Chronic and Acute Exposures to the World Trade Center Disaster and Lower Respiratory Symptoms: Area Residents and Workers

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Objectives. We assessed associations between new-onset (post–September 11, 2001 [9/11]) lower respiratory symptoms reported on 2 surveys, administered 3 years apart, and acute and chronic 9/11-related exposures among New York City World Trade Center–area residents and workers enrolled in the World Trade Center Health Registry.

Methods. World Trade Center–area residents and workers were categorized as case participants or control participants on the basis of lower respiratory symptoms reported in surveys administered 2 to 3 and 5 to 6 years after 9/11. We created composite exposure scales after principal components analyses of detailed exposure histories obtained during face-to-face interviews. We used multivariate logistic regression models to determine associations between lower respiratory symptoms and composite exposure scales.

Results. Both acute and chronic exposures to the events of 9/11 were independently associated, often in a dose-dependent manner, with lower respiratory symptoms among individuals who lived and worked in the area of the World Trade Center.

Conclusions. Study findings argue for detailed assessments of exposure during and after events in the future from which potentially toxic materials may be released and for rapid interventions to minimize exposures and screen for potential adverse health effects. (*Am J Public Health.* Published online ahead of print April 19, 2012: e1–e9. doi:10.2105/AJPH.2011.300561)

The attack on the New York World Trade Center on September 11, 2001 (9/11), and its effects on the surrounding area have been well documented. Pulverized materials from the collapse of buildings, products of combustion during and for several months after 9/11, and continual resuspension of particulate matter during rescue, recovery, and cleanup operations exposed hundreds of thousands of individuals to environmental contaminants well after 9/11. Known respiratory irritants and other toxic agents have been identified in samples of ambient air[1] and dust[2–4] that settled both outdoors and inside buildings. From aerial photographs, estimates of peak concentrations of particulate matter of all sizes were as high as 1000 micrograms per cubic meter.[5] The proportion of respirable (< 2.5 μm) particles identified in samples of smoke[5] and settled dust[3,5,6] ranged from 1% to 4%, with concentrations of respirable particles near Ground Zero estimated at between 5 and 60 micrograms per cubic meter. Although these measurements cannot be used to estimate actual exposure to individuals, it is assumed that individuals who lived (residents) or worked (area workers) in the area are likely to have experienced both acute exposure to these contaminants on 9/11 and chronic exposure in and around homes and workplaces during the following months.

Acute and chronic exposures to the effects of 9/11 have been consistently implicated as risk factors for adverse respiratory outcomes, including asthma and respiratory symptoms, among residents[7–11] and area workers[11–14] up to 8 years after 9/11. Changes in lung function associated with 9/11 can be identified only in the subset of the exposed population (i.e., New York City firefighters) for whom pre-9/11 results are available,[15,16] although elevated rates of lung function abnormalities were reported in both residents and area workers up to 8 years after 9/11.[7,11] Few studies have assessed the effects of acute and chronic 9/11-related exposures on residents and area workers simultaneously or have estimated the effects of each while adjusting for the effects of the other. In addition, most studies linking 9/11-related exposures and respiratory symptoms have assessed symptoms on a single occasion. This study was designed to assess associations between repeatedly reported lower respiratory symptoms and detailed measures of both acute and chronic 9/11-related exposures.

METHODS

This case–control study was nested within the adult cohort of the World Trade Center Health Registry, which was created to prospectively monitor individuals with high likelihood of exposure to the events of 9/11 and their aftermath. Descriptions of the registry and its creation are reported elsewhere.[9,17] Participants were selected from groups of adult World Trade Center Health Registry enrollees who completed surveys in both 2003 to 2004 (wave 1) and 2006 to 2007 (wave 2); consented to be contacted for future studies; had not performed 9/11-related rescue or recovery work; currently resided in New York, New Jersey, or Connecticut; and lived south of Canal Street or worked south of Chambers Street in New York City on 9/11.

Enrollees were eligible to be case participants if they reported at least 1 new-onset (post-9/11) lower respiratory symptom at wave 1 and reported either the same symptom occurring for 8 or more of the previous 30 days or the use of an inhaler at wave 2. Eligible control participants included enrollees who reported no lower respiratory symptoms or inhaler use and no current or past lung disease on either survey. Excluded from the study were enrollees who reported a history of smoking (≥ 100 cigarettes in lifetime), asthma, reactive airways dysfunction syndrome, chronic bronchitis, sarcoidosis, emphysema, or another lung or cardiovascular disease that was diagnosed before 9/11 or who were pregnant or taking a β-blocker antihypertensive agent at the time of recruitment.

Participants were recruited by mail, e-mail, and telephone between 2008 and 2010 and were scheduled for a single visit to a field site in lower Manhattan. The final study sample of 785 participants (274 case participants; 511 control participants; 56.7% of 1385 potential participants) included 363 (46.2%) residents, 306 (39.0%) area workers, and 116 (14.8%) participants who were both.

