Reproductive Outcomes Following Maternal Exposure to the Events of September 11, 2001, at the World Trade Center, in New York City

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Objectives. To estimate associations between exposure to the events of September 11, 2001, (9/11) and low birth weight (LBW), preterm delivery (PD), and small size for gestational age (SGA).

Methods. We matched birth certificates filed in New York City for singleton births between 9/11 and the end of 2010 to 9/11-related exposure data provided by mothers who were World Trade Center Health Registry enrollees. Generalized estimating equations estimated associations between exposures and LBW, PD, and SGA.

Results. Among 3360 births, 5.8% were LBW, 6.5% were PD, and 9% were SGA. Having incurred at least 2 of 4 exposures, having performed rescue or recovery work, and probable 9/11-related posttraumatic stress disorder 2 to 3 years after 9/11 were associated with PD and LBW during the early study period.

Conclusions. Disasters on the magnitude of 9/11 may exert effects on reproductive outcomes for several years. Women who are pregnant during and after a disaster should be closely monitored for physical and psychological sequelae.

Public Health Implications. In utero and maternal disaster exposure may affect birth outcomes. Researchers studying effects of individual disasters should identify commonalities that may inform postdisaster responses to minimize disaster-related adverse birth outcomes. (*Am J Public Health.* Published online ahead of print August 23, 2016: e1–e8. doi:10.2105/AJPH.2016.303303)

Adverse reproductive outcomes have been linked to in utero exposure to ambient air pollution and particulate matter (PM)[1] including constituents of PM identified in samples of ambient air[2] and dust[3] collected after the events of September 11, 2001 (9/11), at the World Trade Center (WTC) in New York City. Heavy metals including lead,[4] polycyclic aromatic hydrocarbons (PAHs) including benzo[a]pyrene,[5] polybrominated diphenyl ethers,[6] and other toxic substances identified in WTC-area samples have been associated with reduced birth weight, length, and head circumference,[7–9] and intrauterine growth retardation.[10]

Elevated levels of biomarkers of exposure have been documented in women who were pregnant and in the vicinity of the WTC on and after 9/11, although associations with self-reported exposure have been inconsistent. Perera et al.[11] found elevated levels of PAH–DNA adducts indicating exposure-related genetic damage in maternal and umbilical cord blood from women exposed to the disaster while pregnant. Wolff et al.[12] also found elevated levels of PAH-adducts in women exposed during pregnancy. The PAH–DNA adduct levels correlated with self-reports of time in the vicinity of, and distance from, the WTC in the Perera et al. study, and with time of sample collection, but not an exposure index combining self-report and modeled emissions data in the Wolff et al. study. Biomarkers of several metals, organochlorines, and polybrominated diphenyl ethers, also associated with adverse birth outcomes,[9,13,14] did not correlate with either measure of exposure in the Wolff et al. study.

Evidence linking self-reported exposures and birth outcomes is also inconsistent. In the Perera et al. cohort, Lederman et al.[15] reported decrements in birth weight and length associated with proximity of residence to the WTC, and decrements in length of gestation and head circumference associated with trimester of exposure. Comparing the Wolff et al. cohort with a presumably unexposed cohort, Berkowitz et al.[16] observed associations between exposure and intrauterine growth retardation, but neither birth weight nor length of gestation. Eskenazi et al.[17] reported an increase in moderately low birth weight (LBW; < 2000 g) infants in New York City, but not elsewhere in New York State during the week of 9/11, and associations between timing of exposure and very LBW (< 1500 g) in both areas. Among infants born in New York City to mothers pregnant on and shortly after 9/11, Lipkind et al.[18] found no differences in birth weight or gestational age associated with exposure.

Adverse reproductive outcomes have also been repeatedly linked to maternal stress

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during pregnancy[19] and before conception,[20,21] and to disaster-related stress, in particular. Compounding potential risks of 9/11-related physical exposures may be effects of behavioral[22] and physiological[17,23] responses to disaster-related stress on the developing fetus,[24] although, again, findings are inconsistent. Lipkind et al. reported higher rates of both LBW and preterm delivery (PD; < 37 weeks) in births to exposed women with probable 9/11-related posttraumatic stress disorder (PTSD), and Engel et al.[25] reported positive associations between scores on screens for PTSD (and depression) and gestational age, but negative correlations between these measures and head circumference at birth.

Environmental exposures associated with 9/11, and 9/11-related PTSD continued long after 9/11, raising the question of whether and for how long effects on reproductive outcomes may persist. To date, most studies have focused on pregnancies occurring on or shortly after 9/11, precluding analyses of outcomes among exposed women who became pregnant later. Furthermore, most studies have relied on cohorts created on the basis of pregnancy status, or used comparison groups for which exposure assessments were not available. As a consequence, associations between adverse outcomes and both chronic 9/11-related exposures and prolonged effects of acute exposures have not been well studied. We therefore examined rates of LBW, PD, and small-for-gestational-age (SGA; < 10% of standard, by gender) status among births occurring between 9/11 and the end of 2010 in a cohort of infants derived on the basis of detailed measures of maternal 9/11-related exposure.

