

## ENVIRONMENTAL DETERMINANTS

# Respiratory Health of 985 Children Exposed to the World Trade Center Disaster: Report on World Trade Center Health Registry Wave 2 Follow-up, 2007–2008

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**Background.** The World Trade Center (WTC) disaster of September 11, 2001, has been associated with early respiratory problems including asthma in workers, residents, and children. Studies on adults have documented persistence of longer term, 9/11-related respiratory symptoms. There are no comparable reports on children. **Methods.** We surveyed 985 children aged 5–17 years who enrolled in the WTC Health Registry in 2003–04, and who were re-surveyed in 2007–08. Health data were provided by parents in both surveys and focused on respiratory symptoms suggestive of reactive airway impairment (wheezing or the combination of cough and shortness of breath) in the preceding 12 months. At follow-up, adolescents aged 11–17 years completed separate surveys that screened for post-traumatic stress symptoms and behavior problems (Strengths and Difficulties Questionnaire, SDQ). Associations between respiratory symptoms in the prior 12 months with 9/11 exposures and behavioral outcomes were evaluated with univariate and multivariate methods. **Results.** Of the 985 children, 142 (14.4%) children reported respiratory symptoms in the prior 12 months; 105 (73.9%) children with respiratory symptoms had previously been diagnosed with asthma. Among children aged 5–10 years, respiratory symptoms were significantly elevated among African-Americans (adjusted odds ratio, (aOR) 3.8; 95% confidence interval (CI) 1.2–11.5) and those with household income below \$75,000 (aOR 1.9; CI 1.0–3.7), and was more than twice as great in children with dust cloud exposure (aOR 2.2; CI 1.2–3.9). Among adolescents aged 11–17 years, respiratory symptoms were significantly associated with household income below \$75,000 (aOR 2.4; CI 1.2–4.6), and with a borderline or abnormal SDQ score (aOR 2.7, 95% CI 1.4–5.2). Symptoms were reported more than twice as often by adolescents with vs. without dust cloud exposure (24.8% vs. 11.5%) but the adjusted odds ratio was not statistically significant (aOR 1.7; CI 0.9–3.2). **Conclusions.** Most Registry children exposed to the 9/11 disaster in New York City reported few respiratory problems. Respiratory symptoms were associated with 9/11 exposures in younger children and with behavioral difficulties in adolescents. Our findings support the need for continued surveillance of 9/11 affected children as they reach adolescence and young adulthood, and for awareness of both physical and behavioral difficulties by treating clinicians.

**Keywords** air pollution, asthma, behavior, children, disaster, respiratory symptoms, World Trade Center

## INTRODUCTION

Respiratory illnesses associated with exposure to the World Trade Center (WTC) terrorist attacks of September 11, 2001 in New York City have been reported among adults (1–3) and children (4). Increased new-onset and persistent respiratory health effects in adult residents of Lower Manhattan were reported during the first 16 months after 9/11 (1), and were found to be associated with dust contamination in the home up to 6 years after the attacks (5–7). Our group previously reported on new asthma diagnoses in 3184 potentially exposed children below the age of 18 years who were enrolled in the World Trade Center Health Registry (the “Registry”) in 2003–04 (Wave 1). We found that 45% of these children reported dust cloud exposure on 9/11, and that this exposure was significantly associated with a new post-9/11 asthma diagnosis (4).

Over a decade after the World Trade Center attacks,

persistent respiratory symptoms continued to be reported in 9/11 exposed rescue/recovery workers (8, 9) as well as Lower Manhattan residents (6, 7, 10, 11); no new reports have yet been available for children. The present report updates respiratory conditions in Registry enrollees under 18 years of age who completed the Registry’s Wave 2 follow-up survey in 2007–08. We examined associations between respiratory symptoms suggestive of reactive airway impairment and WTC disaster exposures that have previously been shown to affect respiratory function (12). In contrast to our earlier report, in this analysis, we elected to use as outcome respiratory symptoms that suggest possible wheezing disorder, rather than self-report of asthma diagnosis, given that reactive airways, wheezing disorders, and asthma constitute a spectrum of illness, and the fact that children’s medical providers do not consistently use the term “asthma” when explaining wheezing illness to parents. Respiratory symptoms and asthma have both been found to be comorbid with mental health conditions such as post-traumatic stress disorder in 9/11-exposed adults (8, 9, 11–13), and post-traumatic stress symptoms have been reported in children as a result of 9/11 (14, 15). We therefore examined a possible association between WTC-

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related stress and behavioral difficulties in children who were of adolescent age in the Wave 2 survey and reports of respiratory symptoms.

