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Major Flood Related Strains and Pregnancy Outcomes

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Objective: To assess the impact of experiencing a major flood during pregnancy on fetal growth and length of gestation, and to consider how flood-related strains might contribute to these effects. ***Method:*** The Red River Pregnancy Project was a prospective study carried out for 3 months immediately after the historic 2009 crest of the Red River in Fargo, North Dakota. Pregnant community residents who were at least 18 years old with a singleton, intrauterine pregnancy participated in the study ($N = 169$). Analyses examined if birth weight and length of gestation were associated with residential distance from flooding and gestational age at time of the flood crest. ***Results:*** For pregnancies earlier in gestation during the crest (–1 $SD = 12$ weeks), birth weight decreased as distance from flooding decreased (-42.29 g/mi, $p < .01$). For pregnancies later in gestation at crest ($+1$ $SD = 26$ weeks), distance was not associated with birth weight ($p > .10$). Biparietal growth trajectories showed a decrease in growth after the crest of the flood but only for women early in pregnancy. However, various measures of flood related and general stress or strain did not explain these effects. Length of gestation was not associated with distance from or the timing of the flood. ***Conclusions:*** Pregnant women in the first trimester who experience a major flood near their homes are at risk of having lower birth weight neonates due to a reduction in fetal growth. The mechanisms of this effect deserve further attention in rapidly mounted investigations after disaster.

Keywords: pregnancy, stress, natural disaster, fetal growth

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There is a small but significant body of research on the pregnancy outcome effects of major disasters such as earthquakes, nuclear disasters, and terrorist attacks occurring during a woman's pregnancy. Studies have shown effects of disasters like these on length of gestation and birth weight (Dancause et al., 2011; Glynn, Wadhwa, Dunkel-Schetter, Chicz-Demet, & Sandman, 2001; Lederman et al., 2004; Zhu, Tao, Hao, Sun, & Jiang, 2010). In this study, we examined whether experiencing a major flood disaster would adversely influence pregnancy outcomes. Specifically, we tested whether distance of a woman's residence from flooding predicted birth weight and length of gestation, and considered the trimester of pregnancy in which the flood occurred. Furthermore, taking a biopsychosocial approach to pregnancy (Dunkel Schetter, 2011; Dunkel Schetter & Glynn, 2011), we examined general stress and specific flood-related factors such as physical exertion, coping behavior, and financial loss and whether they contributed to or accounted for the effects of the flood on pregnancy outcomes.

Flooding is the most commonly occurring natural disaster in the world, accounting for >35% of natural disasters and >50% of the individuals affected by natural disasters. Flooding can impact health in many ways. The immediate health effects include orthopedic injuries, acute medical conditions such as rashes and asthma aggravation, and death by drowning (Noji, 2005). The distal health effects are less clear, but can include psychiatric illnesses such as posttraumatic stress disorder (Schlenger et al., 2002) and medically unexplained symptoms often in the form of somatic complaints, sleep disturbance, or fatigue (Hassett & Sigal, 2002).

In addition, experiencing a catastrophic disaster and the distress resulting from such an experience have been linked to adverse birth outcomes (Engel, Berkowitz, Wolff, & Yehuda, 2005; Holstius, Reid, Jesdale, & Morello-Frosch, 2012; Lederman et al., 2004; Xiong et al., 2008). When timing in pregnancy of the disaster is considered, the effects on pregnancy outcomes are most severe when the disaster occurs early in pregnancy (e.g., first to early second trimester). For instance, Glynn et al. (2001) found

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Lexi Kvasnicka-Gates is now at the Department of Social Science, Dakota College at Bottineau. Ai Ni Teoh is now at the School of Life Sciences, Heriot-Watt University Malaysia. Konrad Bresin is now at the Department of Psychology, University of Illinois at Urbana–Champagne. Siri Fiebiger is now at Allina Health, Minneapolis, Minnesota.