METHODS

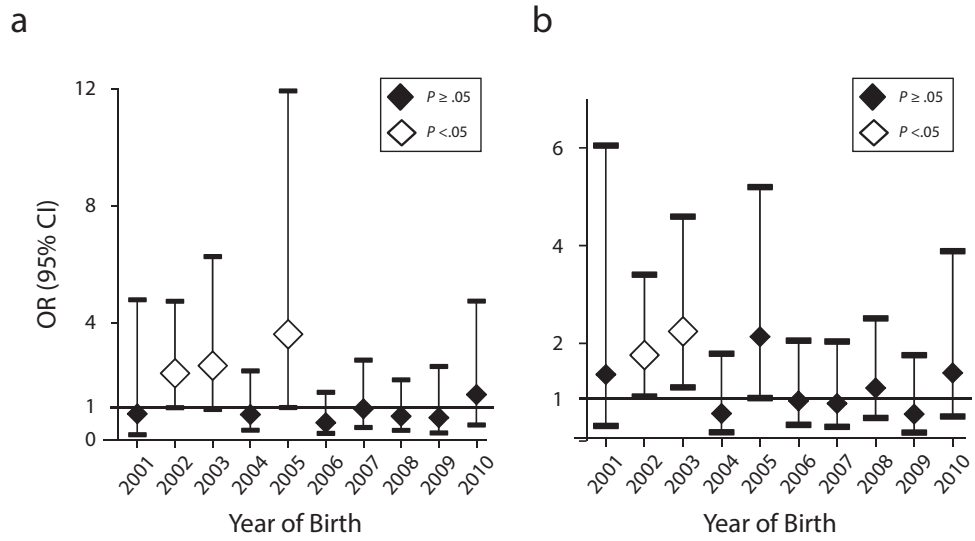
The Registry is a prospective cohort of individuals with high likelihood of exposure to the events of 9/11.[26] Surveys administered 3 to 4 years apart elicit information about exposures incurred on and in the aftermath of 9/11, physical and mental health, health care utilization, and other measures of functional status. At the time of the study, 3 waves of data had been collected, in 2003–2004 (wave 1), 2007–2008 (wave 2), and 2011–2012 (wave 3). The study sample comprised infants delivered to Registry enrollees in New York City between 9/11 and the end of 2010, identified by matching information for female enrollees of childbearing age (15–49 years) between 1998 and 2010 with corresponding information on birth certificates filed in New York City during the same period. Using a confidential identification number and algorithm devised for this purpose, the Office of Vital Statistics at the New York City Department of Health and Mental Hygiene identified potential matches among birth certificates with comparable information for mother's first, middle, and last name; address; date of birth; or social security number. Potential matches were independently confirmed by at least 2 trained reviewers; discordant ratings were evaluated by a third reviewer.

Maternal, pregnancy, and infant characteristics, including birth weight and gestational age, were obtained from birth certificates of confirmed matches. We defined SGA by using reference values for single live births in the United States in 2003, by gender.[27] Congenital anomalies were too few in number to be analyzed as an outcome, but were considered as a covariate. Other covariates included neonatal sex, method of delivery (vaginal or cesarean section; if vaginal, forceps or vacuum-assisted), timing and number of prenatal care visits, eligibility for the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), maternal chronic hypertension, prepregnancy weight, weight gain, medical (eclampsia, gestational diabetes, or pregnancy-associated hypertension) and behavioral (use of cigarettes, alcohol, or illicit drugs) risk factors during pregnancy, age, level of education, and number of previous live births. We used zip code and census tract to determine proximity of residence to the WTC site at the time of delivery.

Indicators of 9/11 exposures, obtained from Registry data, included having engaged in rescue or recovery work and exposures unique to those who did, including days worked (0, 1 to < 8, ≥ 8) and work on the pile of debris resulting from the collapse of buildings on 9/11 (the pile). Having resided in the WTC area on 9/11 (residents), defined as south of Canal Street in Manhattan, was, in itself, a measure of exposure, as was having evacuated a residence in that area. Exposures that potentially affected all mothers (common exposures) included having been present in the cloud of dust that resulted from the collapse of buildings (dust cloud), having evacuated a building, having sustained 1 or more of several specified injuries, having been present in a building that collapsed, and having witnessed at least 3 of 5 specified potentially traumatizing events on 9/11. Injuries included a broken bone or dislocation; a cut, abrasion, or puncture wound; a concussion, head injury, or being "knocked out" by a hit to the head; a burn; or a strain or sprain. Traumatic events included witnessing an airplane hitting the WTC towers, buildings collapsing, people running from a cloud of smoke, people injured or killed, and people falling or jumping from the WTC. We assessed PTSD at wave 1 by using the PTSD Checklist,[28] tailored to be specific to the events of 9/11; a score of 44 or greater was categorized as "probable PTSD." Because rates of adverse outcomes[29] and concentrations of particulate matter[30] vary seasonally, we examined distributions of outcomes for seasonal trends. We categorized births by trimester of pregnancy relative to September 11 in the year following conception (first, second, third, not pregnant on 9/11).

Preliminary examination of exposure–outcome associations revealed relatively strong and significant effects in 2002 and 2003, but not thereafter. With the exception of 2005, in which measures of association were comparably high and either marginally or not statistically significant, associations appeared to taper after 2003, as is shown for a single exposure measure in Figure 1. We therefore dichotomized the sample into early (September 11, 2001, to December 31, 2003) and late (January 1, 2004, to December 31, 2010) periods by year of birth, and conducted subsequent analyses separately within each period.