## METHODS

### *Population and Data Collection*

Study design and enrolment methods have been described previously (10, 16). Briefly, between September, 2003, and November, 2004, 71,434 people completed a computer-assisted (95%) or in-person (5%) interview that gathered demographic, health, and detailed exposure information. Eligibility was confined to rescue/recovery workers, Lower Manhattan residents and workers, passersby on 9/11, and persons attending or working in area schools. In particular, children under 18 years were eligible if they lived or attended school in Manhattan south of Canal Street, were present south of Chambers Street on the morning of 9/11, or participated in disaster-related rescue-recovery efforts. Additional recruitment details are presented by Thomas et al. (4)

### *Wave 1*

Proxy interviews by parents or guardians of 3184 children under 18 years of age were done by telephone (88%) or personal interview (12%), and included questions on demographics, 9/11-related exposures and injuries, and physical and mental health symptoms and conditions both before and after 9/11.

### *Wave 2*

A follow-up survey of parents and children was conducted between June, 2007, and December, 2008, to update physical and mental health data for enrollees still under 18 years of age via a self-administered paper questionnaire, available in English, Spanish, or Chinese. For persons under 11 years in 2007, the entire survey was completed by a parent. For adolescents aged 11–17 years, a parent completed a questionnaire about the subject's physical health and health care access while the adolescent completed a questionnaire on behavior and mental health that was to be returned in a separate envelope to allow for confidentiality. Both, the parent questionnaire for children under 11 years and the adolescent questionnaire contained questions on intensity of dust cloud exposure and condition of the home, details that had not been asked at Wave 1. Wave 2 surveys were mailed to the most recent address available for each enrollee under the age of 18 years. Door-to-door outreach was conducted in parts of lower Manhattan, emphasizing neighborhoods with high proportions of Asian immigrants, in an effort to increase response rates.

Dust cloud exposure was expressed as a three-level variable coded as none, some, or intense. It was based on a combination of the response to the Wave 1 dust cloud question "On September 11th, [were you/was SUBJECT] outdoors within a dust or debris cloud resulting from the collapse of the World Trade Center towers" plus five exposure questions introduced in the Wave 2 Survey.

Enrollees who answered "yes" to any dust cloud exposure were asked whether during their time in the dust cloud they could not see more than a few feet, had trouble finding their way, had to find shelter, were covered head to toe with dust and debris, or could not hear anything. Exposure was considered "intense" in persons answering "yes" to any one of these five exposures. The condition of the home with respect to WTC-related dust or damage was based on a Wave 2 question: "What was the condition inside your child's home after the WTC disaster (*before any cleanup*)?" Multiple-choice responses included "no damage", "fine coating of dust on surfaces", "heavy coating of dust on surfaces (so thick you couldn't see what was underneath)", "broken windows", "damage to home or furnishings", and "debris present from the disaster." History of the child's having witnessed disturbing events was taken from the Wave 1 survey: "Did the child witness an airplane crashing into a tower, buildings collapsing, people running away from a cloud of smoke, anyone who was injured or killed, or someone falling or jumping from one of the towers?" Time spent in lower Manhattan was estimated from the Wave 1 response: for resident children who attended school in lower Manhattan, exposure was assumed to be 24 hours a day from 9/11/01, or, if they evacuated, from the date they returned to their homes until 12/20/01. For resident children who attended school outside of the area, 8 hours per day was subtracted for school days (5 days per week minus school holidays). For students who were not residents, exposure to lower Manhattan was assumed to be 8 hours per day on school days (Monday to Friday, minus school holidays).

### *Outcome Variables*

Surveys based on parental reports of asthma overlook many children with active disease, and pediatricians may not uniformly use the term "asthma" for their patients with wheezing (17, 18). We therefore used as our primary outcome a combination of respiratory symptoms suggestive of possible asthma, namely, wheezing or the combination of cough plus shortness of breath in the past 12 months. Two psychological measures are available for the adolescents in the Wave 2 survey. The Disc Predictive Scale (DPS) with 9/11-specific questions was used to assess probable post-traumatic stress symptoms. The DPS is a modification of the National Institute of Mental Health DISC Version VI (19) that incorporates items most predictive of DSMV-IV PTSD diagnosis with good psychometric properties (20). It was used to study probable mental health disorders among New York City school students in the first 6 months after 9/11 (14). The Strengths and Difficulties Questionnaire (SDQ) was used for self-assessment of function in adolescents 11 to 17 years of age. The SDQ is a 25-question validated behavioral screening questionnaire that incorporates five scales of emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and prosocial behavior (21). For this analysis, we summed items in the first four scales to arrive at a total score that is interpreted as suggestive of severe emotional distress (22). The DPS and SDQ measures were each

investigated for possible associations with respiratory symptoms in children aged 11–17 years.