This study was performed in the Fargo, North Dakota, area by members of the North Dakota State University Department of Psychology in collaboration with the MeritCare Hospital (now Sanford Health) OB/GYN Department and the Innovis Health (now Essentia Health) OB/GYN Department. Clayton J. Hilmert had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. We thank Theresa Theige, RN, BSN, manager of the MeritCare OB/GYN Department, Linda Hoefs, RN, manager of the Innovis OB/GYN Department, Margaret Mickelson, MD, research physician at the MeritCare OB/GYN Department and Kevin McCaul, PhD, dean of the NDSU College of Science and Mathematics. We also thank Christine Dunkel Schetter, PhD for comments on an earlier draft of this manuscript.

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that women who experienced an earthquake earlier in pregnancy had shorter gestations.

Dancause et al. (2011) and Zhu et al. (2010) showed that women in the first and second trimesters who lived through a major ice storm, or who experienced a greater number of severe life events had shorter gestations and gave birth to lower birth weight infants than women who experienced these events later in pregnancy. The lesser effects later in pregnancy may be due to a progressive dampening of psychophysiological responses to stress to protect the mother and fetus (Glynn, Schetter, Wadhwa, & Sandman, 2004).

Natural disasters have biopsychosocial impacts and pregnancy is a biopsychosocial phenomenon. Therefore, there are a number of different biological, psychological, and behavioral pathways by which disaster-related factors can "get under the skin" and influence the length of pregnancy and fetal development. Stress has been repeatedly associated with pregnancy outcomes, and the literature examining the biological (e.g., neuroendocrine, cardiovascular, and immune system) processes mediating this link continues to grow (Coussons-Read, Okun, Schmitt, & Giese, 2005; Hilmert et al., 2014; Sandman et al., 2006). However, there are other potential natural disaster and pregnancy outcome pathways that have been relatively unexplored.

Few studies have considered how practical challenges associated with living through a disaster, such as physical exertion to prepare for and cope with a disaster, relocation, and financial loss might help explain the effects of the disaster on pregnancy outcomes. In contrast to sudden disasters, flooding is usually forecast and therefore can involve an active and stressful preparation period. The rise of the Red River in Fargo, North Dakota and Moorhead, Minnesota in 2009 was unprecedented; in the 18 days leading up to a more than 40-foot crest on March 28, the National Weather Service repeatedly increased the predicted crest level. Residents and the National Guard filled, lifted, and placed 6 million sandbags to build and heighten levees. Earlier in pregnancy, a woman might be more likely to participate in such strenuous activities, which could adversely affect length of gestation and birth weight (Ahlborg Jr, Bodin, & Hogstedt, 1990; Runge et al., 2013; Saurel-Cubizolles et al., 2004) possibly by affecting blood flow to the uterus and fetus (Szymanski & Satin, 2012). Thus, we felt it was important to assess physical exertion in this study.

Other disaster-related challenges could also influence pregnancy outcomes adversely such as evacuation, which can involve lasting psychological strains of relocation (Martin, 1995), involve strenuous lifting, and affect regular health care access. Financial losses due to the flood could compromise prenatal nutrition and health care. Unhealthy coping behaviors that increase the risk of adverse pregnancy outcomes, such as smoking, may increase during preparation or following a disaster (Parslow & Jorm, 2006).

In the present study, we tested each of these possibilities as well as the main hypotheses that living closer to flood areas would shorten length of pregnancy and decrease birth weight, especially for women early in pregnancy during the flood. By identifying the contributions of a variety of flood-related factors to the effects of an objective stressor, distance from flooding, on pregnancy outcomes we will inform future interventions designed to mitigate these effects.

Materials and Method

Participants

To take part in the Red River Pregnancy Project, a participant had to be at least 18 years of age and pregnant during the flood with a singleton, intrauterine pregnancy. Table 1 presents the sociodemographic characteristics of the full study sample and a subset of participants discussed below. The study sample was primarily White/Caucasian (n = 124, 91.18%), followed by African American (n = 5, 3.68%), Native American (n = 3, 2.21%), Hispanic (n = 3, 2.21%), and Asian (n = 1, 0.74%). The sample was representative of the racial and ethnic makeup of the geographic area in which the flood occurred (U.S. Census Bureau, 2010).