Because of differences in extent and type of exposure,[31] we excluded infants whose mothers had performed rescue or recovery work exclusively at the Staten Island site to which debris was transferred or on barges that transported debris (n = 37). We also excluded infants whose outcomes may have been affected by circumstances independent of exposure (e.g,. multiple births, prepregnancy diabetes) or with missing or



Note. CI = confidence interval. At least 2 of the following on 9/11: present in dust cloud, injured, witnessed ≥ 3 traumatic events, in building that collapsed.

FIGURE 1—Unadjusted Odds Ratios (ORs) by Year of Birth for World Trade Center Exposure and (a) Low Birth Weight and (b) Preterm Delivery: New York City, September 11, 2001, and the End of 2010

implausible values for birth weight (< 500 g or > 5000 g) or gestational age (< 26 weeks or > 42 weeks; n = 235). We identified a total of 3632 births, which, after applying these exclusions, yielded a final analytic sample of 3360 births delivered by 2450 mothers.

We used χ^2 and *t* tests to assess bivariate associations between outcomes and maternal and pregnancy characteristics, and generalized estimating equations (GEEs) to assess associations between outcomes and 9/11-related exposures to account for potential within-mother correlations. Covariates associated with outcomes at a $P \leq .15$ in bivariate analyses in either time period were included in multivariate analyses. To address possible mediation of 9/11-related exposure–outcome associations by 9/11-related PTSD, additional analyses included only individuals without the disorder; comparable models limited to those individuals with PTSD had insufficient numbers for analysis. We excluded individuals missing data for covariates included in multivariate models from all GEE models. Tests were 2-sided, and assessed significance at 5% type I error. We conducted all analyses with SAS version 9.4 (SAS Institute, Cary, NC).

RESULTS

Table 1 presents maternal, pregnancy, and exposure characteristics describing the final sample, and bivariate associations with LBW (5.3%) and PD (6.5%). Criteria for SGA were met by 9% of the sample; we observed no substantive associations between 9/11-related exposures and this outcome, and further data are not presented. The largest proportions of mothers were aged 30 to 35 years, non-Hispanic White, college graduates, and ineligible for WIC, each of which was associated with significantly lower likelihoods of LBW and PD.

Slightly more than half of infants were male. Fewer than one tenth were born to mothers who were pregnant on 9/11, and there was minimal variation by trimester of pregnancy; neither categorization of timing of birth was associated with an adverse outcome. Infants born in the early period were more likely to be PD. Mothers of most (86.6%) infants sought prenatal care during their first trimester; rates of both outcomes were significantly lower among infants whose mothers had 10 or more visits. Most births were to mothers with no medical risk factors, although having at least 1 was associated with both LBW and PD. Less than 1% of infants were born with a congenital anomaly, and this was not associated with either outcome. First births accounted for slightly more than half of all births, and gaining either 25 pounds or less, or 36 pounds or more during pregnancy was significantly associated with both outcomes.

Distributions of 9/11-related exposures and bivariate associations with LBW and PD, stratified by period of delivery, are shown in Table 2. Mothers of just more than one third (35.9%) of infants reported at least 2 of the 4 common exposures. Nearly 15% engaged in rescue or recovery work; among those, a similar proportion (14.3%) worked on the pile, and nearly half (46.8%) worked for 8 or more days. Mothers of nearly one third of infants were WTC-area residents on 9/11; among those, nearly one quarter remained in their homes after the events of that day. Mothers of just more than one fifth of infants reported a WTC-area residence at the time of delivery; this information was unavailable for 10.2% of the sample. Mothers of 13.7% of infants reported symptomatology indicative of probable PTSD at wave 1.

In the early period, infants whose mothers reported at least 2 common exposures were significantly more likely to be LBW (odds ratio [OR] = 2.3; 95% confidence interval [CI] = 1.3, 4.0) and PD (OR = 2.1; 95% CI = 1.3, 3.2), and infants whose mothers

TABLE 1—Characteristics of Mother and Pregnancy, by Low Birth Weight and Preterm Delivery Status: New York City, Births From September 11, 2001, to End of 2010