### Statistical Analysis

We used bivariate analysis to describe background characteristics and exposures associated with respiratory symptoms. Separate logistic regressions were conducted for children aged 5–10 years ( $n = 469$ ) and 11–17 years ( $n = 516$ ) to calculate crude and adjusted odds ratios (ORs), and 95% confidence intervals (CIs) for association of respiratory symptoms with exposures and, for adolescents, post-traumatic stress and behavioral difficulties. Possible predictors included gender, age of the child on September 11, 2001, race/ethnicity, household income at Wave 2, dust cloud exposure, witnessing disturbing events on 9/11, evacuation of home or school on 9/11, post-9/11 condition of the home as measured by reported damage, residual dust and debris, and time spent South of Canal Street during the first 100 days after the attacks. Besides age, we retained those predictors whose bivariate  $p$ -values were  $< 0.05$ . We used SAS 9.2 for all calculations.

## RESULTS

Table 1 shows distribution of background characteristics, respiratory symptoms, and selected 9/11 exposures that were previously reported to be risk factors for respiratory illness in children enrolled in the Registry (4). While 38.9% of the original pediatric cohort were age 12–17 on 9/11, by the time of the Wave 2 survey children age 13 and older on 9/11 had aged into adulthood, so that 100% of Wave 2 participants were 12 years old or less at the time of the disaster and 43.9% were under 5 years old on 9/11. Girls slightly outnumbered boys (51.3% vs. 48.7%), 53.6% of the children were White, 20.5% Asian, 13.3% Hispanic, and 5.4% were Black. Household income varied widely within the cohort, exceeding \$100,000 for 43.4% of the cohort, and less than \$25,000 for 14.6%. One-fourth of the children ( $n = 246$ ) had been diagnosed with asthma by Wave 2. Of these, 110 (45%) children were diagnosed before and 135 children (55%) after 9/11.

Of the 2030 eligible children under 18 years of age, responses were received for 1022 (50.3%) children. Non-responding children at Wave 2 did not differ significantly from those who responded in gender, age, residence South of Canal Street vs. elsewhere, attendance on 9/11 at a school South of Canal Street, witnessing disturbing sights or events, or reported exposure to the dust cloud. Response rates were significantly higher for White (56.1%) and Asian children (56.0%) than for Black (36.1%) and Hispanic (36.5%) children ( $p < 0.001$ ). Among children for whom a previous diagnosis of asthma was reported at Wave 1, the response rate of 47% was not significantly different from the overall rate. Response by specific disaster-related exposures was 50% for children who had been residents of lower Manhattan on 9/11/01, 52% for children enrolled in school in lower Manhattan, who were not residents, 50% among those who had reported dust

cloud exposure, and 51% among those who had witnessed a disturbing event (e.g. plane crashing into building, someone falling from a building). The analysis in this report is based on the 985 children (96.4% of those responding) for whom information on asthma, wheezing, and other respiratory symptoms was reported on the Wave 2 survey.

The children had a wide range of experiences and exposures to the initial attack and collapse of the World Trade Center and surrounding buildings. One-third of the children ( $n = 304$ ) were reported to have been exposed to the dust cloud, and just over half of those ( $n = 159$ ) reported “intense” exposure; 59.5% ( $n = 568$ ) of the children witnessed one or more disturbing events. Of the 876 children who lived in the residential zone South of Canal Street, two-thirds ( $n = 580$ ) of the children had evacuated their homes on 9/11, and 14.9% of the children ( $n = 128$ ) returned to find their homes damaged with a layer of heavy dust. The median time spent in Lower Manhattan from September 11 to December 20, 2001 was 73 days. The great majority (89.8%) of adolescents who were at school South of Canal Street reported evacuating the school.

Prevalence of respiratory symptoms among children in the 12 months prior to the 5–6 years follow-up is shown in Table 1, within each category of demographic and exposure variables. The overall prevalence was 14.4%, and was significantly greater in boys (16.9%) than in girls (12.1%,  $p = 0.04$ ). Respiratory symptom prevalence did not differ significantly with age, but was higher in African-American (22.6%) and Hispanic (21.4%) than in White children (11.0%,  $p < 0.01$ ). It was substantially higher in children of low-income families compared to high-income families. Among seven types of exposure measured, only dust cloud and condition of home after 9/11 were associated with respiratory symptoms ( $p = 0.05$ ,  $p < 0.001$ , respectively). Respiratory symptoms were reported more than twice as frequently in children who were exposed to the dust cloud than in those not exposed. Children whose homes suffered 9/11-related damage had a significantly higher frequency of respiratory symptoms than those living in undamaged homes ( $p < 0.05$ ).

As shown in Table 1, the criterion for post-traumatic stress (PTS) was met by 30 of 490 (6.1%) adolescents, while 83 of 479 (17.3%) adolescents with valid SDQ scores were adjudged “borderline” or “abnormal” for severe emotional disturbance. Among 516 children, 11 to 17 years of age at Wave 2, and who were therefore offered the SDQ and DPS questions, respiratory symptoms were reported in 32.7% of adolescents with borderline and 35.7% with abnormal total SDQ scores compared to 11.4% of those with normal scores ( $p < 0.001$  for both). Respiratory symptoms were reported in 46.7% of children who screened positive for post-traumatic stress symptoms, compared to 13.3% of children who did not ( $p < 0.001$ ).

