loss: race/ethnicity, total household income, and education. More specifically, non-Hispanic black residents and area workers were 30% less likely to report income loss greater than 50% as compared to non-Hispanic white residents and area workers (AOR = 0.7, 95% CI: 0.6–1.0). Other racial/ethnic groups did not show significantly higher or lower odds of experiencing substantial income loss compared to non-Hispanic whites. Compared to the lowest income group (<$25,000), the three middle income groups ($25,000–<$50,000, $50,000–<$75,000, and $75,000–<$150,000) were less likely to have substantial income loss (AOR = 0.5, 95% CI: 0.3–0.8; AOR = 0.6, 95% CI: 0.3–0.9; AOR = 0.6, 95% CI: 0.4–1.0, respectively); however, the highest income group (≥$150,000) did not show significantly higher or lower odds of experiencing substantial income loss. Enrollees with some college experience or a college degree had a significantly higher likelihood of substantial income loss compared to enrollees with lower education attainment (AOR = 1.2, 95% CI: 1.0–1.6). Each level of 9/11-related disaster exposure was highly associated with post-retirement income loss in

a dose-response manner. The highest level of exposure increased the odds of having substantial income loss by 2.5 times compared to those with little or no exposure (AOR = 2.5, 95% CI: 1.7–3.6).

Table 3. Post-retirement income loss, chronic physical health conditions and post-traumatic stress disorder (PTSD) comorbidity, and other characteristics among retirees reporting decreased income.

Sample Characteristics	Post-Retirement Income Loss more than 50%				Likelihood of Substantial Income Loss	
	No (*N*, %)		Yes (*N*, %)			
	1469	61.3	926	38.7	AOR [a]	95% CI [b]
Sex						
Female	787	63.3	456	36.7	Ref	
Male	682	59.2	470	40.8	1.0	0.8, 1.2
Race/ethnicity						
Non-Hispanic white	990	59.1	685	40.9	Ref	
Non-Hispanic black	234	69.6	102	30.4	0.7	0.6, 1.0
Hispanic	145	66.5	73	33.5	0.8	0.5, 1.1
Non-Hispanic Asian	57	58.8	40	41.2	1.1	0.7, 1.7
Other race or multi-racial	43	62.3	26	37.7	1.0	0.5, 1.7
Total household income in 2002, $						
<25,000	46	47.9	50	52.1	Ref	
25,000 to <50,000	255	68.5	117	31.5	0.5	0.3, 0.8
50,000 to <75,000	280	67.3	136	32.7	0.6	0.3, 0.9
75,000 to <150,000	499	64.4	276	35.6	0.6	0.4, 1.0
≥150,000	226	48.3	242	51.7	1.3	0.8, 2.1
Education						
High school diploma or lower	299	65.9	155	34.1	Ref	
Some college or college graduate	780	60.0	521	40.0	1.2	1.0, 1.6
Post-graduate	380	60.8	245	39.2	1.0	0.8, 1.4
Marital status						
Married or living with partner	961	60.7	623	39.3	Ref	
Divorced or separated	236	59.9	158	40.1	1.2	0.9, 1.6
Widowed	66	71.0	27	29.0	0.7	0.4, 1.1
Never married	195	63.1	114	36.9	1.0	0.8, 1.4
Disaster exposure						
Low/none	362	71.7	143	28.3	Ref	
Medium	653	63.6	373	36.4	1.4	1.0, 1.7
High	360	55.8	285	44.2	1.7	1.2, 2.2
Very high	94	42.9	125	57.1	2.5	1.7, 3.6
Number of chronic conditions [c] without PTSD						
0	546	65.7	285	34.3	Ref	
1	316	64.6	173	35.4	1.1	0.9, 1.5
2	129	68.6	59	31.4	0.9	0.6, 1.3
≥3	59	62.8	35	37.2	1.4	0.9, 2.2
Number of chronic conditions [c] with PTSD						
0	118	53.2	104	46.8	1.7	1.2, 2.5
1	114	53.0	101	47.0	1.8	1.2, 2.5
2	104	55.9	82	44.1	1.6	1.1, 2.3
≥3	83	48.8	87	51.2	1.9	1.3, 2.7

[a] AOR: Adjusted odds ratio and was adjusted for all factors listed in this table. [b] 95% CI: 95% confidence interval. [c] Chronic physical health conditions include asthma, heart diseases, stroke, lung diseases, diabetes, gastroesophageal reflux disease (GERD), and autoimmune diseases.

Substantial post-retirement income loss was also significantly associated with the number of 9/11-related health conditions but only for those who suffered from PTSD alone or PTSD comorbid with physical conditions. In other words, enrollees without PTSD who only had chronic physical health conditions did not have higher odds of losing more than 50% of their income post-retirement compared to those who had no health conditions. Once enrollees had PTSD, their likelihood of having

substantial income loss increased significantly as compared to those without any health conditions (e.g., AOR = 1.7, 95% CI: 1.2–2.5). PTSD comorbid with one or more physical health conditions had a similar effect on enrollees' odds of experiencing substantial income loss as PTSD alone.

4. Discussion

The impact of the 9/11 disaster on early retirement and post-retirement well-being among survivors has rarely been studied until now. This study examined the association of 9/11-related health and early retirement for residents and area workers who resided and/or worked near the WTC site on 9/11. Furthermore, we assessed the longer-term impact of 9/11-related health on post-retirement income loss among survivors.