Characteristic	Total, No. (%)	Low Birth Weight, % (95% CI)	Preterm Delivery, % (95% CI)
Mother characteristics			
Age on 9/11, y			
<30	593 (17.6)	6.8 (4.7, 8.8)	7.3 (5.2, 9.3)
30–35	1534 (45.7)	3.8 (2.8, 4.7)	5.2 (4.0, 6.3)
>35	1233 (36.7)	6.5 (5.1, 7.9)	7.9 (6.4, 9.4)
Race/ethnicity			
Non-Hispanic White	1829 (54.4)	2.7 (1.9, 3.4)	3.7 (2.8, 4.5)
Non-Hispanic Black	461 (13.7)	11.1 (8.2, 13.9)	11.9 (9.0, 14.9)
Hispanic	587 (17.5)	7.7 (5.5, 9.8)	9.0 (6.7, 11.4)
Other	483 (14.4)	6.8 (4.6, 9.1)	9.1 (6.5, 11.7)
College graduate			
No	1010 (30.1)	7.0 (5.5, 8.6)	8.2 (6.5, 9.9)
Yes	2342 (69.9)	4.6 (3.7, 5.4)	5.8 (4.9, 6.8)
Eligible for WIC			
No	3034 (90.5)	4.9 (4.2, 5.7)	6.2 (5.4, 7.1)
Yes	319 (9.5)	8.8 (5.7, 11.9)	9.4 (6.2, 12.6)
Pregnancy characteristics			
Infant gender			
Male	1734 (51.6)	4.8 (3.8, 5.9)	7.0 (5.8, 8.2)
Female	1626 (48.4)	5.8 (4.7, 6.9)	6.0 (4.9, 7.2)
Pregnant on 9/11			
No	3037 (90.4)	5.3 (4.5, 6.1)	6.5 (5.6, 7.4)
Yes	323 (9.6)	5.6 (3.1, 8.1)	6.5 (3.8, 9.2)
Period of birth			
Early[a]	1008 (30.0)	5.9 (4.4, 7.3)	8.0 (6.4, 9.7)
Late[b]	2352 (70.0)	5.1 (4.2, 6.0)	5.9 (4.9, 6.8)
Trimester of pregnancy on September 11 of year following conception			
Not pregnant on 9/11	855 (25.4)	6.3 (4.6, 7.9)	6.2 (4.6, 7.8)
First	787 (23.4)	5.0 (3.6, 6.5)	7.0 (5.2, 8.8)
Second	855 (25.4)	5.8 (4.2, 7.5)	5.4 (3.9, 6.9)
Third	863 (25.7)	4.1 (2.8, 5.4)	7.5 (5.8, 9.3)
Received prenatal care in first trimester			
No	436 (13.4)	4.8 (2.8, 6.8)	7.8 (5.3, 10.3)
Yes	2821 (86.6)	5.3 (4.4, 6.1)	6.2 (5.3, 7.1)
Total no. of prenatal care visits			
>10	1636 (49.2)	3.1 (2.2, 3.9)	3.8 (2.9, 4.7)
≤10	1691 (50.8)	7.3 (6.1, 8.6)	9.0 (7.6, 10.4)
One or more medical risk factor[c]			
No	3132 (93.2)	4.8 (4.1, 5.6)	5.9 (5.1, 6.7)
Yes	228 (6.8)	11.8 (7.7, 16.0)	15.4 (10.7, 20.0)
One or more congenital anomaly			
No	3327 (99.0)	5.2 (4.5, 6.0)	6.4 (5.6, 7.3)
Yes	33 (1.0)	12.1 (1.0, 23.3)	15.2 (2.9, 27.4)

Continued

performed rescue or recovery work were significantly more likely to be PD (OR = 1.9; 95% CI = 1.1, 3.4); neither exposure unique to rescue or recovery workers was associated with an adverse outcome. Also during the early period, infants whose mothers had been WTC-area residents on 9/11 or at delivery were less likely to be PD (OR = 0.5; 95% CI = 0.3, 0.8, and OR = 0.5; 95% CI = 0.3, 1.0, respectively). During the late period, infants whose mothers were WTC-area residents were significantly less likely to be LBW (OR = 0.3; 95% CI = 0.2, 0.7).

In adjusted analyses, both LBW and PD in the early period were significantly associated with having at least 2 common exposures, with effect sizes only slightly lower than those observed in bivariate analyses (OR = 2.1; 95% CI = 1.1, 4.0, and OR = 1.8; 95% CI = 1.1, 3.1, respectively; Table 3). Also during the early period, effect sizes for rescue or recovery work increased slightly with adjustment, becoming statistically significant for LBW (OR = 2.1; 95% CI = 1.0, 4.5), and remaining significant for PD (OR = 2.2; 95% CI = 1.1, 4.1). Maternal residence in the WTC-area on 9/11 was not associated with either outcome in adjusted models, although maternal residence in the WTC-area at delivery remained significantly associated with lower likelihood of LBW during the late period (OR = 0.3; 95% CI = 0.1, 0.7). Probable PTSD remained significantly associated with both outcomes in the early period (OR = 2.3; 95% CI = 1.1, 4.9, and OR = 2.7; 95% CI = 1.4, 5.2 for LBW and PD, respectively). Posttraumatic stress disorder did not appear to mediate exposure–outcome associations appreciably; limiting the analysis to individuals without probable PTSD revealed slightly larger effect sizes for the common exposures and rescue or recovery work (data not shown).

DISCUSSION

In the years immediately after 9/11, several exposures related to that day were associated with PD, and with LBW when not adjusted for gestational age. No associations were observed between 9/11-related exposures and SGA, which was unexpected, given evidence of associations with comparable in utero exposures. Comparing groups with

TABLE 1—*Continued*

Characteristic	Total, No. (%)	Low Birth Weight, % (95% CI)	Preterm Delivery, % (95% CI)
Previous live births			
None	1753 (52.2)	5.9 (4.8, 7.0)	6.9 (5.7, 8.0)
≥1	1607 (47.8)	4.6 (3.6, 5.6)	6.2 (5.0, 7.3)
Prepregnancy weight, lbs			
<130	1107 (33.5)	5.8 (4.4, 7.2)	5.5 (4.2, 6.9)
130–149	1066 (32.3)	4.6 (3.3, 5.9)	6.3 (4.8, 7.7)
≥150	1127 (34.2)	5.4 (4.1, 6.7)	7.9 (6.3, 9.5)
Maternal weight gain, lbs			
≤25	1066 (32.4)	8.9 (7.2, 10.6)	10.2 (8.4, 12.0)
26–35	1185 (36.0)	4.5 (3.3, 5.7)	5.3 (4.0, 6.6)
≥36	1039 (31.6)	2.7 (1.7, 3.7)	4.1 (2.9, 5.4)

Note. 9/11 = September 11, 2001; CI = confidence interval; NS = not significant at $P < .05$; WIC = Special Supplemental Nutrition Program for Women, Infants, and Children. Of 3360 births, 178 (5.3%) had low birth weight and 219 (6.5%) had preterm delivery. The sample size was n = 3360.