Table 2 shows multivariate adjusted associations of demographic variables and risk factors with reported respiratory symptoms in the preceding 12 months for 469 children aged 5–10 years at Wave 2. Respiratory

symptoms were not associated with age, but were significantly associated with gender (male vs. female gender aOR 1.9 [95% CI 1.1–3.4]), African-American race/ethnicity (aOR 3.8 (1.2–11.5), household income (<\$75,000 aOR 1.9 (1.0–3.7)), and dust cloud exposure on 9/11 (aOR 2.2 (1.2–3.9)). The frequency of respiratory symptoms among children who experienced home damage with some or heavy dust was nearly twice as high (19.6%) as among children in undamaged homes (10.1%), but the OR was not statistically significant (aOR 1.5 (0.8–2.9)).

Table 3 presents multivariate assessments of respiratory symptoms for 516 adolescents aged 11–17 years in relation to demographic and 9/11-risk factors, with the addition of the two behavioral predictors measured in this older group, namely, post-traumatic stress symptoms and total

SDQ. Neither age nor gender was significantly associated with respiratory symptoms. Symptoms were reported twice as often by Hispanic (25.0%) than non-Hispanic White adolescents (10.6%), but the adjusted OR was not significant (aOR 1.2; 0.5–2.6). Of the demographic variables only income showed a strong association with respiratory symptoms (income < \$75K aOR 2.4 (1.2–4.6)). Dust cloud exposure and home damage with dust were reported more often by adolescents with respiratory symptoms; adjusted ORs for both exposures were identical and nearly two-fold, but were not significantly different from unity (aOR 1.7 (0.9–3.2)). Borderline/abnormal SDQ was significantly associated with respiratory symptoms (aOR 2.7 (1.4–5.2)). Thirty of 490 adolescents (6.1%) screened positive for symptoms of traumatic stress, and fourteen of these reported respiratory symptoms, but

TABLE 1.—Selected background characteristics, prevalence of respiratory symptoms (combination of both cough and shortness of breath, and/or wheeze), and selected 9/11 exposures of 985 children aged 5–17 years participating in Wave 2 of the WTCHR, 2007–2008.

	No. children	(%)	No. with respiratory symptoms	(%)	<i>p</i> <sup>a</sup>
Total	985	(100.0)	142	(14.4)	
Gender					
Male	480	(48.7)	81	(16.9)	<.05
Female	505	(51.3)	61	(12.1)	
Age on 9/11					
< 2	173	(17.6)	30	(17.3)	n.s.
2 to <5	259	(26.3)	30	(11.6)	
5 to 12	553	(56.1)	82	(14.8)	
Race/ethnicity					
White	528	(53.6)	58	(11.0)	<.01
Black	53	(5.4)	12	(22.6)	
Hispanic	131	(13.3)	28	(21.4)	
Asian	202	(20.5)	32	(15.8)	
Multiracial/other	71	(7.2)	12	(16.9)	
Household income					
< \$25K	135	(14.6)	30	(22.2)	<.001
\$25K - < \$50K	136	(14.7)	25	(18.4)	
\$50K - < \$75K	126	(13.6)	28	(22.2)	
\$75K - < \$100K	126	(13.6)	11	(8.7)	
\$100K & up	401	(43.4)	39	(9.7)	
Asthma diagnosis					
Before 9/11	110	(11.2)	48	(43.6)	<.001
After 9/11	136	(13.7)	57	(42.2)	
Never	739	(75.0)	37	(5.0)	
Selected exposures					
Resident but not in school S. of Canal Street on 9/11	361	(36.7)	57	(15.8)	n.s.
Enrolled in school but not resident S. of Canal St. on 9/11	100	(10.2)	12	(12.0)	
Both resident and enrolled in school	515	(52.3)	71	(13.8)	
Other	9	(0.9)	2	(22.2)	
Dust cloud exposure					
None	607	(66.6)	66	(10.9)	<.001
Some	145	(15.9)	32	(22.1)	
Intense	159	(17.5)	34	(21.4)	
Witnessed disturbing events <sup>b</sup>					
Yes	568	(59.5)	91	(16.0)	n.s.
No	386	(40.5)	46	(11.9)	
Evacuated residence <sup>b,c</sup>					
Yes	580	(66.3)	77	(13.3)	n.s.
No	295	(33.7)	51	(17.3)	

TABLE 1.—(Continued).