Trained nurse-interviewers administered a computer-assisted personal interview and recorded height and weight, from which body mass index (BMI, defined as weight in kilograms divided by the square of height in meters) was determined; trained technicians administered pulmonary function tests. The interview was developed in close collaboration with members of the exposed resident and area worker communities and gathered more detailed information about 9/11-related exposures than was available from surveys at waves 1 and 2, as well as information about current health, with an emphasis on respiratory symptoms.

Exposure Variables

Acute exposures. Measures of acute exposure referred to the cloud of dust and debris resulting from the collapses of the World Trade Center towers on 9/11. Participants used scales of personal appearance after being in the cloud and of degree of visibility while in the cloud to rate the density of the thickest part of the cloud in which they recalled being caught. Also recorded were duration of time spent in the dust cloud, proportion of time spent in the thickest part of the cloud, and the point in time at which participants were first caught (i.e., after the collapse of the first tower, within 1 hour of the collapse of the second tower, or more than 1 hour after the collapse of the second tower). We used ArcGIS 9.1 (Environmental Systems Research Institute, Redlands, CA) to determine the distance from the midpoint between the World Trade Center towers to the location when first caught.

Chronic exposures. Measures of chronic exposure referred to conditions at the home or workplace during the several months immediately following 9/11 (through December 31, 2001), including dust, damage, and smoke; cleaning; and time spent at the home or workplace. Dust exposure was rated according to extent of surface dust coverage, depth of the thickest layer of dust, and proportion of rooms having the thickest layer of dust. Two scales assessed whether and for how long smoke, fumes, or other 9/11-related odors were detected inside and outside homes and workplaces. Participants were asked whether, how, and by whom each of several common items found in homes and workplaces was cleaned or whether and by whom it was discarded. We also ascertained the amount of time spent in the home or workplace before any cleaning occurred, while engaged in cleaning, and while someone else cleaned. Timing of participants' first return to the home or workplace after 9/11 was recorded, and the number of days present in the area south of Canal Street in New York City was documented, taking into account time at temporary residences or workplaces. We recorded the number of days participants spent at the home or workplace living, working, or "visiting" (e.g., cleaning, retrieving items) and average length of visits, facilitating estimates of overall time at the home or workplace. Area workers were asked to portray their workplace on 9/11 by selecting 1 of several descriptors (e.g., "office, or suite, or group of offices in a building," "'behind the scenes' at a single building where repairs, maintenance, wiring, installations occur," "restaurant or other indoor food establishment").

Composite Exposure Scales

We performed principal components analyses of groups of interview items addressing the dust cloud, the home, the workplace, cleaning of the home, and cleaning of the workplace to identify exposure domains represented by clustered items and to reduce the pool of items for subsequent multivariate analyses. Participants missing values for variables in a particular principal components analysis were excluded from that analysis. Selection of components was based on proportions of variance accounted for by successively extracted components, conceptual meaning of components, and simplicity of rotated (orthogonally) component structures. Composite scales were derived by weighting individual item responses with scoring coefficients from each selected component; weighted responses were added to create composite scale scores for each exposure domain. Scores for participants who were both residents and area workers were derived by summing responses to home and workplace items, each weighted by coefficients from the corresponding group-specific analyses.

Tests of Pulmonary Function

Following American Thoracic Society and European Respiratory Society standards for spirometry,[18] trained technicians assessed participants' forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC). Lung function was categorized as normal (FEV_1/FVC and FVC at or greater than the fifth percentile), obstructed (FEV_1/FVC lower than the fifth percentile), or restricted (FVC lower than the fifth percentile and normal FEV_1/FVC) according to published reference values.[19]

Data Analyses

Bivariate analyses of associations between lower respiratory symptoms and exposures specific to the home or the workplace excluded participants who were both residents and area workers. We determined bivariate associations between categorical variables and lung function with the χ^2 test; we used the Cochran-Armitage test to detect trends in associations with ordinal categories. Multivariate logistic regression models were used to predict lower respiratory symptoms from composite exposure scales. Predictor variables independently associated with lower respiratory symptoms in bivariate analyses were entered into preliminary models; variables were retained if their exclusion changed odds ratios (ORs) of interest by more than 10%.

RESULTS

In bivariate analyses, case participants were more likely than control participants to be female and Black, Hispanic, or in the "other" race category than either White or Asian

(Table 1). Case participants were older than control participants, were less likely to be college educated or to have been working at wave 2, had lower household incomes in 2002, and were more likely to be in the "overweight" (25-29) or "obese" (≥ 30) BMI category. Nearly 66% of the case participants and 7.1% of the (previously symptom-free) control participants reported having 1 or more lower respiratory symptoms (or use of an inhaler) during the 30 days prior to being interviewed. Most frequently reported was cough (16.7%), followed by dyspnea (14.9%) and wheeze (11.8%), mirroring the relative frequency distribution seen among case participants at waves 1 and 2 (65.3%, 53.8%, and 35.9% for cough, dyspnea, and wheeze, respectively). The majority of participants (80.7% of the case participants and 87.9% of the control participants) tested within normal ranges of lung function. Case participants were more likely to show signs of lung function abnormality (nearly 10% of the case participants showed signs of obstructive lung disease with or without restriction, and nearly 10% showed signs of restrictive disease with no obstruction; among control participants, the corresponding proportions were 8.4% and 3.7%, respectively); however, the associations were no longer statistically significant after stratification by symptom status at the time of testing.