[a]September 11, 2001, to December 31, 2003.

[b]January 1, 2004, to December 31, 2010.

[c]Eclampsia, gestational diabetes, pregnancy-associated hypertension.

varying degrees of exposure, rather than any versus no exposure, may have made effects more difficult to detect. In addition, this study addressed physical and stress-related exposures simultaneously, and disentangling these effects is difficult. Disaster-related stress likely varies with degree of PM exposure, and both vary with similar other factors, including stage of pregnancy during which they occur, and consequent behavioral changes. Stress may affect birth outcomes through exacerbation of effects of disaster-related toxins.[32] Associations between both LBW and PD and 9/11-related exposures in the early period appeared to be independent of associations between these outcomes and 9/11-related PTSD; however, this does not rule out the possible involvement of other clinically relevant forms of stress not captured by the PTSD-specific screening instrument. Furthermore, there is evidence to suggest prolonged, rather than reduced gestation associated with some forms of stress,[33] which may have attenuated observed associations, or explain inconsistencies with findings reported elsewhere.

Prevalence of both LBW and PD was relatively low, in part because the sociodemographic composition of the sample was weighted toward more favorable outcomes, and because we excluded infants with higher likelihoods of adverse outcomes attributable to circumstances unrelated to exposure. Nonetheless, associations between adverse birth outcomes and 9/11-related exposures were observed among infants conceived more than a year after 9/11. Although the most intense exposures undoubtedly occurred on and shortly after 9/11, continued exposure and potential for related stress lasted much longer. Fires at the WTC site burned through December of 2001, clean-up operations lasted through June 2002, and Environmental Protection Agency–sponsored testing and cleanup of residences lasted through 2003. Reports of 9/11-related PTSD at least 13 years after 9/11 appear in the literature.[34] It is therefore difficult to determine the extent to which these findings may reflect effects of acute exposures on and shortly after 9/11, or effects of more prolonged exposure to the extended aftermath of the event.

Currie and Schwandt[35] analyzed births occurring beyond the end of the early period, but did not compare outcome rates across time, making it unclear whether a similar reduction in magnitude of associations occurred in the cohort studied by these authors. It is also unclear why exacerbations of effects during the first trimester of pregnancy and on male infants were observed by these authors and not in the current study, even when restricting analyses to a similar time period. This may be attributable to relatively few infants born to mothers who were pregnant on 9/11 in this study, but may also reflect differences in definitions of exposure. In this study, rates of LBW were significantly lower during the later period among infants who, like those in the Currie study, were born to mothers who resided in the WTC area at the time of delivery (regardless of location of residence on 9/11). This finding is difficult to interpret; although not explained by several indicators of socioeconomic status, it may be associated with other factors related to changes in the demographic composition of lower Manhattan during the study period that were not measured in this study.

In this study, we did not find differential effects between women who were, and were not, pregnant on 9/11, nor did we find an effect of trimester of exposure among those who were; this may reflect the small proportion of pregnancies that overlapped with 9/11. Other limitations to this study include the possibility of incomplete or variable ascertainment of information. Although a true rate of ascertainment is impossible to determine, the proportion of women who, at wave 1, reported being pregnant on 9/11 and contributed an infant to the sample with a date of birth consistent with this report, suggests a rate of ascertainment of at least 54.9%. The true rate is presumed to be higher given that the sample was limited to New York City births, and both 9/11 exposure and expanding family size may have prompted relocation (and delivery) outside New York City. These same phenomena may have been a source of bias in study findings; the Registry comprises 17% of the estimated exposed population, and enrollment was voluntary. However, comparison of infants born to mothers who self-enrolled in response to advertisements with those born to mothers who enrolled in response to targeted outreach suggested little effect on findings. Residence in the WTC vicinity could be determined on 9/11 and at delivery, but not, in most cases, at conception, although supplemental analyses suggested that relocation in and out of the area was not extensive enough to introduce significant bias.