Procedures

The institutional review boards of the participating institutions approved of all study protocols. Data collection occurred over the 3 months following the Red River crest in Fargo, North Dakota, and Moorhead, Minnesota, on March 28, 2009. Women were recruited with fliers at local hospitals and newspaper ads, and by physician referrals. After providing informed consent, participants completed questionnaires that assessed all self-report study variables including sociodemographic factors, flood-related activities, and psychosocial stress.

Medical data, including birth weight and gestational age (GA) at birth, were extracted from medical records postpartum. A medical risk score was computed by summing up a total of 19 possible historical (e.g., previous preterm delivery) and current risk conditions (e.g., anemia) that were recorded in medical records. This quantitative method of identifying high-risk pregnancies with perinatal variables has been validated (Hobel, Youkeles, & Forsythe, 1979) and used in previous studies to statistically control for the effects of these factors on pregnancy outcomes (Glynn, Schetter, Hobel, & Sandman, 2008; Hilmert et al., 2008).

Predictors

Distance and timing. Participants were asked, "Approximately how far do you live from areas that had to evacuate?" Answers ranged from 0 to 56 mi (90.12 km). Seventeen values over 10 mi (16 km) were recorded as 10 mi to prevent biased results due to outliers. Using a best obstetric estimate of GA at birth (American College of Obstetricians and Gynecologists, 2009), we calculated GA at the time of the flood crest.

Flood-related strain. Questionnaires asked about three categories of specific challenges faced by the participants: physical strain, evacuation strain, and financial strain. Example items are presented in Table 2. We standardized responses and then averaged scores to create indices on physical strain, evacuation strain, and financial strain.

Psychological stress. We measured general stress using standardized scales of perceived stress (Cohen, Kamarck, & Mermelstein, 1983), state anxiety (Spielberger, 1985), and pregnancy anxiety (Rini, Dunkel-Schetter, Wadhwa, & Sandman, 1999). These scales were standardized and then averaged to create a psychological stress index (Hilmert et al., 2008).

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Table 1
Participant Demographics

	Full sample (n = 136)			Noninduced/Assisted sub sample (n = 84)		
	%	*n*	*M* (*SD*)	%	*n*	*M* (*SD*)
Age, years						
18–24	17.6%	24		19.0%	16	
25–29	52.9%	72	27.7	48.8%	41	27.9
30–34	2.1%	29	(4.5)	23.8%	20	(4.3)
≥35	8.1%	11		4.8%	4	
Adjusted Income*						
<$5,000	7.4%	10		8.4%	7	
$5,001–$15,000	21.3%	29	$24,531	20.5%	17	$25,009
$15,001–$25,000	25.0%	34	(13,259)	18.1%	15	(13,306)
$25,001–$35,000	28.7%	39		32.5%	27	
$35,000–$45,000	10.3%	14		13.3%	11	
<$45,000	7.4%	10		7.2%	6	
Highest degree of education*						
<High school	5.1%	7		6.0%	5	
High school graduate	8.1%	11	n/a	3.6%	3	n/a
Some college	32.4%	44		33.3%	28	
Bachelor's degree	35.3%	48		35.7%	30	
Graduate degree	19.1%	26		21.4%	18	
Distance from flooding (mi)						
<1.0	25.0%	34		25.0%	21	
1.0–2.9	29.4%	40	3.7	29.8%	25	4.2
3.0–5.9	17.6%	24	(3.5)	16.7%	14	(5.1)
6.0–9.9	13.2%	18		17.9%	15	
≥10.0	14.7%	20		10.7%	9	
Gestation at flood						
< 13 weeks	23.5%	32	18.6	17.6%	12	19.6
14–20 weeks	30.1%	41	(6.8)	29.4%	20	(7.0)
21–26 weeks	33.1%	45		36.8%	25	
<26 weeks	13.2%	18		16.2%	11	
Gestation length						
Preterm (<37 weeks)	5.9%	8	39.2	3.6%	3	39.0
Term (≥37 weeks)	94.1%	128	(1.6)	96.4%	81	(1.3)
Birth weight						
Low birth weight	2.9%	4	3443.4	1.2%	1	3428.5
(<2,500 g)	97.1%	132	(517.3)	98.8%	83	(402.7)

Note. n/a = not applicable.
* Household income divided by persons in the household.