Acute Exposure

In bivariate analyses, case participants were nearly 4 times as likely as control participants to report having been caught in the dust cloud (OR = 3.9; 95% confidence interval [CI] = 2.8, 5.5) and reported more severe exposure while in the cloud. Strong, significant associations were observed for every measure of severity of dust cloud exposure; tests for trend indicated dose–response relationships (all $P < .001$; Table 2). Statistically significant ORs for measures of personal appearance after being in the thickest part of the cloud ranged from 2.1 (for appearing with no or little apparent dust) to 13.2 (for appearing with abundant dust). Case participants were significantly more likely to report impaired visibility in the cloud, with ORs ranging from 2.6 (for little impairment) to 9.2 (for being unable to see at all). Overall, case participants spent more time in the cloud than did control participants (with ORs ranging from 3.7 for ≤ 0.5 hours to 6.1 for 2–5 hours) and larger proportions of time in the thickest part of the cloud (with ORs ranging from 3.2 for very little of the time to 9.0 for more than half the time). Although the OR for the highest category, spending "about the whole time" in the thickest part of the cloud, decreased to 3.7, a significant trend was observed between this variable and lower respiratory symptoms. Case participants reported having been first caught in the cloud earlier (OR = 4.9, OR = 4.7, and OR = 2.8 for having been caught between the first and second tower collapses, within 1 hour of the collapse of the second tower, and more than 1 hour after the collapse of the second tower, respectively) and at shorter distances from the World Trade Center than did control participants (OR = 5.9, OR = 3.4, and OR = 3.0 for having been first caught in the cloud ≤ 1500 ft, 1500–2000 ft, and > 2000 ft away, respectively).

Chronic Exposure

Patterns and magnitudes of association were similar for analogous exposures in the home and workplace, although the ranges of magnitude were generally higher for workplace associations. Bivariate associations between lower respiratory symptoms and chronic exposures in the home and workplace are shown in Table 3. ORs for increasing extent of surface dust coverage in the home ranged from 2.2 to 2.8; in workplaces, this range was from 2.9 to 5.9. For depth of the thickest layer of dust (ranging from a thin layer to a layer > 1-in thick), ORs were between 2.5 and 2.8 for the home; the corresponding workplace ORs ranged from 3.4 to 6.4. Strong, significant ORs were observed for categories indicating that more than half of the rooms in homes and about half of the rooms in workplaces were affected to the extent reported. Damage extensive enough to require repairs but not to preclude use of the home or workplace was significantly associated with lower respiratory symptoms (OR = 3.9), and a significant trend was observed with increasing damage to the home. Analogous measures of damage to the workplace were not significantly associated with lower respiratory symptoms. Smelling smoke, fumes, or odors both inside and outside the workplace, and doing so for more than 3 months were significantly associated with lower respiratory symptoms. Statistically significant trends ($P < .05$) were detected for all measures of chronic exposure to conditions in homes and all but extent of damage to workplaces.

Cleaning of homes, but not cleaning of workplaces, after 9/11 was significantly associated with lower respiratory symptoms (OR = 2.7). However, participation in cleaning was significantly associated with lower respiratory symptoms in participants at both locations (OR = 2.2 and OR = 2.7 for home and workplace, respectively), as were numbers of items cleaned by the participant. Amounts of time participants spent cleaning and were present while someone else cleaned homes and workplaces assumed significant dose–response relationships with lower respiratory symptoms. Neither the amount of time spent at the home nor the month during which participants first returned significantly differentiated resident case participants and control participants; a significant trend was observed for both variables among area workers ($P < .05$ in both cases).

Principal Components Analyses

Principal components analyses identified 6 exposure domains, from which 6 composite scales with high loadings on clustered variables (≥ 0.90) were derived (Table 4):

1. dust cloud: density,
2. dust cloud: time,
3. dust: home/workplace,
4. smoke: home/workplace,
5. time: home/workplace, and
6. cleaning: home/workplace.

Cronbach's α values showed high internal consistency on all scales, being at least 0.92 for all but the time: home/workplace scale, for which it was 0.85. Separate analyses of residents and area workers found slightly lower values among residents on the chronic exposure scales, but none lower than 0.82.

Multivariate Analyses

In adjusted analyses, case participants were significantly more likely than control participants to score higher on the dust cloud: density measure of acute exposure and on the dust: home/workplace and smoke: home/workplace measures of chronic exposure (Table 4).

