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Disasters and Perinatal Health: A Systematic Review

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Abstract

Background—The empirical literature on the effects of disaster on pregnancy and the postpartum period is limited. The objective of this review was to examine the existing evidence on the effect of disasters on perinatal health.

Methods—A systematic review was conducted by searching electronic databases (MEDLINE, EMBASE, Cinahl, PsycInfo), including literature on disasters and pregnancy outcomes (e.g., preterm birth, low birthweight, congenital anomalies), mental health, and child development. 110 articles were identified, but many published reports were anecdotes or recommendations rather than systematic studies. The final review included 49 peer-reviewed studies that met inclusion criteria.

Results—Studies addressing the World Trade Center disaster of September 11th and other terrorist attacks, environmental/chemical disasters, and natural disasters such as hurricanes and earthquakes were identified. Disasters of various types may reduce fetal growth in some women, though there does not appear to be an effect on gestational age at birth. Severity of exposure is the major predictor of mental health issues among pregnant and postpartum women. The mother's mental health after a disaster may more strongly influence on child development than any direct effect of disaster-related prenatal stress.

Conclusions—There is evidence that disaster impacts maternal mental health and some perinatal health outcomes, particular among highly-exposed women. Future research should focus on under-studied outcomes such as spontaneous abortion. Relief workers and clinicians should concentrate on the most exposed women, particularly with respect to mental health.

Disasters

Pregnant and postpartum women, and their infants, may be particularly vulnerable to natural or technical disasters. Women's place in society may render them more vulnerable to injury, sexual violence, and sexually transmitted diseases (1; 2), as well as disaster-related economic impacts and medical disruptions (3; 4). For instance, more women and children died due to the 2004 South Asian tsunami than men (1; 2). Health care needs that are particularly relevant to women, such as contraception and abortion, are likely to be given a low priority in disaster situations (1; 2; 5; 6). Pregnant women and infants may also be physically more vulnerable to disaster-related toxins such as chemical and biological

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terrorism agents (7). In addition, pregnant women are subject to the usual risks of disaster, such as injury, with potentially more complicated care (8-10). Finally, almost all studies addressing the topic indicate that women are more prone to post-disaster psychopathology than men (11), and pregnant and postpartum women may be especially vulnerable to the mental health consequences of disasters (12; 13). Psychological studies after Three Mile Island and Chernobyl accidents have led mothers of young children to be labeled a particularly high-risk group (14-17), though this was not seen after the 2004 South Asian tsunami (18).

However, the empirical literature on pregnant and postpartum women during disaster is limited. Many of the published reports and recommendations are anecdotal or based on the experience and impressions of relief workers (2) and clinicians (1; 19; 20) rather than systematic studies. While invaluable to our understanding, these reports focus on those who are most affected and who present for clinical care, rather than the entire population, which can lead to serious decisions being made on limited evidence; for example, pregnant women exposed to Chernobyl were advised to get abortions (21), although later studies showed limited effects on most pregnancies (22). This paper provides an evidence-based overview of the population impacts of several disasters on pregnant and postpartum women and infants.

Methods

Literature Search

PubMed, PsycInfo, CINAHL, and EMBASE (January 1966 to June 2010) were searched using the keywords “disaster” and “pregnancy”, “pregnant”, “postpartum”, “prenatal”, “antepartum”, “preterm”, “birthweight”., “birth weight”, “fetal outcomes”, “pregnancy complications”. In addition, articles with the keywords “disaster” and (“parents” or “parenting” or “mother”) and (“mental health”), limited to adult human women, were examined for possible insights. We also examined disaster-themed special issues of journals. For articles listed in our tables, other studies that cite those articles, as well as papers found by the databases’ “related articles” function, were examined.

Study Inclusion criteria

Articles that pertained to natural and technological disasters and their effects on spontaneous abortion, congenital anomalies, birthweight, fetal growth, gestational age at birth, mental health, and infant development (<2 years) were extracted. One hundred and ten relevant articles were identified by the search strategy. The environmental effects of Chernobyl on pregnant women and their children have been reviewed extensively (17; 22; 25-27), and so are not included in the tables (13 articles related to Chernobyl excluded). Review articles were excluded (n=1) as were letters to the editor (n=2), anecdotal descriptions (n=5), reflections by disaster workers and recommendations for clinicians (these often overlapped; n=40); these are incorporated as background but were excluded from the tables. Tables in this paper include only peer-reviewed, systematic investigations of the effects of disaster on pregnancy outcomes (n=31); mental health (n=10); and infant development (n=8).

Data extraction

We extracted odds ratios (OR), risk ratios (RR), and changes in outcome (e.g., difference in birthweight in the groups compared) from the selected studies, along with other study characteristics (study location, sample size, definitions of disaster exposure, timing of disaster exposure).

Study quality assessment

We did not formally assess the quality of the selected studies because of the difference in the disaster exposures and measures of perinatal health outcomes.