	No. children	(%)	No. with respiratory symptoms	(%)	<i>p</i> <sup>a</sup>
Condition of home <sup>c</sup>					
No damage	660	(76.9)	84	(12.7)	<.05
Damage without heavy dust	70	(8.2)	16	(22.9)	
Damage with heavy dust	128	(14.9)	26	(20.3)	
Evacuated school on 9/11 <sup>b,d</sup>					
Yes	299	(89.8)	41	(13.7)	n.s.
No	34	(10.2)	6	(17.6)	
No. days spent S. of Canal St. 9/12/01 to 12/20/01 <sup>b</sup>					
Zero Days	111	(11.3)	18	(16.2)	n.s.
1–60	199	(20.2)	29	(14.6)	
61–100	331	(33.6)	39	(11.8)	
>100	302	(30.7)	52	(17.2)	
Missing	42	(4.3)	4	(9.5)	
SDQ Total Score <sup>e</sup>					
Normal	396	(82.7)	45	(11.4)	<.001
Borderline	55	(11.5)	18	(32.7)	
Abnormal	28	(5.9)	10	(35.7)	
Post-Traumatic Stress Symptoms <sup>e</sup>					
No	460	(93.9)	61	(13.3)	<.001
Yes	30	(6.1)	14	(46.7)	

Notes: WTCHR, World Trade Center Health Registry; n.s., not statistically significant.

<sup>a</sup>Chi-square test comparing distribution of given variable in children with vs. without reported respiratory symptoms at Wave 2; <sup>b</sup>Data reported at Wave 1; <sup>c</sup>Restricted to Residents of Lower Manhattan on 9/11; <sup>d</sup>Restricted to those enrolled in school in Lower Manhattan on 9/11; <sup>e</sup>Restricted to respondents 11–17 years of age at time of Wave 2 survey.

TABLE 2.—Adjusted odds ratios for associations of World Trade Center risk factors with respiratory symptoms (combination of both cough and shortness of breath, and/or wheeze) in the 12 months prior to the Wave 2 survey, among 469 children age 5–10 participating in Wave 2 of the WTCHR, 2007–2008.

	Total children age 5–10	No. (%) with cough plus shortness of breath and/or wheeze	OR <sup>a</sup>	(95% Conf. Int.)
Gender				
Male	242	42 (17.4)	1.9	(1.1–3.4)
Female	227	22 (9.7)	1.0	Ref.
Age on 9/11				
< 2	173	30 (17.3)	1.9	(0.6–6.1)
2 to <5	259	30 (11.6)	1.0	(0.3–3.1)
5 to <12	37	4 (10.8)	1.0	Ref.
Race/ethnicity				
White	254	29 (11.4)	1.0	Ref.
Black	19	7 (36.8)	3.8	(1.2–11.5)
Hispanic	59	10 (16.9)	1.3	(0.5–3.0)
Asian	98	15 (15.3)	1.3	(0.6–2.9)
Multiracial/other	39	3 (7.7)	0.7	(0.2–2.7)
Household income, Wave 2				
\$75 K+	272	27 (9.9)	1.0	Ref.
< \$75 K	167	33 (19.8)	1.9	(1.0–3.7)
Missing	30	4 (13.3)	1.5	(0.5–5.0)
Exposure to dust cloud				
None	267	27 (10.1)	1.0	Ref.
Intense/some	179	35 (19.6)	2.2	(1.2–3.9)
Missing	23	2 (8.7)	0.7	(0.1–3.4)
Condition of home				
No damage	324	40 (12.3)	1.0	Ref.
Damage with some/heavy dust	93	19 (20.4)	1.5	(0.8–2.9)
Non-resident/ missing	52	5 (9.6)	0.7	(0.3–2.1)

Notes: WTCHR, World Trade Center Health Registry; OR, odds ratio; C.I., confidence interval, Ref, reference.

<sup>a</sup>Adjusted for all other variables in the table.

TABLE 3.—Adjusted odds ratios for associations of World Trade Center risk factors with respiratory symptoms (combination of both cough and shortness of breath, and/or wheeze) in the 12 months prior to the Wave 2 survey, among 516 adolescents age 11–17 years, participating in Wave 2 of the WTCHR, 2007–2008.

	Total adolescents age 11–17	No. (%)with cough plus shortness of breath and/or wheeze	OR <sup>a</sup>	(95% Conf. Int.)
<b>Gender</b>				
Male	238	39 (16.4)	1.4	(0.8–2.5)
Female	278	39 (14.0)	1.0	Ref.
<b>Age on 9/11</b>				
5 to 8	266	39 (14.7)	1.0	Ref.
9 to 12	250	39 (15.6)	1.0	(0.6–1.7)
<b>Race/ethnicity</b>				
White	274	29 (10.6)	1.0	Ref.
Black	34	5 (14.7)	0.6	(0.2–2.0)
Hispanic	72	18 (25.0)	1.2	(0.5–2.6)
Asian	104	17 (16.3)	1.1	(0.5–2.4)
Multiracial/other	32	9 (28.1)	2.2	(0.8–6.2)
<b>Household income, Wave 2</b>				
\$75 K+	255	23 (9.0)	1.0	Ref.
<\$75 K	230	50 (21.7)	2.4	(1.2–4.6)
Missing	31	5 (16.1)	1.6	(0.5–5.1)
<b>Exposure to dust cloud</b>				
None	340	39 (11.5)	1.0	Ref.
Intense/some	125	31 (24.8)	1.7	(0.9–3.2)
Missing	51	8 (15.7)	1.4	(0.5–3.9)
<b>Condition of home</b>				
No damage	336	44 (13.1)	1.0	Ref.
Damage with some/heavy dust	105	23 (21.9)	1.7	(0.9–3.2)
Non-resident/ missing	75	11 (14.7)	0.8	(0.4–1.9)
<b>SDQ Total Score</b>				
Normal	396	45 (11.4)	1.0	Ref.
Borderline/Abnormal	83	28 (33.7)	2.7	(1.4–5.2)
<b>Post-Traumatic Stress Symptoms</b>				
No	460	61 (13.3)	1.0	Ref.
Yes	30	14 (46.7)	2.3	(0.9–5.9)