TABLE 1—New York City World Trade Center–Area Residents and Workers, by Case Status: 2008–2010

	Case Participants (n = 274), No. (%)	Control Participants (n = 511), No. (%)	*P*
Gender			
Male	93 (33.9)	254 (49.7)	<.001[a]
Female	181 (66.1)	257 (50.3)	
Race			
White	143 (52.2)	390 (76.3)	<.001[a]
Black	48 (17.5)	27 (5.3)	
Hispanic	45 (16.4)	24 (4.7)	
Asian	22 (8.0)	66 (12.9)	
Other	16 (5.8)	4 (0.8)	
Age at interview, y			
21–29	7 (2.6)	36 (7.0)	<.001[b]
30–39	47 (17.2)	121 (23.7)	
40–49	86 (31.4)	146 (28.6)	
50–59	76 (27.7)	140 (27.4)	
60–64	26 (9.5)	34 (6.6)	
≥ 65	32 (11.7)	34 (6.6)	
College graduate (wave 2)			
Yes	174 (63.5)	424 (83.3)	<.001[a]
No	100 (36.5)	85 (16.6)	
Employment status (wave 2)			
Working	213 (77.7)	435 (85.3)	.01[a]
Not working	60 (21.9)	75 (14.7)	
Income in 2002, $			
≥ 150 000	38 (15.8)	128 (28.6)	<.001[b]
75 000–149 999	60 (24.9)	160 (35.7)	
50 000–74 999	43 (17.8)	68 (15.2)	
25 000–49 999	60 (24.9)	50 (11.2)	
< 25 000	40 (16.6)	42 (9.4)	
BMI category			
Normal/underweight (≤ 24)	77 (28.2)	288 (56.9)	<.001[b]
Overweight (25-29)	93 (34.1)	150 (29.6)	
Obese (≥ 30)	103 (37.7)	68 (13.3)	
Lower respiratory symptoms reported at interview			
Yes	180 (65.7)	36 (7.1)	<.001[a]
No	94 (34.3)	474 (92.9)	
Lung function[c]			
Normal	221 (80.7)	449 (87.9)	<.005[a]
Obstructed	26 (9.5)	43 (8.4)	
Restricted	27 (9.9)	19 (3.7)	
Probable PTSD (wave 2)			
Yes	92 (35.0)	25 (5.0)	<.001[a]
No	172 (65.0)	477 (95.0)	

Note. BMI = body mass index (defined as weight in kilograms divided by the square of height in meters); PTSD = posttraumatic stress disorder. Numbers reported for individual variables may not sum to group total because of missing values; proportions are of participants for whom data were available. The sample size was n = 785.
[a]Chi-square test.
[b]Cochran-Armitage test for trend.
[c]Determined by spirometry.

Separate analyses of residents and area workers showed magnitudes of effect that were comparable but slightly higher among area workers, with the association with smoke in the home being just shy of statistical significance (95% CI = 0.9, 2.4). Final adjusted models included each of the remaining exposure scales, as well as age, race/ethnicity, education, income, and BMI category.

DISCUSSION

Both acute and chronic exposures to the effects of 9/11 were independently associated with lower respiratory symptoms reported 2 to 3 years and again 5 to 6 years after 9/11. Moreover, distinct dimensions of exposure associated with lower respiratory symptoms were identified and, with alternative weighting schemes, used to simultaneously assess effects of acute exposures in the dust cloud and chronic exposures in homes and workplaces of participants who reported exposure from 1, 2, or all 3 sources.

Statistically significant associations between lower respiratory symptoms and both dust and smoke, but not time spent in the home or workplace, and between damage to the home and respiratory symptoms are consistent with findings reported by Lin et al.[10] Residents whose homes were severely damaged but livable, but not those whose homes were uninhabitable until repairs had been made, had a significantly increased risk of lower respiratory symptoms, suggesting that being absent from the home may have been associated with decreased risk for lower respiratory symptoms. These findings are consistent with those of previous World Trade Center Health Registry studies that showed increased risk of adverse respiratory effects 2 to 3 years[9] and 5 to 6 years[12] after 9/11 in residents who did not evacuate their homes.

Case-defining symptoms reported at wave 2 referred to the 30 days prior to interview, making it unclear whether symptoms had persisted since first reported at wave 1 or were transient, possibly unrelated symptoms. This raises the possibility that findings could be attributable to associations between exposures and wave 1 symptoms, regardless of symptom status at wave 2. However, when contrasted with enrollees reporting lower respiratory symptoms at wave 1 but not wave 2, those who

TABLE 2—Acute Exposures Following September 11, 2001, by Case–Control Status in New York World Trade Center–Area Residents and Workers