Statistical analysis

Due to the heterogeneity of outcomes and exposures, and the number of repeated or non-independent samples, it was not appropriate to apply statistical methods (quantitative meta-analysis) to estimate combined effect of disaster on perinatal health.

Methodological issues

Two major issues need to be considered when examining the effects of disaster on pregnant women and their children: definition and timing of exposure.

Definition of exposure—The United Nations defines disaster as "A serious disruption of the functioning of a community or a society causing widespread human, material, economic, or environmental losses which exceed the ability of the affected community or society to cope using its own resources" (28). For the purpose of this paper, "disaster" also implies a discrete precipitating event, such as a hurricane, earthquake, terrorist attack, or chemical spill. Such events share some similar qualities, but differ as well. For this reason, the definition of exposure to disaster needs to be considered. For example, stress is likely to be widespread after almost any disaster (29; 30). Environmental exposures, however, might be specific to the disaster, and are likely to be limited to a smaller proportion of the population (31). Access to health care and other resources (such as nutritious food) will be problematic for some women but not others (23; 32; 33).

Similarly, the measurement of such exposures will vary by study. In some studies, "stress due to disaster" was defined simply by residence in an area (34; 35), while others interviewed women about their perceptions of stress (36; 37), or assessed the effects of that stress on women's mental health (38; 39). "Environmental exposure" has been directly measured by biomarkers (40) or imputed based on place of residence (41). Generally, the case for a causal relationship is stronger when individual-level exposures are measured well, although sometimes the larger sample size that can be provided by ecological studies will carry more weight. Obviously, causal relationships are more convincing when they are confirmed at both the individual and the ecological levels.

Timing of exposure—Particularly for pregnancy outcomes, timing of exposure is critical. Congenital anomalies are generally produced by exposure in the first trimester, while outcomes like fetal growth and length of gestation may be affected by exposures throughout the pregnancy (42). If different studies of the same disaster indicate different gestational periods of greatest vulnerability, this suggests that the observed results are due to chance or bias, rather than true effects (43). Similarly, comparing effects for a large number of discrete time periods (weeks of pregnancy or months across five years of data, for instance) creates the possibility of multiple comparisons with subsequent chance findings (44).

Results

The World Trade Center disaster and other terrorist attacks (table 1)

On September 11th, 2001, planes piloted by terrorist attackers were flown into the Pentagon and the World Trade Centers, causing the collapse of the latter. The effects on those in and out of New York City included injury, loss of family and co-workers, stress due to the

disruption, uncertainty about effects and future attacks, and exposure to the dust and particulates released into the air during the collapse (39; 45-47).

Two studies (five analyses) focused primarily on the environmental effects of this disaster. An increased risk of intrauterine growth retardation was reported among women exposed to the environmental effects of the WTC, though other birth outcomes did not differ (45). Infants born to residents near the WTC were slightly shorter and lighter and born slightly earlier than those outside a two-mile radius (48); mercury levels in these women were not strongly associated with fetal growth or length of gestation (49). The combination of polycyclic aromatic hydrocarbons (PAH)-DNA adducts with environmental tobacco smoke was associated with reductions in birthweight and head circumference, though PAH did not have an independent effect on these outcomes (46).

The remainder of the studies focused on aspects of stress as the major purported causal mechanism. Most of these studies are based on large cohorts or vital statistics analyses, with smaller studies examining details of exposure or mental health. In these studies, some women experienced stress due to direct exposure to the disaster and some experienced it by hearing about the disaster through the media Studies that examined preterm birth or gestational age at birth in women who learned about the disaster through the media found either no effect (in military families or in Arab-named women (50; 51)), or a reduction in risk (in Boston women (47) and another study of Arab-named women in New York post 9/11 (53)). Another study found a reduction in risk among women with symptoms of post-traumatic stress disorder (PTSD) or depression (39). The possible exception is a slight shortening of gestation reported in Dutch women post-9/11 who learned about the disaster through the media (0.7 days, $p=0.07$)(54). Studies of fetal growth have more varied results. One study of Arab-named women post-9/11 found a reduction in very low birth weight and no effect on low birth weight (51), while another found the reverse, an increase in low birth weight and no effect on very low birth weight (52). An increase in low birth weight following 9/11 was also reported in Dutch women (54). An increase in birth weights of 1500 to 1999 grams during the week after 9/11 and an increase in births < 1500 grams at two other post 9/11 time periods in New York City (based on vital statistics) have been reported (35), but a large study of military families found no increase in small for gestational age births (50). One study found a reduction in head circumference in babies born to women with post-9/11 PTSD (39). A study of a large cohort military families found no effects on infant growth (50).

Some studies also examined the effects of the WTC disaster on the health of pregnant and postpartum women and their infants. Studies of mental health have generally been smaller than those of birth outcomes and use convenience samples. One study of pregnant women exposed more directly to the attacks found that they were more likely to have depressive symptoms (38). Women who developed PTSD due to the WTC disaster rated their infants as having more distress and less interest in novelty (55), and some subpopulations said the disaster affected their ability to bond (38). In one study, women who developed PTSD had lower awakening and bedtime cortisol levels, as did their infants.(56).