Notes: WTCHR, World Trade Center Health Registry; OR, odds ratio; C.I., confidence interval, Ref, reference  
<sup>a</sup>Adjusted for all other variables in the table.

the association was not significant after multivariate adjustment (aOR 2.3 (0.9–5.9)).

*Asthma Severity/Asthma Control*

Seventy-four percent (105/142) of children who had wheezing or a combination of cough or shortness of breath

also had a prior diagnosis of asthma. As shown in Figure 1, the annualized incidence rate of asthma fell from an initial level of 6 per 100 per year immediately after the World Trade Center disaster to approximately 1 per 100 per year in 2006–08, which is similar to the average rate for children aged 17 years and below recently reported by Winer

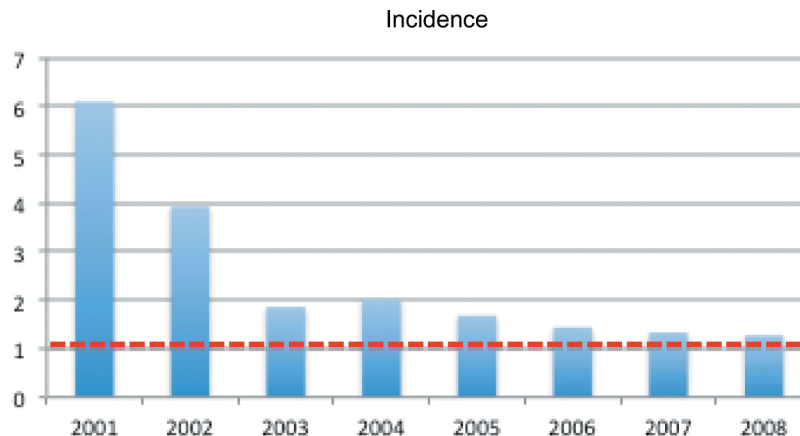


FIGURE 1.—Annualized incidence (per 100) of asthma among at-risk children<sup>a</sup> in the World Trade Center Health Registry, 2001–2008.  
<sup>a</sup>Children were age <2 to 12 years old on Sept. 11, 2001. Dashed line is incidence rate for children < 18 years, Behavioral Risk Factor Surveillance System Asthma Callback Survey – US, 2006–08 (23).

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TABLE 4.—Frequency (%) of diagnosed asthma by time period among 985 children, and respiratory symptoms in the past 12 months among children with and without a history of diagnosed asthma.

Asthma status	N	Respiratory symptoms <sup>a</sup> in past 12 months N (%) <sup>b</sup>
Never diagnosed	739	37(5.0)
Ever diagnosed	246	105(42.7)
<i>Before 9/11</i>	110	48(43.6)
<i>After 9/11: 2001–02</i>	49	25(51.0)
<i>After 9/11: 2003–08</i>	67	28(41.8)
<i>After 9/11: Year unknown</i>	20	4(20.0)
Total children	985	142(14.4)

Notes: <sup>a</sup>Cough plus shortness of breath and/or wheeze (sometimes, often, or very often) within the last 12 months; <sup>b</sup>Percent of children with indicated asthma status.

et al. (23) Table 4 shows that 49 of 116 (42.2%) post-9/11 asthma cases with known diagnosis dates occurred in the first 2 years after 9/11, but that respiratory symptoms among these children did not vary much by diagnosis period. Also, among children ever diagnosed with asthma, 58% reported at least one asthma attack in the year prior to the survey, and among those with asthma who also had respiratory symptoms in the prior 12 months, 35.0% also reported at least one Emergency Department visit. By comparison, in the 2008 NHIS survey, among children with current asthma, 57.2% had at least one asthma attack in the preceding 12 months, and 32.5% had at least one emergency department or urgent care visit (24). The great majority (76.3%) of children with both asthma and recent respiratory symptoms were in households with income below \$75,000. Parents overwhelmingly reported that their children had good access to health care at Wave 2: almost all children (97.9%) had a routine checkup with a primary care provider within the 2 years prior to the survey, and only 5% reported one or more unmet health care needs such as difficulty accessing a specialist physician.