Sixteen years after the 9/11 disaster, among the 3486 retired residents and area workers in our study sample, about 35% had retired before reaching 60 years of age. Early retirement was found to be significantly associated with chronic 9/11-related physical health conditions in a dose-response manner, and a sensitivity analysis estimating the magnitudes of the effects in terms of years of work lost found consistent results. More specifically, the likelihood of reporting early retirement versus not-yet retired grew as the number of physical health conditions increased. The odds of reporting early retirement increased further when these conditions were comorbid with PTSD but not when PTSD was reported in the absence of any 9/11-related physical conditions. These findings suggest that residents or area workers who suffered from 9/11-related PTSD but not other chronic physical conditions were not more likely to retire early due to this mental health condition alone; several explanations may clarify this. One reason is that PTSD may not severely impact daily working life, especially if the PTSD is mild. Only 6% of the early retirees in this study sample reported having Accidental Disability Retirement (ADR), a benefit available to members of certain plans if they become permanently physically or mentally incapacitated and are unable to perform the duties of their job due to an accident that took place on the job [41]. The percentage of early retirees with ADR and PTSD but no other chronic condition is even lower (4%), which suggests the proportion of enrollees with severe PTSD alone is low. Another potential reason is that stigma associated with a mental health condition such as PTSD may prevent one from recognizing the condition, let alone coping with it by retiring early.

Despite the fact that PTSD alone did not show a significant association with reporting early retirement, this study found that residents and area workers with PTSD alone or PTSD comorbid with any number of physical conditions were significantly more likely to experience substantial income loss post-retirement. PTSD comorbid with one or more physical health conditions had a similar effect, in terms of significance and magnitude, on the odds of experiencing substantial income loss as PTSD alone. Having any number of physical conditions (including three or more conditions) in the absence of PTSD was not significantly associated with substantial post-retirement income loss, which suggests PTSD is the key and driving factor in this association. The economic impact of 9/11-related PTSD, although not directly reflected in the form of early retirement, tended to be stronger in the long-term as individuals suffering PTSD were less likely to assume income-generating activities that could ultimately lead to significant income loss. Like having PTSD alone, disaster exposure did not show a significant association with early retirement but was highly related to post-retirement income loss. The absence of exposure's effect in the model for early retirement is likely a result of having the 9/11-related health measure in the same model absorbing its effect. We re-ran our model for Table 1 without the health measure and found that disaster exposure at a very high level was significantly associated with 50% higher likelihood of early retirement (AOR = 1.5, 95% CI: 1.1–2.0, results not shown) compared to those who had low or no exposure during the disaster. This finding implies that the health measure we chose for this study represented the impact of this disaster well. A closer look at the data suggested that enrollees in the highest category of the 9/11 exposure scale were most likely to have suffered PTSD or PTSD comorbid with physical health conditions (results not shown) which made their comparable associations with the two outcomes unsurprising.

Similar to the findings in our earlier study [7], those with higher household income or lower education were more likely to report early retirement than staying in the labor force as compared to the low income group or higher education achievers. This seemingly contradictory impact of high income and low education reflects the complexity of the retirement decision-making process. For residents and area workers with 9/11-related poor health, having a higher income may have allowed them to voluntarily retire early or made them more likely to afford early retirement without considerable additional financial concern compared to having a lower income. On the other hand, the early retirement decision for the lower education group was less likely to be a "choice", as their low education (usually accompanied with low income) and poor health may not have allowed them to maintain their work, especially when the work was more physical or manual in nature. The association of lower socioeconomic status and higher risk of involuntary labor force exit was also found in previous studies [42,43].

This study provided evidence of a strong association between 9/11-related poor health and early retirement among survivors who lived and worked near the WTC site. Furthermore, with additional information collected from the HES, we demonstrated, for the first time, the significant impact of 9/11-related PTSD and 9/11-related physical–mental comorbidity on substantial post-retirement income loss. Our findings suggest that after labor force exit, poor health, especially PTSD, continued to adversely affect survivors' overall well-being in the form of considerable income reduction. The compromised post-retirement well-being as a result of poor health did not come as a surprise because many of the affected people could have involuntarily experienced early retirement before securing their full retirement benefits; or, they might be less likely to participate in any income-generating activities, particularly if they experienced mental health or physical–mental comorbidity issues after retirement. This lasting effect of poor health, along with the fact that certain race/ethnicity (Hispanic and non-Hispanic black) and low education groups are more likely to retire early, should direct future 9/11-related resources by placing a greater focus on limiting sharp income loss and providing adequate and affordable health care services to retirees from various vulnerable groups to maintain a certain level of quality of life.

One notable advantage of this study is that we directly assessed the relationship between 9/11-related health and post-retirement income loss using statistical modeling. This investigation provides the first look at one aspect of survivors' well-being beyond retirement and will lead to additional exploration of the economic impact of 9/11, such as the relationship between substantial income loss and worsening health and its associated high medical cost, poor health reducing survivors' ability to re-enter the workforce to compensate for post-retirement income loss, and how survivors' retirement plans directly affect their post-retirement well-being. In addition, future research should also assess other aspects of post-retirement well-being such as retirees' current health status or health-related quality of life (as in an ongoing study by our group) and insurance coverage. These results will not only give us a broader picture of retirees' overall well-being but also help estimate the realistic gap on health care access in terms of making policy recommendations.

5. Conclusions

This study found that 9/11-related health conditions were significantly associated with the likelihood of early retirement among residents and area workers who survived the 9/11 attacks. The likelihood of reporting early retirement increased as the number of health conditions increased. Having PTSD alone was not associated with early retirement; however, PTSD was the driving factor out of all 9/11-related health conditions studied that was linked to substantial income loss post-retirement. For future studies of 9/11 economic impact, our findings emphasize the key role that PTSD may play in the longer-term.

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