Other Terrorist Attacks

Analysis of vital statistics data during terrorist attacks in Colombia in 1998-2003, hospital record review during a three-month bombing of Belgrade in Serbia in 1999, and a small, hospital-based study after the terrorist train bombings in Madrid in 2004 have also been conducted to examine the effects of terrorist activity on pregnancy outcome. A reduction in birthweight was found for women exposed to attacks in Colombia and Serbia (57; 58). There was no statistically significant increase in birth defects in women exposed to the Serbian bombings; head circumference was larger but there was no difference in birth length or

gestational age at birth (58). The incidence of pre-eclampsia was lower in these women. The incidence of premature rupture of membranes, specifically, was higher in the weeks after the Madrid train bombings (59).

Anecdotal evidence also supports adverse effects of disaster on birth outcomes. After the U. S. Embassy bombing in Nairobi in 1998, several women reported spontaneous abortions and premature labor (60). In addition, these women reported exaggerated startle response in their infants, and that the children slept poorly and seemed nervous (60).

Environmental/technical disasters (table 2)

Several prominent environmental or technical disasters have been studied. These include the nuclear reactor accidents at Chernobyl, Ukraine, in 1986 and at Three Mile Island, Pennsylvania, in 1979[1]; the release of toxic methyl isocyanate gas from the Union Carbide factory in Bhopal, India in 1984; and exposure to toxic waste including chlorinated hydrocarbons, fatty acids, and caustic alkaline waste from the manufacture of dyes, perfumes, and solvents that were dumped at Love Canal, identified in 1978. Reviews of the effects of the Chernobyl disaster indicate increased rates of Down syndrome and neural tube defects in some countries; however, most birth defects did not increase in most countries (22; 25; 26; 61). Although the data for the most-exposed areas are limited (22), a suggestion of an increase in congenital anomalies in the immediate vicinity of Chernobyl has been reported (27). After the Bhopal gas release, population based surveys indicated an increased incidence of cardiovascular complications, anemia, pulmonary complications of pregnancy and spontaneous abortion, though not congenital anomalies, among pregnant women in refugee camps (62, 63, 64). Exposure to Love Canal was not associated with preterm birth in a population-based cohort (65), but there was an increased incidence of birth defects and low birth weight (< 2500 grams) in exposed women (65). In a population-based study, the incidence of spontaneous abortions among women living near Three Mile Island at the time of the disaster was comparable to background levels (66).

Although the physical effects of environmental disasters are usually the major source of concern, psychological effects of these disasters can be significant as well (29). Levi found that anxiety due to Chernobyl, but not the environmental threat itself, was associated with earlier births in a sample of Swedish women (67). Increased speech and emotional disorders were seen in a group of children exposed to Chernobyl prenatally, along with reduced IQ, in a follow-up study of 260 children. This did not correlate with radiation dose, leading the authors to attribute these deficits to the difficulties of adaptation and relocation (68). A higher level of depression and anxiety in those pregnant immediately after Three Mile Island was seen compared to a control group of women pregnant at a different time (69)

Earthquakes, hurricanes, and other natural disasters (table 3)

Earthquakes—The consequences of several earthquakes have been examined. These include multiple small tremors in Israel (70); the 1985 Mexico City earthquake, which caused at least 8,000 deaths (71); the 1994 Northridge earthquake in California in 1994 (37); the 1999 Chi-Chi earthquake in Taiwan, which displaced at least 100,000 people (72); the 2007 Noto earthquake in Japan, which displaced 2,500 people (73); and the large 2008 earthquake in China, which caused nearly 70,000 deaths (74). Perhaps because of its severity, the Chinese earthquake was associated with many birth complications, including higher rates of low birth weight, preterm birth, birth defects, and lower Apgar scores in a large study of survivors (74). The Taiwan earthquake was also associated with high levels of low birth weight and psychiatric distress, but no changes in Apgar scores or birth length, in a

[1]Chernobyl involved a much larger radiation leak and affected many more people than Three Mile Island.

hospital-based cohort (75). Among 40 women enrolled in a larger study, those exposed to the Northridge earthquake gave birth earlier than expected, and the effect was strongest for those exposed in the first trimester (38.06 weeks observed versus 39.29 weeks expected) (37). An increase in preterm delivery was seen in a hospital after two of the five Israeli earthquakes, although there was no difference in Apgar scores (70). Women who were anxious about the Japanese earthquake were more likely to be depressed, but overall depression scores were not high in a hospital-based sample of 99 women (73). Of note, 23 infants who were rescued after being buried under rubble after the Mexico City earthquake showed no evidence of psychopathology or abnormal development (76).