## DISCUSSION

Many children residing or attending schools near the World Trade Center were exposed to the physical and psychological traumatic events of the attacks such as the massive dust cloud that resulted from the collapse of the two WTC towers, persistent respirable dust in homes and schools, and from fumes and particulate matter generated by the fires that continued for several months and the cleanup effort that continued through July, 2002. Because these exposures have been associated in numerous studies with adult respiratory illnesses, including asthma, as well as PTSD (10, 12, 25) it is plausible that children could be affected as well. Six to seven years after 9/11, respiratory symptoms consisting of wheezing, a combination of cough and shortness of breath, or all three were reported by 142 or 14.4% of the 985 children enrolled in the Registry who were 0–12 years old on September 11, 2001. Respiratory symptoms were associated most strongly with dust cloud exposure, household income below \$75,000, residential damage and dust in

residences south of Canal street and, among adolescents, with emotional distress as measured by a borderline or abnormal Strengths and Difficulties (SDQ) score.

We chose as our outcome a symptom complex (combination of cough plus shortness of breath and/or wheeze) rather than a reported diagnosis of asthma because it is considered by pulmonologists to suggest possible underlying asthma or reactive airway disease. This broader range of pulmonary symptoms provides comparability with recent studies of WTC-exposed adults, while avoiding some of the problems in the reporting of childhood asthma, such as the variability of diagnostic terminology used by pediatric clinicians. With respect to asthma, it has been pointed out that “clinical manifestations are syndromic and not unimodal,” and there is “marked variability in severity of symptoms.” (18) Wright, for example, has noted that recurrent cough without wheeze in children is a “distinct syndrome from classic asthma,” (26) while Martinez has pointed out that wheezing in most infants is transient and does not necessarily presage later asthma (27). Children presenting with wheezing may be diagnosed with “wheezy bronchitis” by some clinicians, “reactive airway disease” or asthma by others, yet other clinicians reserve the term asthma for children who demonstrate a persistent tendency to wheeze over several years (18). Nevertheless, it is useful to point out that the prevalence of current respiratory symptoms in the 246 children with reported asthma, whether diagnosed before or after 9/11, is 43% (Table 1), compared to 5% for the 739 children with no reported diagnosis.

Respiratory symptoms were significantly associated with male gender (nearly two-fold) in the younger children, but not in adolescents; they were not associated with age on 9/11 in either group. We previously reported at Wave 1 a two-fold risk of new asthma among Hispanic relative to non-Hispanic White children (4). Wave 2 adolescent data continue to show a significant association between respiratory symptoms and Hispanic ethnicity, consistent with the higher prevalence of 9/11-related respiratory symptoms and asthma reported by Hispanic adults in the Registry at both Wave 1 and Wave 2 (10, 16). The association with ethnicity in this much smaller adolescent cohort, however, became non-significant after adjustment for background and exposure variables. Household income was significantly associated with respiratory symptoms in both age groups, but much more strongly among adolescents than among the younger children. Low income is associated with higher rates of asthma exacerbation in many populations and may be due to many factors including poor access to health care, poor asthma control, or environmental factors such as living near highways or in older, poorly maintained buildings, and other stressors (28). Most cohort members reported access to regular health care, but the survey did not collect detail about quality or type.

Exposure to the dust cloud was previously reported at Wave 1 to be strongly associated with a new asthma diagnosis (4). At Wave 2, dust cloud exposure was reported about twice as often among children with

respiratory symptoms in both age groups, although after adjustment for background variables and home condition the odds ratio in adolescents was no longer significant. The dust cloud on 9/11 contained particulates, pulverized cement and glass, and other potential respiratory irritants or toxins emanating from collapsing and burning buildings (29), and the increase in respiratory symptoms associated with the dust cloud and post-disaster dust in homes raises the concern that mild chronic disease could have resulted from these exposures (1, 4, 10, 11). In the months following the disaster, children were further exposed to smoke and particulates that spread over lower Manhattan and beyond that had settled on walls and surfaces of homes and schools, and that was subsequently disturbed by cleanup activities and re-suspended in the indoor atmosphere (30). In a nested study of adult residents of Lower Manhattan in the Registry, significant associations were observed between chronic exposure to household dust and fumes and lower respiratory symptoms up to 9 years after 9/11 (7), while pulmonary function testing provided evidence of distal airway dysfunction associated with persistent lower respiratory symptoms (12). Comparable pulmonary function data are not available for enrollees who were under 18 years on 9/11.