Use of cigarettes, alcohol, or illicit drugs during pregnancy was reported by too few women at the time of delivery to determine how these behaviors may have had

TABLE 2—Unadjusted Odds Ratios for Birth Outcomes and 9/11 Exposures by Period of Birth: New York City, Births From September 11, 2001, to End of 2010

		Low Birth Weight		Preterm Delivery	
Variable	No. (%)	Early Period,[a] OR (95% CI)	Late Period,[b] OR (95% CI)	Early Period,[a] OR (95% CI)	Late Period,[b] OR (95% CI)
Common exposures[c]					
0–1 (Ref)	2132 (64.1)	1	1	1	1
≥2	1195 (35.9)	2.3 (1.3, 4.0)	1.1 (0.7, 1.6)	2.1 (1.3, 3.2)	1.2 (0.7, 1.5)
Rescue or recovery worker					
No (Ref)	2866 (85.3)	1	1	1	1
Yes	494 (14.7)	1.8 (0.9, 3.6)	1.1 (0.7, 1.9)	1.9 (1.1, 3.4)	0.9 (0.5, 1.5)
Worked on pile[d]					
No (Ref)	421 (85.7)	1	1	1	1
Yes	70 (14.3)	1.6 (0.3, 8.1)	2.1 (0.7, 6.3)	1.1 (0.2, 4.9)	1.7 (0.5, 5.4)
Days worked at WTC site[d]					
1–7 d (Ref)	242 (53.2)	1	1	1	1
≥8 d	213 (46.8)	0.9 (0.3, 3.2)	1.3 (0.5, 3.6)	1.1 (0.4, 3.2)	1.5 (0.6, 4.0)
WTC-area resident on 9/11					
No (Ref)	2297 (68.4)	1	1	1	1
Yes	1063 (31.6)	0.6 (0.3, 1.1)	0.7 (0.4, 1.1)	0.5 (0.3, 0.8)	0.8 (0.6, 1.3)
Remained in home[e]					
No (Ref)	810 (76.3)	1	1	1	1
Yes	252 (23.7)	1.3 (0.4, 4.3)	2 (0.8, 4.9)	1.8 (0.6, 5.0)	1.7 (0.7, 3.9)
WTC-area resident at birth					
No (Ref)	2302 (68.5)	1	1	1	1
Yes	716 (21.3)	0.5 (0.3, 1.0)	0.3 (0.2, 0.7)	0.5 (0.3, 1.0)	0.8 (0.5, 1.4)
Unknown	342 (10.2)	0.6 (0.3, 1.7)	0.9 (0.5, 1.7)	0.9 (0.4, 1.8)	0.7 (0.5, 1.6)
Probable PTSD at wave 1					
No (Ref)	2822 (86.3)	1	1	1	1
Yes	449 (13.7)	3.0 (1.6, 5.6)	1.5 (0.9, 2.5)	2.8 (1.7, 4.9)	1.7 (1.1, 2.7)

Note. 9/11 = September 11, 2001; CI = confidence interval; OR = odds ratio; PTSD = posttraumatic stress disorder; WTC = World Trade Center. Low birth weight in the early period: n = 56 (5.8%) and in the late period: n = 112 (5.0%). Preterm delivery in the early period: n = 78 (8.1%) and in the late period: n = 130 (5.8%). Unadjusted odds ratios accounting for correlated outcomes within mothers. Sample with complete data in multivariate analyses. The sample size was n = 3207.

[a]September 11, 2001, to December 31, 2003.

[b]January 1, 2004, to December 31, 2010.

[c]Caught in dust cloud, sustained an injury, witnessed ≥3 traumatic events, or escaped from collapsed building on 9/11.

[d]Rescue and recovery workers only.

[e]Residents only.

an impact on outcomes. Although many women likely discontinued or curtailed these behaviors during pregnancy, self-reported rates in Registry surveys suggest underreporting on birth certificates. Including smoking status at wave 1 in multivariate models produced no appreciable effects on findings for either outcome, in either period.

Defining the cohort on the basis of fixed calendar dates may have resulted in underrepresentation of births with shorter gestations at the beginning, or longer gestations at the end of the study period. However, restricting analyses to births originated and delivered during the study period did not affect study findings. Data were not available to determine prevalence of, or associations between exposure and miscarriage, or between exposure and either infertility or desire to conceive, which may have affected composition of the study population. Statistically significant findings may have occurred by chance because of multiple comparisons. Finally, study findings may not generalize to other populations because of the unique sociodemographic composition of the sample, intentional exclusion of high-risk births, and inherent limitations described previously.

Strengths of this study include a sample comprising birth outcomes among women in an exposure Registry, regardless of pregnancy status. The sample included infants delivered to exposed mothers who were pregnant on, immediately after, and up to more than 8 years after 9/11. Comparison groups were defined not only by exposure, but also by timing of pregnancy and delivery. As a consequence, this study had robust numbers in groups that differed with respect to exposure and timing of delivery, but were otherwise similar with respect to several potential confounders. It also had the benefits

TABLE 3—Adjusted Odds Ratios for Birth Outcomes and 9/11-Related Exposures by Period of Birth: New York City, Births From September 11, 2001, to End of 2010

	Low Birth Weight		Preterm Delivery	
Variable	Early Period,[a] AOR (95% CI)	Late Period,[b] AOR (95% CI)	Early Period,[a] AOR (95% CI)	Late Period,[b] AOR (95% CI)
Common exposures[c]				
0–1 (Ref)	1	1	1	1
≥2	2.1 (1.1, 4.0)	0.9 (0.6, 1.4)	1.8 (1.1, 3.1)	0.9 (0.6, 1.4)
Rescue or recovery worker				
No (Ref)	1	1	1	1
Yes	2.1 (1.0, 4.5)	1.0 (0.6, 1.8)	2.2 (1.1, 4.1)	0.9 (0.5, 1.5)
WTC-area resident on 9/11				
No (Ref)	1	1	1	1
Yes	1.3 (0.4, 4.5)	1.1 (0.6, 2.0)	0.6 (0.1, 2.7)	0.9 (0.5, 1.5)
WTC-area resident at birth				
No (Ref)	1	1	1	1
Yes	0.6 (0.2, 2.5)	0.3 (0.1, 0.7)	1.4 (0.3, 7.0)	0.9 (0.5, 1.7)
Unknown	1.0 (0.4, 2.8)	1.1 (0.5, 2.1)	1.4 (0.6, 3.2)	1.1 (0.5, 2.0)
Probable PTSD at wave 1				
No (Ref)	1	1	1	1
Yes	2.3 (1.1, 4.9)	1.1 (0.7, 1.9)	2.7 (1.4, 5.2)	1.4 (0.8, 2.3)