Hurricanes—The consequences of two hurricanes have been studied. Hurricane Gilbert struck Jamaica in 1988, causing destruction of crops and livestock. Hurricane Katrina struck the U. S. Gulf Coast in 2005, causing the deaths of at least 1800 people and displacement of at least 2 million people (77; 78). An increase in neural tube defects was noted after Hurricane Gilbert, thought to be due to decreased folic acid intake after crop destruction (79). Vital statistics data indicated a fall in very preterm birth and no change in low birth weight or overall preterm birth after Hurricane Katrina (80), while a smaller study reported a higher rate of low birth weight and an insignificant increase in preterm birth after Katrina (36). Studies of pregnant and postpartum women found an increased incidence of PTSD and depression symptoms with increased exposure to the storm, but overall rates were comparable to nonpregnant populations (81; 82), while another found high rates of depression, especially in postpartum women (83). Serious experiences of Hurricane Katrina did not directly increase the incidence of difficult infant temperament, but maternal mental health problems such as post traumatic stress disorder, depression, or hostility were significantly associated with difficult infant temperament (84).

Floods—Three studies examined floods: one in New York in 1978 (85), one in a village in Southern Poland in 1997 (86), and the flooding of the Red River in North Dakota in 1997 (87). The first two studies reported an increased incidence of spontaneous abortion, including a very high rate of pregnancy losses in the Polish women (86). An increased incidence of preterm birth and low birth weight was seen among the Polish women and in North Dakota residents, although there was no increase in small for gestational age in the North Dakota sample. No association between the New York floods and birth defects was found.

Ice storm—An ice storm hit Quebec in 1998, causing widespread power outages to 3 million people for up to 5 weeks (88). A cohort of women who were pregnant during the storm, and their children, has been followed to assess the effects of prenatal stress during different periods. While one-third of the women were depressed according to questionnaire data, only 1% were depressed when interviewed by a clinician (89). Infants exposed prenatally to the storm were more likely to have developmental issues with language, mental development, and play, when both subjective and objective stress were considered (5; 90; 91).

Ferry sinking—501 people died in the 1994 storm- related sinking of the Swedish ferry *Estonia* (92). A subsequent 15% increase in very low birth weight was reported in the Swedish population (92).

Discussion

Disasters potentially influence a range of reproductive outcomes (93). Even in the absence of a direct exposure to the disaster, surrounding circumstances may lead to an increased risk

of adverse pregnancy outcomes – for instance, more unplanned pregnancies and sexually transmitted infections (62, 94, 95). Some studies have indicated that pregnant women with PTSD are at increased risk of adverse birth outcomes (96), as well as being more likely to smoke, use alcohol and other drugs, and receive inadequate prenatal care (97).

However, the literature on disasters indicates limited effect on birth outcomes. Disaster, in and of itself, does not seem to shorten gestation or cause preterm birth. Several large studies of terrorist attacks, hurricanes, and chemical disasters support this conclusion (40; 45; 48; 50; 51; 58; 65). In fact, more studies have found a reduction in risk (after 9/11 (35; 39; 47; 52) and hurricanes (34)) than have found an increase in risk (after earthquakes (37; 74) and floods (86; 87)). Although gestational age is measured less well than birthweight (99), the consistency of the results and lack of associations with very preterm birth (which is more consistently measured) implies a true lack of effect. Negative effects on fetal growth and birthweight have been seen more consistently, after terrorist attacks and bombings (35; 39; 45; 48; 51; 54; 57; 58), environmental disaster (65), and natural disasters (36; 75; 86; 92), though counter-examples can be found (34; 50; 52). It should be noted that many studies have looked at multiple indicators of fetal growth (birth weight, low birth weight, very low birth weight, small for gestational age, birth length, and/or head circumference), and found an association with only one (35; 39; 45; 46; 48; 51; 58; 75; 87). The growth indicators variously reported to be associated with disaster exposure have not been consistent, nor has a consistent risk period during the pregnancy been identified.

The effects of disaster on congenital anomalies are likely to vary by type of disaster, with disasters that have a strong environmental (e.g., Chernobyl (22)) or nutritional component (e.g., Hurricane Gilbert in Jamaica (79)) more likely to yield increased risk. An increase in spontaneous abortion has been reported after floods (85; 86), but the published studies are small and thus difficult to interpret. Gaps in the literature include the absence of detailed studies of spontaneous abortion, as well as other complications of pregnancy such as pre-eclampsia. Most studies have not found major effects of low-level disaster-related environmental exposure (22; 41), but the effects of environmental exposures will vary by disaster and it may be difficult to extrapolate from the existing studies to future disasters.

With respect to mental health, women are generally more vulnerable to post-disaster psychopathology than men (11), and some evidence indicates that mothers are more vulnerable than other women (14). However, the factors that predict poor mental health are similar for pregnant and other women, particularly the severity of the disaster exposure (e.g., (73; 81; 82)). The evidence so far indicates that pregnancy does not render a woman at particularly high risk (73; 82), but studies designed specifically to address this question have not been performed. Current studies also indicate a possible relationship between disaster-related prenatal stress (as measured during the ice storm studies (5; 91)) and child development, but indicate that maternal mental health after a disaster is more influential on child development than the disaster itself (68; 84). Future studies should examine this issue in larger-scale studies with sufficient sample size, and determine the relevance of the small effects seen in the existing studies.