	Case Participants (n = 274), No. (%)	Control Participants (n = 511), No. (%)	Unadjusted OR (95% CI)	*P*
Caught in dust/debris cloud				<.001[a]
No	65 (23.7)	281 (55.0)	1.0 (Ref)	
Yes	209 (76.3)	230 (45.0)	3.9 (2.8, 5.5)	
Personal appearance after being in thickest part of cloud				<.001[b]
Not in dust cloud	65 (25.3)	281 (61.1)	1.0 (Ref)	
No or little apparent dust	36 (14.0)	75 (16.3)	2.1 (1.3, 3.4)	
Much apparent dust	92 (35.8)	83 (18.0)	4.8 (3.2, 7.2)	
Abundant apparent dust	64 (24.9)	21 (4.6)	13.2 (7.5, 23.1)	
Visibility in thickest part of cloud				<.001[b]
Not in dust cloud	65 (26.3)	281 (61.4)	1.0 (Ref)	
Little impairment; could see clearly	52 (21.1)	88 (19.2)	2.6 (1.7, 4.0)	
Could not see clearly; some visibility	94 (38.1)	72 (15.7)	5.6 (3.8, 8.5)	
Could not see at all	36 (14.6)	17 (3.7)	9.2 (4.8, 17.3)	
Duration of time in dust cloud, h				<.001[b]
No time (not in dust cloud)	65 (24.0)	281 (55.1)	1.0 (Ref)	
≤ 0.5	86 (31.7)	101 (19.8)	3.7 (2.5, 5.5)	
> 0.5–2	78 (28.8)	98 (19.2)	3.4 (2.3, 5.1)	
> 2–5	42 (15.5)	30 (5.9)	6.1 (3.5, 10.4)	
Proportion of time spent in thickest part of cloud				<.001[b]
Not in dust cloud	65 (24.2)	281 (56.2)	1.0 (Ref)	
Very little of the time	23 (8.6)	31 (6.2)	3.2 (1.8, 5.9)	
< Half the time	45 (16.7)	51 (10.2)	3.8 (2.4, 6.2)	
About half the time	44 (16.4)	45 (9.0)	4.2 (2.6, 6.9)	
> Half the time	23 (8.6)	11 (2.2)	9.0 (4.2, 19.5)	
About the whole time	69 (25.7)	81 (16.2)	3.7 (2.4, 5.6)	
Time first caught in cloud, relative to World Trade Center tower collapses				<.001[b]
Not in dust cloud	65 (24.5)	281 (58.7)	1.0 (Ref)	
≥ 1 h after second collapse	32 (12.1)	49 (10.2)	2.8 (1.7, 4.8)	
< 1 h after second collapse	47 (17.7)	43 (9.0)	4.7 (2.9, 7.7)	
Between first and second collapses	121 (45.7)	106 (22.1)	4.9 (3.4, 7.2)	
Distance from World Trade Center when first caught in cloud, ft				<.001[b]
Not in dust cloud	65 (32.0)	281 (63.7)	1.0 (Ref)	
> 2000	67 (33.0)	95 (21.5)	3.0 (1.9, 4.5)	
> 1500–2000	28 (13.8)	33 (7.5)	3.4 (1.8, 6.1)	
≤ 1500	43 (21.2)	32 (7.3)	5.9 (3.4, 10.1)	

Note. CI = confidence interval; OR = odds ratio. Numbers reported for individual variables may not sum to group total because of missing values; proportions are of participants for whom data were available. The sample size was n = 785.
[a]Chi-square test.
[b]Cochran-Armitage test for trend.

reported symptoms at both time points had significantly higher scores on measures of both acute and chronic exposures, suggesting that symptoms reported at both time points may, in fact, represent continued illness associated with 9/11-related exposures. A higher prevalence of lung function abnormalities among case participants, shown to be attributable to the increased likelihood of lower respiratory symptoms among case participants at the time of interview also suggests continued disease burden.

Because many participants either did not know or did not recall relevant details about cleaning that occurred in their absence, it is

TABLE 3—Bivariate Associations Between Lower Respiratory Symptoms and Chronic Exposures Following September 11, 2001, Among New York World Trade Center–Area Residents and Workers, by Case–Control Status