Note. 9/11 = September 11, 2001; AOR = adjusted odds ratio; CI = confidence interval; PTSD = post-traumatic stress disorder; WTC = World Trade Center. Odds ratios adjusted for maternal age, race/ethnicity, ≤10 prenatal care visits, Special Supplemental Nutrition Program for Women, Infants, and Children eligibility, trimester of pregnancy, ≥1 medical risk factor, parity, maternal weight gain. Sample with complete data. The sample size was n = 3207.

[a]September 11, 2001, to December 31, 2003.

[b]January 1, 2004, to December 31, 2010.

[c]Caught in dust cloud, sustained an injury, witnessed ≥3 traumatic events, or escaped from collapsed building on 9/11.

of detailed exposure histories and measures of event-related PTSD, and could link, on an individual basis, these measures with outcomes of births occurring more than 9 years after the event.

This study supports previous evidence linking both PD and LBW to both exposure to the events of 9/11 and event-related PTSD. It suggests that an event on the magnitude of 9/11 may have effects on birth outcomes in exposed populations several years later, and that women who are exposed to a disaster and are, or may become, pregnant during the ensuing years should be monitored closely, through early and adequate prenatal care. However, these findings may not generalize to other populations, or to other disasters, which generally occur suddenly, without warning, and under unique sets of circumstances, precluding systematic study of their effects. Nevertheless, neonatal, disaster, and other researchers should jointly consider comparability of findings, and identify commonalities that may inform postdisaster responses to minimize disaster-related adverse birth outcomes in the future. AJPH

CONTRIBUTORS

C. B. Maslow designed the study, conducted the analyses, and wrote the article. K. Caramanica reviewed relevant literature, assisted with analyses, and provided editorial and technical support. J. Li consulted on statistical methodology and study design. S. D. Stellman and R. M. Brackbill consulted on study design. All authors reviewed and revised the article.

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HUMAN PARTICIPANT PROTECTION

This study was approved by the institutional review board of the New York City Department of Health and Mental Hygiene.

REFERENCES

1. Maisonet M, Correa A, Misra D, Jaakkola JJ. A review of the literature on the effects of ambient air pollution on fetal growth. *Environ Res*. 2004;95(1):106–115.

2. Lorber M, Gibb H, Grant L, Pinto J, Pleil J, Cleverly D. Assessment of inhalation exposures and potential health risks to the general population that resulted from the collapse of the World Trade Center towers. *Risk Anal*. 2007;27(5):1203–1221.

3. Landrigan PJ, Forman J, Galvez M, Newman B, Engel SM, Chemtob C. Impact of September 11 World Trade Center disaster on children and pregnant women. *Mt Sinai J Med*. 2008;75(2):129–134.

4. McGee JK, Chen LC, Cohen MD, et al. Chemical analysis of World Trade Center fine particulate matter for use in toxicologic assessment. *Environ Health Perspect*. 2003;111(7):972–980.

5. Landrigan PJ, Lioy PJ, Thurston G, et al. Health and environmental consequences of the World Trade Center disaster. *Environ Health Perspect*. 2004;112(6):731–739.

6. Agency for Toxic Substances and Disease Registry. Public health statement: polybrominated diphenyl ethers. 2004. Available at: http://www.atsdr.cdc.gov. Accessed May 26, 2015.

7. Perera FP, Whyatt RM, Jedrychowski W, et al. Recent developments in molecular epidemiology: a study of the effects of environmental polycyclic aromatic hydrocarbons on birth outcomes in Poland. *Am J Epidemiol*. 1998;147(3):309–314.

8. Perera FP, Jedrychowski W, Rauh V, Whyatt RM. Molecular epidemiologic research on the effects of environmental pollutants on the fetus. *Environ Health Perspect*. 1999;107(suppl 3):451–460.

9. Lignell S, Aune M, Darnerud PO, Hanberg A, Larsson SC, Glynn A. Prenatal exposure to polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) may influence birth weight among infants in a Swedish cohort with background exposure: a cross-sectional study. *Environ Health*. 2013;12:44.

10. Dejmek J, Selevan SG, Benes I, Solansky I, Sram RJ. Fetal growth and maternal exposure to particulate matter during pregnancy. *Environ Health Perspect*. 1999;107(6):475–480.

11. Perera FP, Tang D, Rauh V, et al. Relationships among polycyclic aromatic hydrocarbon-DNA adducts, proximity to the World Trade Center, and effects on fetal growth. *Environ Health Perspect*. 2005;113(8):1062–1067.