Another gap in the literature involves the location and type of disaster assessed. The majority of published studies were conducted in the United States; few were conducted in developing countries. Further research on the effects of disaster in developing countries would be appropriate. A large number of studies have addressed the 9/11 disaster; several have addressed natural disasters; and fewer have addressed other technological disasters. We did not find any studies that addressed wildfires, tornadoes, plane crashes, or most chemical disasters. However, since a variety of natural and technological disasters have been studied,

the research performed is likely to be applicable to these other situations. The exception would be research on the effects of specific chemical exposures.

In conclusion, the research so far indicates that the major concerns for pregnant women exposed to disaster relate to decreased fetal growth and maternal mental health problems, especially in the most directly exposed women. Clinicians treating pregnant women under these conditions should be especially sensitive to these issues, and researchers should attempt to address the gaps in our knowledge.

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Table 1

Studies of the World Trace Center disaster of September 11[h], 2001 and other terrorist attacks

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Berkowitz, 2003[a] (45)	WTC (United States)	GA IUGR LOW BIRTH WEIGHT PTB	Proximity to WTC	187 exposed, 2367 controls	GA: 39.1 vs 39.0, p=0.55 BW: 3203 vs 3267, p=0.14 PTB: 9.9% vs. 9.2%, p=0.76 LOW BIRTH WEIGHT: 8.2% vs 6.8%, p=.47 IUGR: 8.2% vs. 3.8%; OR 2.2, 1.3-3.71; aOR1.9, 1.05-3.71	no difference by trimester or time of recruitment
Brand, 2006 (55)	WTC (United States)	maternal report of infant distress, response to novelty		98	women with post traumatic stress disorder rated infants as more distress, less likely novelty; no difference in other temperament traits	9 months old infant
Camacho, 2008 (57)	terrorist attacks (Colombia)	BW	location of residence	781000	8.7 g reduction for living in area with landmine explosions	strongest in first trimester
El-Sayed, 2008 (52)	WTC (United States)	VERY low birth weight LOW BIRTH WEIGHT PTB	timing	3133 Arab, 126251 non-Arab	VERY low birth weight aOR: 0.49, 0.31-0.76 LOW BIRTH WEIGHT aOR: 0.97, 0.78-1.06 PTB aOR: 0.78, 0.98?-0.90	
Endara, 2009 (50)	WTC (United States)	birth defects PTB SGA Infant growth deficiency (infant health registry)	timing of birth	164743 infants born to active-duty military families; compared to 2000 and 2002 babies	Birth defects: aOR 1.01, 0.93-1.09 PTB: aOR 1.02, 0.98-1.06 SGA: aOR 1.00, 0.92-1.09 Growth: aOR 1.00, 0.95-1.06	Estimated date of delivery June 12, 2000-September 11, 2001
Engel, 2005[a] (39)	WTC (United States)	GA BW HC	post traumatic stress disorder/depression	52 women enrolled while pregnant, 5 zones	post traumatic stress disorder and depression associated with longer gestations post traumatic stress disorder assoc with smaller HC week after 9/11- more births <2000 g, fewer births 2000-2500 g	
Eskenazi, 2007 (53)	WTC (United States)	VERY low birth weight MLOW BIRTH WEIGHT LOW BIRTH WEIGHT VPTB MPTB PTB	timing of birth	1,660,401 New York State women (birth certificate data)	VERY low birth weight: aOR 1.44, MLOW BIRTH WEIGHT: aOR 1.67 BW 2000-2500 g: aOR 0.83 VERY low birth weight: in Dec and Jan - aOR 1.36, 1.28 MPTB in first 8 weeks after disaster in NYC: aOR 0.87 MPTB in first 4 weeks after disaster in upstate, aOR 0.89	months after 9/11