	Residents[a] (n = 364)			Area Workers[a] (n = 307)		
	Case Participants, No. (%)	Control Participants, No. (%)	Unadjusted OR (95% CI) or P[b]	Case Participants, No. (%)	Control Participants, No. (%)	Unadjusted OR (95% CI) or P[b]
Extent of surface dust coverage			<.01			<.001
No exposed surfaces	15 (16.1)	86 (32.5)	1.0 (Ref)	57 (41.9)	112 (74.2)	1.0 (Ref)
Some exposed surfaces	30 (32.3)	80 (30.2)	2.2 (1.1, 4.3)	24 (17.7)	15 (9.9)	3.1 (1.5, 6.5)
Most exposed surfaces	18 (19.4)	38 (14.3)	2.7 (1.2, 6.0)	16 (11.8)	11 (7.3)	2.9 (1.2, 6.6)
Every exposed surface	30 (32.3)	61 (23.0)	2.8 (1.4, 5.7)	39 (28.7)	13 (8.6)	5.9 (2.9, 11.9)
Depth of thickest layer of dust			<.01			<.001
No dust	15 (16.1)	86 (32.6)	1.0 (Ref)	57 (42.2)	112 (74.2)	1.0 (Ref)
Thin layer	60 (64.5)	140 (53.0)	2.5 (1.3, 4.6)	54 (40.0)	31 (20.5)	3.4 (2.0, 5.9)
< 1 in, unable to see through	14 (15.1)	29 (11.0)	2.8 (1.2, 6.4)	13 (9.6)	4 (2.7)	6.4 (2.0, 20.5)
≥ 1 in	4 (4.3)	9 (3.4)	2.5 (0.7, 9.3)	11 (8.2)	4 (2.7)	5.4 (1.6, 17.7)
Proportion of rooms affected			<.001			<.001
None	15 (17.2)	86 (35.8)	1.0 (Ref)	57 (44.5)	112 (75.7)	1.0 (Ref)
< half	8 (9.2)	27 (11.2)	1.7 (0.7, 4.4)	10 (7.8)	9 (6.1)	2.2 (0.8, 5.7)
About half	10 (11.5)	29 (12.1)	2.0 (0.8, 4.9)	9 (7.0)	2 (1.4)	8.8 (1.8, 42.3)
> half	13 (14.9)	27 (11.2)	2.8 (1.2, 6.5)	17 (13.3)	10 (6.8)	3.3 (1.4, 7.8)
All	41 (47.1)	71 (29.6)	3.3 (1.7, 6.5)	35 (27.3)	15 (10.1)	4.6 (2.3, 9.1)
Extent of damage			<.05			NS[b]
No damage	77 (83.7)	243 (91.0)	1.0 (Ref)	76 (66.1)	83 (73.5)	1.0 (Ref)
Minor damage, no repairs necessary	5 (5.4)	10 (3.8)	1.6 (0.5, 4.8)	8 (7.0)	8 (7.1)	1.1 (0.4, 3.1)
Needed repairs but usable	5 (5.4)	4 (1.5)	3.9 (1.0, 15.1)	13 (11.3)	5 (4.4)	2.8 (1.0, 8.3)
Needed repairs before use	5 (5.4)	10 (3.8)	1.6 (0.5, 4.8)	18 (15.7)	17 (15.0)	1.2 (0.6, 2.4)
Smelled smoke, fumes, or odors			<.05			<.001
Not at all	5 (5.4)	19 (7.4)	1.0 (Ref)	29 (21.2)	55 (36.7)	1.0 (Ref)
Outside the area only	12 (13.0)	73 (28.5)	0.6 (0.2, 2.0)	17 (12.4)	36 (24.0)	0.9 (0.4, 1.9)
Inside and outside the area	75 (81.5)	164 (64.1)	1.7 (0.6, 4.8)	91 (66.4)	59 (39.3)	2.9 (1.7, 5.1)
Duration of time smelled smoke, fumes, or odors			<.01			<.005
No time	5 (5.7)	19 (7.6)	1.0 (Ref)	29 (21.2)	55 (36.7)	1.0 (Ref)
≤ 2 wk	5 (5.7)	21 (8.4)	0.9 (0.2, 3.6)	7 (5.1)	8 (5.3)	1.7 (0.5, 5.0)
> 2 wk–1 mo	8 (9.1)	37 (14.7)	0.8 (0.2, 2.9)	14 (10.2)	13 (8.7)	2.0 (0.8, 4.9)
> 1 mo–3 mo	23 (26.1)	101 (40.2)	0.9 (0.3, 2.6)	31 (22.6)	46 (30.7)	1.3 (0.7, 2.4)
> 3 mo	47 (53.4)	73 (29.1)	2.4 (0.9, 7.0)	56 (40.9)	28 (18.7)	3.8 (2.0, 7.2)
Area was cleaned post-9/11			<.05[d]			NS[c,d]
No	6 (6.6)	43 (16.2)	1.0 (Ref)	10 (9.4)	16 (16.3)	1.0 (Ref)
Yes	85 (93.4)	223 (83.8)	2.7 (1.1, 6.7)	96 (90.6)	82 (83.7)	1.9 (0.8, 4.4)
Participant helped with cleaning			<.05[d]			<.01[d]
No	15 (17.7)	71 (31.8)	1.0 (Ref)	42 (47.2)	51 (70.8)	1.0 (Ref)
Yes	70 (82.4)	152 (68.2)	2.2 (1.2, 4.1)	47 (52.8)	21 (29.2)	2.7 (1.4, 5.2)
No. of item categories cleaned[e,f]			NS[c,d]			<.05[d]
0	9 (9.6)	51 (19.0)	1.0 (Ref)	56 (37.8)	81 (51.3)	1.0 (Ref)
1–5	50 (53.2)	13 (49.4)	2.1 (1.0, 4.6)	76 (51.4)	63 (39.9)	1.7 (1.1, 2.8)
6–10	35 (37.2)	85 (31.6)	2.3 (1.0, 5.2)	16 (10.8)	14 (8.9)	1.7 (0.7, 3.7)