Finally, among adolescents who completed the SDQ assessment in 2007–08, we observed a significant odds ratio of 2.7 for the association of respiratory symptoms with a borderline or abnormal difficulties score. This is comparable in magnitude to the findings of Calam et al. who reported a significant two-fold association between borderline/abnormal total difficulties and a reported asthma diagnosis in a population-based sample of children in England and Wales; the association in that study was restricted to adolescents in “poor health.” (31) The stronger association in our adolescent population (OR = 2.7) may be due in part to intense exposures to environmental pulmonary irritants. Associations of respiratory symptoms and asthma with exposure to external stressors have been observed in numerous studies, although a clear causal link in either direction is not firmly established (32, 33). While the prevalence of post-traumatic stress symptoms (PTSS) became statistically non-significant after adjustment for background and exposure variables, it retained a relatively high point estimate of association with an adjusted OR of 2.3 (95% CI 0.9–5.9). Our sample was too small to fully evaluate the possible confounding role of the environment associated with lower household income, in relation to both respiratory and psychological symptoms.

### Limitations

Our data are limited by their self-reported nature and by the varying terminology used by parents and clinicians to describe children’s respiratory problems, as described above. Variability in diagnostic terminology used by clinicians could have resulted in under- or over-reporting of asthma in our cohort. Asking parents about symptoms such as wheezing and shortness of breath may also be subject to

error. Parents may misinterpret noisy or strained breathing as wheezing. Parents of exposed children, who may themselves have been similarly exposed, may have been more likely to recall both symptoms and exposures. However, the response rate among children with asthma reported at Wave 1 was lower than the overall response rate, while the response rate among children exposed to the dust cloud was about the same as the overall rate. In children, most asthma is associated with atopy (the tendency to hypersensitivity also associated with allergy and eczema). It is likely that persons already predisposed to asthma could first clearly manifest the condition at the time of acute exposure to airborne particulates and irritants. We lack data on other respiratory risk factors such as specific allergies, pets, or smoking in the home, nor do we have data on prevalence of atopy in this population, although such data were gathered in the recently completed Wave 3.

The response rate of 50.3% raises the obvious question of how well Wave 2 respondents represent the entire cohort. Respondents and non-respondents within our cohort differed very little with respect to gender, age, exposure, home evacuation, and witnessing 9/11 events. As noted above, the Wave 2 response rate was slightly lower among children with a prior asthma diagnosis, and it was significantly lower for Black and Hispanic children compared to Whites and Asians. Response rate by household income is not known, as this information was not collected in the Wave 1 survey. Reports of respiratory symptoms and asthma may also be affected by increased surveillance within the cohort. The children participating in the Wave 2 survey reported very good access to health care. Almost all (97.9%) had had a routine check-up with a primary care provider within the past 2 years, and only 5% reported one or more unmet health care need such as difficulty in accessing a specialist physician. However, the survey is weighted towards wealthier families and it is possible that the small number of children of lower SES (family income <\$75,000) may not have had as good access, as evidenced by significantly higher emergency department use. This could have resulted in under-ascertainment of children with ongoing respiratory symptoms, especially in view of the established higher risks of ongoing asthma symptoms in inner city, impoverished populations (28, 34, 35).

### CONCLUSION

In this cohort of 985 children and adolescents, we confirmed the initial (Wave 1) findings of associations of lower respiratory symptoms with exposures to the dust cloud generated by the collapse of the towers and subsequently to WTC-generated dust in the home. We extended those findings with 3–4 additional years of follow-up (Wave 2) in which 14.4% of the under-18 enrollees reported persistent respiratory symptoms that were also associated with 9/11 exposures.

Respiratory symptoms have been found to be comorbid with probable PTSD in the adult component of the



Registry (11, 13), while respiratory illnesses, including asthma, are frequently found to be related to anxiety disorders in children (36, 37). This led us to hypothesize corresponding associations in Registry youth, and in fact among 516 adolescents within this pediatric cohort we observed significant unadjusted associations between respiratory symptoms and 9/11-related stress symptoms, measured by the DPS, as well as with emotional distress, as measured by total SDQ; the latter remained significant after adjustment for other respiratory risk factors. Our relatively small cohort size makes it difficult to determine whether PTSD-like symptoms and behavioral problems, which are associated with each other and which may result from the same set of 9/11 exposures, or from an unmeasured other environmental effect associated with lower socioeconomic status, affect respiratory outcomes independently. Additional studies are needed to gain a better understanding of these relationships, especially in children with an identifiable traumatic exposure.

While asthma and wheezing comprise a continuum of illness that likely has more than one etiology, both are clearly exacerbated by breathing air containing particulate matter and irritating chemicals (38–41). In this article, we demonstrate an association of respiratory symptoms with WTC exposures long after those exposures occurred. It is possible that inhalation of sufficient amounts of particulates and irritants could result in lung damage with a wheezy bronchitis or asthma-like condition (42, 43). It will be important to now provide pulmonary function and other testing, including atopy, for children with respiratory symptoms who were exposed to the airborne irritants and particulates following the WTC attacks of 9/11/01, to better delineate the underlying cause of their illness.

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#### DECLARATION OF INTEREST

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