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Lauderdale, 2006 (51)	WTC (United States)	LOW BIRTH WEIGHT VERY low birth weight PTB	timing and Arabic last name	15064 Arab named, 1532311 non-Arab named	LOW BIRTH WEIGHT: aOR 1.34, 1.04-1.73 VERY low birth weight, PTB: no association	Six months after vs. six months before
Lederman, 2004[b] (48)	WTC (United States)	BW HC BL PI SGA	live or work within 2 miles of WTC	300 fullterm, nonsmokers 329	BW: adjusted 149g less HC: adjusted -0.29, p=0.15 BL; adjusted -0.82 cm less PI: no difference GA: 2-4 days less; -1.22, p=0.18 after adjustment SGA: no difference	
Lederman, 2008[b] (49)	WTC (United States)	BW BL HC GA (all full-term) Bayley scales	mercury exposure; mercury level not associated with proximity to WTC	136-151 infants	no associations	12 and 24 months
Lewis, 2005[c] (38)	WTC (United States)	mother/infant bonding alcohol use (Alcohol Use Disorders and Associated Disabilities Interview Schedule) Depression (CES-D)	explain how affected by terrorism subjective effect of attacks	99 pregnant women	drug users more likely to say disaster affected ability to bond no other main effects No association with alcohol use CES-D scale: 15.1 +/-9.7 (elevated) exposure to attacks associated with depressive symptoms	2-9 months after WTC
Lewis, 2008[c] (100)	WTC (United States)	Depression (CES-D) effect of terrorism	timing and self-report within 9 months of 9/11	99 pregnant women	more trauma predicted subjective effect history of domestic violence/ abuse predicts response to event	
Maric, 2009 (58)	bombing (Serbia)	BW GA BL HC Pre-eclampsia Birth defects	timing (registry data)	1198 exposed, 2617 control	BW: 86 g lighter, 95% CI 67-104 GA, BL: no difference HC: 0.6 cm larger in exposed, p<0.01 Pre-eclampsia: aOR 0.60 (0.41-0.86) Birth defects: aOR 3.3 (0.9-11.7)	
Perera, 2005[b] (46)	WTC (United States)	BW HC PI SGA GA	polycyclic aromatic hydrocarbons Benzo(a)-pyrene DNA adducts (inversely correlated	170 women, 203 infants	no independent effects interactive effect on birthweight with tobacco smoke: 276-g reduction in BW	

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
			with distance from WTC)		1.3 cm reduction in HC no interaction effects on PI, small for gestational age, GA	
Rich-Edwards, 2005 (47)	WTC (United States)	GA PTB	Timing	606 exposed, 1184 matched controls	GA: 0.13 (-0.05, 0.3) weeks longer in exposed PTB: OR 0.60, 0.36-0.98	
Santos-Leal, 2006 (59)	Madrid train bombing (Spain)	PROM			18 in weeks after bombing, vs. average of 9	
Smits, 2006 (54)	WTC (The Netherlands)	BW GA	timing	1885 year after, 1258 year before	48 g (95% CI 14-83) lower in exposed 0.7 days, p=0.07	no variation by trimester
Yehuda, 2005[a] (56)	WTC (United States)	cortisol levels	post traumatic stress disorder after WTC	38	lower cortisol in both mother and baby if mother had post traumatic stress disorder	most likely if mother developed post traumatic stress disorder in 3rd trimester

GA, gestational age; BW, birthweight; low birth weight, low birthweight (<2500 g unless otherwise specified); PTB, preterm birth (<37 weeks' gestation unless otherwise specified); IUGR, intrauterine growth restriction; small for gestational age, small-for-gestational-age; post traumatic stress disorder, post-traumatic stress disorder; OR, odds ratio; aOR, adjusted odds ratio; very low birth weight, very low birthweight (<1500 g unless otherwise specified); VPTB, very preterm birth; WTC, World Trade Center disaster of September 11th; PROM, premature rupture of membranes; NS, non-statistically significant; HC, head circumference; BL, birth length; PI, ponderal index; SAb, spontaneous abortion; MLOW BIRTH WEIGHT, moderately low birthweight, 1500-1999g; MPTB, 33-36 weeks

Studies marked with the same superscript letter are different analyses of the same sample

Obstet Gynecol Surv. Author manuscript; available in PMC 2012 October 16.

Table 2

Studies of other environmental/chemical disasters

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Bhandari, 1990 (64)	Bhopal gas release (India)	SAb Congenital anomalies	Location of residence	2566 exposed, 1218 unexposed	SAb: 24.2% vs. 5.6% Congenital anomalies: 14.2/1000 vs. 12.6/1000	
Goldhaber, 1983 (66)	Three Mile Island (United States)	SAb (hospital record of loss <16 weeks)	living within 5 miles of TMI, timing	479 pregnant women	15% SAb for women pregnant at time of TMI; comparable to other studied populations	pregnant at time of TMI
Goldman, 1985 (65)	Love Canal (United States)	LOW BIRTH WEIGHT Prematurity (<38 weeks)	residence	227	LOW BIRTH WEIGHT: 12.3% vs. 8.6% overall; aOR 3.05, 1.3-7 in homeowners; 1.1 0.5-2.3 in renters no difference in GA	
		Birth defects (maternal report)			Birth defects: aOR 2.0, 1.0-3.7 homeowners; 2.9, 1.2-7.2 renters	
Houts, 1991 (69)	Three Mile Island (United States)	Depression (SCL) Anxiety (SCL)	lived in communities within 10 miles of facility	1833 women who gave birth within 1 year, 1808 who gave birth 1-2 years after	somewhat higher (NS) depression and anxiety in those pregnant immediately after	
Kapoor, 1991 (63)	Bhopal gas release (India)	SAb (<28 weeks)	Area of residence	75 exposed, 60 unexposed	26.7% vs. 10%	Three-quarters of losses in the same month
Levi, 1989 (67)	Chernobyl (Sweden)	GA BW BL Somatic anxiety (Karolinska scale of personality) Psychic anxiety Distress (IES) Chernobyl anxiety score	Anxiety, environmental threat	88 women early in pregnancy at time of Chernobyl	GA: Anxiety associated with lower GA (r=-0.23, -0.26) No association of any outcome with environmental threat mean score, somatic anxiety: 16.3+-4.8; psychic anxiety: 18.9+-4.9; 91% had very or somewhat unpleasant thoughts during the month after accident; 36% believed possibility of harm could not be excluded; 15% changed diet; Chernobyl anxiety scale correlated with IES	In early gestation at time of Chernobyl
Vianna, 1984 (41)	Love Canal (United States)	LOW BIRTH WEIGHT	location of house and timing of birth	383 women	LOW BIRTH WEIGHT higher in the swale than the rest of the canal; lower in area closest to canal than rest of state/historical data	