Continued

TABLE 3—*Continued*

No. of item categories discarded[g]			<.001[d]			NS[c,d]
0	59 (62.8)	219 (81.4)	1.0 (Ref)	140 (94.6)	150 (94.9)	1.0 (Ref)
1–4	35 (37.2)	50 (18.6)	2.6 (1.5, 4.4)	8 (5.4)	8 (5.1)	1.1 (0.4, 2.9)
No. of items cleaned by participant[e,f]			<.05[d]			.0001[d]
0	28 (29.8)	123 (45.7)	1.0 (Ref)	103 (69.6)	138 (87.3)	1.0 (Ref)
1–5	56 (59.6)	124 (46.1)	2.0 (1.2, 3.3)	45 (30.4)	20 (12.7)	3.0 (1.7, 5.4)
6–10	10 (10.6)	22 (8.2)	2.0 (0.9, 4.7)			
Time spent cleaning			<.001			<.001[d]
No time	23 (37.7)	100 (55.9)	1.0 (Ref)	47 (52.2)	59 (74.7)	1.0 (Ref)
≤ 12 h	19 (31.2)	56 (31.3)	1.1 (0.5, 2.2)	28 (31.1)	17 (21.5)	2.1 (1.0, 4.2)
> 12 h	19 (31.2)	23 (12.8)	3.6 (2.3, 9.5)	15 (16.7)	3 (3.8)	6.3 (1.7, 23.0)
Time present while others cleaned			<.001[d]			<.05[d]
No time	23 (37.7)	100 (55.9)	1.0 (Ref)	56 (62.9)	59 (77.6)	1.0 (Ref)
≤ 12 h	19 (31.2)	56 (31.3)	1.5 (0.7, 2.5)	16 (18.0)	11 (14.5)	1.5 (0.7, 3.6)
> 12 h	19 (31.2)	23 (12.8)	3.6 (1.7, 7.7)	17 (19.1)	6 (7.9)	3.0 (1.1, 8.1)
Time at area before cleaned			NS[c,d]			NS[c,d]
No time	4 (4.9)	27 (10.7)	1.0 (Ref)	43 (44.8)	42 (45.6)	1.0 (Ref)
≤ 12 h	27 (33.3)	79 (31.4)	2.3 (0.7, 7.2)	20 (20.8)	21 (22.8)	0.9 (0.4, 2.0)
> 12 h	50 (61.7)	146 (57.9)	2.3 (0.8, 6.9)	33 (34.4)	29 (31.5)	1.1 (0.6, 2.1)
Time at site between 9/11 and 12/31/01[h]			NS[c]			<.05
≤ 6 wk	18 (19.4)	45 (16.7)	1.0 (Ref)			
> 6–9 wk	18 (19.4)	53 (19.7)	0.8 (0.4, 1.8)	38 (27.0)	55 (36.2)	1.0 (Ref)
> 9–10 wk	17 (18.3)	63 (23.4)	0.8 (0.3, 1.5)	14 (9.9)	20 (13.2)	1.0 (0.4, 2.2)
> 10–10.5 wk	15 (16.1)	40 (14.9)	0.9 (0.4, 2.1)	25 (17.7)	22 (14.5)	1.6 (0.7, 4.0)
> 10.5–11 wk	25 (26.9)	68 (25.3)	0.9 (0.5, 1.9)	64 (45.4)	55 (36.2)	1.7 (0.8, 3.6)
Months first returned			NS[c]			<.05
≥ November 2001	14 (15.6)	38 (14.2)	1.0 (Ref)	42 (29.2)	64 (40.8)	1.0 (Ref)
October 2001	20 (22.2)	48 (17.9)	1.1 (0.5, 2.5)	20 (13.9)	16 (10.2)	1.9 (0.9, 4.1)
September 2001	56 (62.2)	182 (67.9)	0.8 (0.4, 1.7)	82 (56.9)	77 (49.0)	1.6 (1.0, 2.7)

Note. CI = confidence interval; OR = odds ratio. Numbers reported for individual variables may not sum to group total because of missing values; proportions are of participants for whom data were available.
[a]Excludes participants who were both residents and area workers.
[b]Cochran-Armitage test for trend or χ^2 test for dichotomous measures.
[c]Not significant at $P < .05$.
[d]*P* value for 2-sided test.
[e]Exteriors, hard surfaces, ceilings, floors, under appliances, nonfabric window treatments, carpets, fabric window treatments, soft items, air conditioners (range = 1–8).
[f]Workplace categories: 0, ≥ 1.
[g]Nonfabric window treatments, fabric window treatments, soft items, carpets (range = 1–4).
[h]Workplace categories = half of home categories (no time, ≤ 3 wk, > 3–4.5 wk, > 4.5 wk).

difficult to determine the extent to which observed associations between cleaning and lower respiratory symptoms were affected by insufficient information. Nonetheless, findings from this study were consistent with those of Lin et al.,[10] who did not observe a significant association between lower respiratory symptoms and cleaning in adjusted analyses. This may reflect an inherent paradox in the act of cleaning, which likely reduced chronic exposure but may have increased acute exposure.

Findings from this study apply, in general, to area workers who described their workplace on 9/11 as an office because this group constituted most (87%) of the area workers in the study. Among those who did not describe their workplace as an office, exposure-outcome associations were comparable to those observed among office workers, although detailed analyses were not feasible given the limited size of this group. Note that further research is needed to determine the effects of 9/11-related exposures on the respiratory and overall health of those area workers whose workplace on 9/11 was not in an office, but elsewhere in a building, outside of a building, in a vehicle, underground, or at other location, particularly given their likely unique patterns of exposure.