12. Wolff MS, Teitelbaum SL, Lioy PJ, et al. Exposures among pregnant women near the World Trade Center site on 11 September 2001. *Environ Health Perspect*. 2005;113(6):739–748.

13. Harley KG, Chevrier J, Aguilar Schall R, Sjodin A, Bradman A, Eskenazi B. Association of prenatal exposure to polybrominated diphenyl ethers and infant birth weight. *Am J Epidemiol*. 2011;174(8):885–892.

14. Lopez-Espinosa MJ, Murcia M, Iniguez C, et al. Prenatal exposure to organochlorine compounds and birth size. *Pediatrics*. 2011;128(1):e127–e134.

15. Lederman SA, Rauh V, Weiss L, et al. The effects of the World Trade Center event on birth outcomes among term deliveries at three lower Manhattan hospitals. *Environ Health Perspect*. 2004;112(17):1772–1778.

16. Berkowitz GS, Wolff MS, Janevic TM, Holzman IR, Yehuda R, Landrigan PJ. The World Trade Center disaster and intrauterine growth restriction. *JAMA*. 2003; 290(5):595–596.

17. Eskenazi B, Marks AR, Catalano R, Bruckner T, Toniolo PG. Low birthweight in New York city and upstate New York following the events of September 11th. *Hum Reprod*. 2007;22(11):3013–3020.

18. Lipkind HS, Curry AE, Huynh M, Thorpe LE, Matte T. Birth outcomes among offspring of women exposed to the September 11, 2001, terrorist attacks. *Obstet Gynecol*. 2010;116(4):917–925.

19. Zhu P, Tao F, Hao J, Sun Y, Jiang X. Prenatal life events stress: implications for preterm birth and infant birthweight. *Am J Obstet Gynecol*. 2010;203(1):34e1–8.

20. Strutz KL, Hogan VK, Siega-Riz AM, Suchindran CM, Halpern CT, Hussey JM. Preconception stress, birth weight, and birth weight disparities among US women. *Am J Public Health*. 2014;104(8):e125–e132.

21. Witt WP, Cheng ER, Wisk LE, et al. Maternal stressful life events prior to conception and the impact on infant birth weight in the United States. *Am J Public Health*. 2014;104(suppl 1):S81–S89.

22. Woods SM, Melville JL, Guo Y, Fan MY, Gavin A. Psychosocial stress during pregnancy. *Am J Obstet Gynecol*. 2010;202(1):61e1–7.

23. Hompes T, Vrieze E, Fieuws S, et al. The influence of maternal cortisol and emotional state during pregnancy on fetal intrauterine growth. *Pediatr Res*. 2012;72(3): 305–315.

24. Glynn LM, Wadhwa PD, Dunkel-Schetter C, Chicz-Demet A, Sandman CA. When stress happens matters: effects of earthquake timing on stress responsivity in pregnancy. *Am J Obstet Gynecol*. 2001;184(4):637–642.

25. Engel SM, Berkowitz GS, Wolff MS, Yehuda R. Psychological trauma associated with the World Trade Center attacks and its effect on pregnancy outcome. *Paediatr Perinat Epidemiol*. 2005;19(5):334–341.

26. Farfel M, DiGrande L, Brackbill R, et al. An overview of 9/11 experiences and respiratory and mental health conditions among World Trade Center Health Registry enrollees. *J Urban Health*. 2008;85(6):880–909.

27. Oken E, Kleinman KP, Rich-Edwards J, Gillman MW. A nearly continuous measure of birth weight for gestational age using a United States national reference. *BMC Pediatr*. 2003;3:6.

28. Deployment Health Clinical Center. PTSD CheckList – Civilian Version. Available at: http://www.mirecc.va.gov/docs/visn6/3_PTSD_CheckList_and_Scoring.pdf. Accessed June 27, 2016.

29. Strand LB, Barnett AG, Tong S. The influence of season and ambient temperature on birth outcomes: a review of the epidemiological literature. *Environ Res*. 2011;111(3):451–462.

30. Savitz DA, Bobb JF, Carr JL, et al. Ambient fine particulate matter, nitrogen dioxide, and term birth weight in New York, New York. *Am J Epidemiol*. 2014; 179(4):457–466.

31. Ekenga CC, Scheu K, Cone J, et al. 9/11-related experiences and tasks of landfill and barge workers: qualitative analysis from the World Trade Center Health Registry. *BMC Public Health*. 2011;11:321.

32. Rauh VA, Whyatt RM, Garfinkel R, et al. Developmental effects of exposure to environmental tobacco smoke and material hardship among inner-city children. *Neurotoxicol Teratol*. 2004;26(3):373–385.

33. Margerison-Zilko CE, Goodman JM, Anderson E, Gemmill A, Catalano R. Post-term birth as a response to environmental stress. The case of September 11, 2001. *Evol Med Public Health*. 2015;2015(1):13–20.

34. Bromet EJ, Hobbs MJ, Clouston SA, Gonzalez A, Kotov R, Luft BJ. DSM-IV post-traumatic stress disorder among World Trade Center responders 11–13 years after the disaster of 11 September 2001 (9/11). *Psychol Med*. 2016;46(4):771–783.

35. Currie J, Schwandt H. The 9/11 dust cloud and pregnancy outcomes: a reconsideration. 2014. National Bureau of Economic Research Working Paper Series 20368.