GA, gestational age; BW, birthweight; low birth weight, low birthweight (<2500 g unless otherwise specified); OR, odds ratio; aOR, adjusted odds ratio; BL, birth length; SAb, spontaneous abortion; IES, impact of event scale; SCL, symptoms checklist; TMI, Three Mile Island; NS, non-signficant

Table 3

Studies of natural disasters

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Earthquakes						
		LOW BIRTH WEIGHT Apgar score BL			8% low birth weight (high for area); correlated with spouse casualty, relative injury, dislocation	
Chang, 2002 (75)	Earthquake (Taiwan)	Minor psychiatric distress (Chinese version of GHQ)		115	Apgar, BL: no associations 29% scored higher than 3=minor psychiatric disease correlation with starvation, injury, negative attitude about hurricane, and relative casualty no association with dislocation	
Glynn, 2001 (37)	Earthquake (United States)	GA	timing of birth stress due to earthquake	40	mean GA longer in those exposed in 2nd and 3rd trimester than 1st r=0.35, p<0.05 mean EDS: 3.8 and 3.9	exposed in trimester and postpartum
Hibino, 2009 (101)	Earthquake (Japan)	Depression (EDS)	anxiety about earthquake	99 with during and after pregnancy measures	anxiety about earthquake associated with more depression intensity, fear, damage, evacuation not associated	during or immediately after earthquake
Lopez, 1989 (76)	Earthquake (Mexico)	Attachment Psychology development LOW BIRTH WEIGHT BW	infants buried under rubble and later rescued	10 long-term burial, 13 shorter-term	High risk (>9): 13% before, 9% after no abnormal attachment in strange situation no evidence of psychopathology normal motor-development LOW BIRTH WEIGHT: 3.7% vs. 5.0%, p<0.01 BW: 3420 g vs. 3251 g, p=0.05 PTB: 5.6% vs. 7.4%, p<0.01	15 months after earthquake
Tan, 2009(74)	Earthquake (China)	PTB GA BL Birth defects Apgar score	Timing	6638 year before, 6365 year after	GA: 39.7 weeks vs. 39.1, p>0.05 BL: 49.9 vs. 49.0, p>0.05 Birth defects: 1.0% vs. 1.2%, p<0.05 Both 1-minute and 5-minute mean Apgar lower	Highest risk of birth defects in those exposed in the first trimester