Enrollment in the World Trade Center Health Registry and this study was voluntary, raising the possibility that individuals experiencing more symptoms and exposure may

TABLE 4—Composite Exposure Scales Following September 11, 2001, and Their Association With Case Status Among New York World Trade Center–Area Residents and Workers

Composite Exposure Scale and Component Variables	All Participants (n = 785)			Residents[d] (n = 479)			Area Workers[d] (n = 422)		
	α[a]	OR[b] (95% CI)	AOR[c] (95% CI)	α[a]	OR[b] (95% CI)	AOR[c] (95% CI)	α[a]	OR[b] (95% CI)	AOR[c] (95% CI)
Acute Exposure									
Dust cloud: density	0.95	1.9 (1.6, 2.3)	1.7 (1.3, 2.2)	0.96	1.9 (1.5, 2.4)	1.5 (1.1, 2.1)	0.94	2.1 (1.7, 2.7)	1.8 (1.2, 2.7)
Personal appearance after thickest part of cloud									
Visibility in thickest part of cloud									
Time first caught, relative to World Trade Center collapses									
Dust cloud: time	0.93	1.3 (1.1, 1.5)	1.0 (0.8, 1.4)	0.92	1.3 (1.1, 1.5)	1.0 (0.7, 1.3)	0.93	1.2 (1.0, 1.5)	1.1 (0.8, 1.7)
Duration of time in dust cloud									
Proportion of time in thickest part of cloud									
Chronic Exposure									
Dust: home/workplace	0.92	1.7 (1.4, 2.0)	2.1 (1.5, 2.8)	0.89	1.6 (1.3, 2.0)	1.8 (1.2, 2.8)	0.94	1.8 (1.4, 2.2)	2.6 (1.7, 4.2)
Extent of dust coverage at home or workplace									
Depth of thickest dust layer at home or workplace									
Proportion of home or workplace most affected									
Smoke: home/workplace	0.92	1.3 (1.1, 1.5)	1.8 (1.3, 2.6)	0.86	1.3 (1.0, 1.6)	1.5 (0.9, 2.4)	0.95	1.3 (1.0, 1.5)	2.5 (1.4, 4.2)
Smelled smoke inside, outside, both									
Duration of time during which smelled smoke									
Time: home/workplace	0.85	0.9 (0.8, 1.0)	1.2 (0.9, 1.6)	0.82	0.8 (0.7, 1.0)	0.9 (0.6, 1.3)	0.86	1.0 (0.8, 1.2)	1.4 (0.9, 2.3)
Time at home or workplace									
Month first at home or workplace after 9/11									
Cleaning: home/workplace	0.94	1.6 (1.4, 1.9)	1.0 (0.7, 1.3)	0.92	1.7 (1.4, 2.1)	1.3 (0.9, 1.9)	0.97	1.6 (1.3, 2.0)	0.8 (0.5, 1.3)
Participated in cleaning of home or workplace									
Number of items cleaned by participant[a]									
Time spent cleaning home									

Note. AOR = adjusted odds ratio; CI = confidence interval; OR = odds ratio.
[a]Cronbach's α for standardized variables.
[b]Odds ratios for 1-point increase in composite exposure measure.
[c]Adjusted for age, race/ethnicity, education, body mass index, and other exposures shown.
[d]Includes participants who were both residents and area workers.

have been more likely to participate in either or both study components. Sparse data in select categories of variables specific to the home or the workplace may have affected observed associations (although most tests for trend were statistically significant), and composite scores could not be computed for participants missing 1 or more component variables. The potential effect of these exclusions was tested by imputation of missing values; ORs for dust and smoke in the workplace were reduced somewhat, although patterns of association and statistical significance remained. Comparison of relevant indicators between groups of participants who did and did not have composite scores identified no differences other than group membership, with a higher proportion of area workers having been excluded from select analyses.

Other limitations included the possibility of recall bias at waves 1 and 2 and during the study interview. However, the study interview confirmed earlier reports and completed or clarified missing or inconsistent data. When data were completed or clarified, consistent exposure data were available from 2 sets of responses; for the majority of participants, exposures were reported consistently at 3 points in time. Objective measures of lung function support the validity of symptom reports at the time of the study interview.

In summary, among populations that lived and worked in the area of the World Trade Center on 9/11, acute exposures to toxic inhalants occurring on and immediately after the events of that day and chronic exposures occurring during the weeks and months thereafter were independently associated, in a dose–response manner, with lower respiratory symptoms reported at initial enrollment in the World Trade Center Health Registry 2 to 3 years and again 5 to 6 years after 9/11. Dimensions of exposure significantly associated with these symptoms included the density of the cloud of dust experienced on 9/11 and both the extent of dust contamination and the presence of smoke and fumes in homes and workplaces during the several months thereafter.

These data suggest the need for immediate and continual multidimensional exposure assessments following disasters or other events from which toxic inhalants may be released. Assessments should be tailored to type (acute or chronic) and location (home, workplace, or other) of exposure and should be used to inform rapid interventions to minimize risks to health by reducing or avoiding exposure to toxic inhalants in the future. ■

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All authors contributed to development and review of the final article. C.B. Maslow contributed to the conceptualization and design of the study; supervised study implementation, including data collection, management, and analysis; and wrote the article. S.M. Friedman contributed to the conceptualization and design of the study, study implementation, and data analysis. P.S. Pillai contributed to study implementation and data collection, management, and analysis. J. Reibman, K.I. Berger, and R. Goldring contributed to the conceptualization and design of the study, pulmonary function testing, and preparation of the article. K.I. Berger also interpreted pulmonary function test results. S.D. Stellman contributed to the data analysis and preparation of the article. M. Farfel contributed to the conceptualization and design of the study and data analysis.

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