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Weissman, 1989 (70)	Earthquake (Israel)	preterm delivery (<37 weeks or weight <2500 g) Apgar scores	2 weeks after earthquake	1613	2/5 earthquakes, increase in preterm deliveries no relation with Apgar scores	
Hurricanes						
Duff, 1994 (79)	Hurricane (Jamaica)	neural tube defects (obvious NTDs referred; no reported cases of anencephaly)		17 cases, 50 controls	mean folate in cases 154 g vs. 254 in controls	11-18 months after Gilbert
Hamilton, 2009 (80)	Hurricane (United States)	VPTB PTB VERY low birth weight LOW BIRTH WEIGHT VPTB PTB VERY low birth weight LOW BIRTH WEIGHT	timing and affected county timing and highly affected county	85223 before vs. 81452 after 34520 before vs. 27848 after	VPTB: 3.1 vs. 3.0% PTB: 17.5 vs. 16.9% VERY low birth weight: 2.3 vs. 2.1% LOW BIRTH WEIGHT: 11.6 vs. 11.2% VPTB: 2.8 vs. 3.1% PTB: 16.7 vs. 16.7% VERY low birth weight: 2.0 vs. 2.1% LOW BIRTH WEIGHT: 10.8 vs. 11.0%	year before vs. year after year before vs. year after
Harville, 2009[a] (102)	Hurricane (United States)	post traumatic stress disorder (PCL) Depression (EDS)	danger, injury, multiple items	292 postpartum	18% depression 13% post traumatic stress disorder	interviewed 9-18 months after storm
Savage, 2010 (103)	Hurricane (United States)	Depression (EDS) self-reported mood anxiety	living in New Orleans post-Katrina	199 pregnant/postpartum	mean EDS, 8.5 postpartum: 37% scores >=10; pregnant: 25% scores >= 10 mean score 9.5 mean score 5.2	
Tees, 2009[a] (84)	Hurricane (United States)	infant temperament	high scores on early infant and toddler temperament questionnaire activity, approach, intensity, mood, adaptability scales	288	hurricane experience not associated with temperament worse mother's mental health associated with more difficult temperament	2 and 12 months; interviewed 8-24 months after hurricane
Xiong, 2008[b] (36)	Hurricane (United States)	LOW BIRTH WEIGHT PTB	experiences of loss, damage, danger during storm post traumatic stress disorder	301	LOW BIRTH WEIGHT: aOR 3.3, 1.1-9.9 PTB: aOR 2.3, 0.8-6.4 LOW BIRTH WEIGHT: aOR 3.1, 0.8-12.6 PTB: aOR 0.8, 0.1-6.4	births 8-18 months after Katrina
Xiong, 2010[b] (82)	Hurricane (United States)	post traumatic stress disorder depression	experiences of loss, damage, danger during storm	301	aOR for post traumatic stress disorder with severe experience: 16.8, 2.6-106.6 Depression: 3.3, 1.6-7.1	Interviewed 6-16 months after Katrina

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Floods						
Janerich, 1981 (85)	Floods (United States)	SAb birth defects	timing in affected counties		SAb: increase in rate in year after 60.9 vs. 51.4/1000 Birth defects: no association	
Neuberg, 1998 (86)	Flood (Poland)	Spontaneous abortion PTB LOW BIRTH WEIGHT	living in affected areas	47 exposed women, 100 controls	SAb: 40% (vs. 12% in controls) PTB: 36% (vs. 8% in controls) LOW BIRTH WEIGHT: 23% (vs. 9% in controls)	clinically pregnant at time of floods
Tong, 2010 (87)	Flood (United States)	LOW BIRTH WEIGHT PTB SGA Pregnancy-associated hypertension Eclampsia Anemia Uterine bleeding	Living in affected counties	57007 total births in state (40% in affected counties)	LOW BIRTH WEIGHT: 1.18, 1.03-1.35 in affected counties; 1.07, 0.96-1.19 in whole state PTB: 1.08, 0.98-1.20 in affected; 1.10, 1.01-1.19 in whole state SGA: 0.98, 0.87-1.10 in affected; 0.99, 0.91-1.08 in whole state Other complications more common after floods	Three years after compared to three years before
Ice storm						
Brunet, 2003[c] (89)	ice storm (Canada)	Depression (GHQ) post traumatic stress disorder (IES)	timing	223	30% depression by GHQ, only 2 clinically diagnosed	6 months after storm; pregnant during or within 3 months of storm
Laplante, 2004[c] (90)	ice storm (Canada)	Distress (IES) productive language receptive language	objective stressors; subjective stressors	58	prenatal stress (objective) causes 12% of variance prenatal stress (subjective) causes 17% of variance	2 years after; stronger effects when exposed in 1,2 trimesters; no effect in 3rd trimester
Laplante, 2007[c] (91)	ice storm (Canada)	Bayley MDI functional play	objective stressors subjective stressors	52	prenatal stress causes 11% of variance in MDI less functional, more stereotypical play; objective prenatal maternal stress explains 18% of variance after subjective prenatal maternal stress controlled	no trimester effect seen
Ferry sinking						

Study	disaster	outcome	definition of exposure	sample size	Results (exposed vs. unexposed)	Notes on timing
Catalano, 2001 (92)	ferry sinking (Sweden)	VERY low birth weight	timing	Average 25930 births/quarter	25 excess very low birth weight births associated with ferry sinking; increase of 15%	only those exposed in 2nd trimester

GA, gestational age; BW, birthweight; low birth weight, low birthweight (<2500 g unless otherwise specified); PTB, preterm birth (<37 weeks' gestation unless otherwise specified); post traumatic stress disorder, post-traumatic stress disorder; OR, odds ratio; aOR, adjusted odds ratio; very low birth weight, very low birthweight (<1500 g unless otherwise specified); VPTB, very preterm birth; NS, non-statistically significant; HC, head circumference; BL, birth length; PI, ponderal index; SAb, spontaneous abortion; EDS, Edinburgh Depression Scales; IES, impact of event scale; post traumatic stress disorder, post-traumatic stress disorder; CES-D, Center for Epidemiologic Studies- Depression; WTC, World Trade Center disaster of September 11; NS, not statistically significant; SCL, symptoms checklist; PCL, post-traumatic checklist; GHQ, general health questionnaire; MDI, mental development index

Studies marked with the same superscript letter are different analyses of the same sample

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