Outcomes

A best obstetric estimate of GA at birth was calculated as recommended by the American College of Obstetricians and Gynecologists (2009) based on last menstrual period and ultrasound exams performed at prenatal visits and recorded in charts. We examined GA and birth weight for GA (fetal growth) to test hypotheses.

Also, in a supplementary analysis we examined the trajectory of fetal growth using ultrasound data of fetal biparietal diameter. This is the distance between a central point (the parietal eminence) on

Table 2
Flood Related Strain Indices Items

Measure	Example items	Range
Physical Strain Index	"Did you participate in sandbagging?"	28 yes; 108 no
	"For how long?"	0–40 hr
	"How much did you physically exert . . .?"	1–6*
Evacuation Strain Index	"Did prepare to evacuate?"	64 yes; 72 no
	"For how long?"	0–14 days
	"Did you evacuate?"	32 yes; 104 no
Financial Strain Index	"Were you financially affect . . .?"	1–7*
	"How damaged was your property?"	1–7*

* Possible range of this scale was 1 (*not at all*) to 7 (*very much*).

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Table 3
Correlations (Pearson's r) Among Study Variables (N = 136)

Variables	Distance from flood	Timing of flood	Medical risk	SES	Parity[a]	BMI	Age	Nicotine use[b]	Psych stress	Financ. strain	Evac. strain	Phys. strain	Assist. deliv.[c]	Labor[d]	Birth weight
Timing of flood	−.07														
Medical risk	.06	−.12													
SES	−.09	.01	$-.18^{*}$												
Parity[a]	−.04	.02	.10	$-.29^{**}$											
BMI	$.19^{*}$	−.06	$.31^{**}$	$-.26^{**}$	$.23^{**}$										
Age	−.11	.07	−.06	$-.24^{**}$	$.46^{**}$	.13									
Nicotine use[b]	.02	.17	.04	$.38^{**}$	−.08	$-.22^{*}$	$.24^{**}$								
Psych stress	−.06	$-.20^{*}$	.02	−.10	.04	.14	−.03	$-.18^{*}$							
Financ. strain	$-.25^{**}$	.09	−.03	−.13	.07	.12	−.02	$-.20^{*}$	.05						
Evac. strain	$-.48^{**}$	.15	−.09	.09	.09	−.01	.02	.00	.03	.17					
Phys. strain	$-.24^{**}$	−.15	−.04	.15	−.01	−.10	.05	−.03	.05	$.18^{*}$	$.23^{**}$				
Assist. deliv.[c]	.04	−.06	.03	.01	−.04	.10	.06	.15	−.07	.09	−.11	−.03			
Labor[d]	−.01	−.12	$.26^{**}$	−.09	.11	.14	.01	.08	.05	.00	−.03	−.12	$.40^{**}$		
Birth weight	.02	.14	−.14	−.03	−.02	.07	−.07	−.03	−.05	.09	.01	−.04	$-.19^{*}$	−.03	
GA	−.02	.15	$-.26^{**}$	.09	−.10	−.01	−.05	.00	−.13	.03	.06	.05	−.15	.14	$.62^{**}$

Note. SES = socioeconomic status; BMI = body mass index; Financ. = financial; Evac. = evacuation; Phys. = physical; Assist. deliv. = assistance in delivery; GA = gestational age at birth.
[a] 0 = nulliparous, 1 = multiparous. [b] 0 = no use during pregnancy, 1 = use during pregnancy. [c] 0 = unassisted delivery, 1 = assisted/instrumental delivery. [d] 0 = spontaneous or augmented labor, 1 = induced labor.
$^{*}p < .05$. $^{**}p < .01$.

each of the parietal bones found on opposite sides of the skull. This distance is correlated with GA (Campbell, Warsof, Little, & Cooper, 1985) and provides a direct estimate of fetal size. Ultrasound data were gathered by physicians or technicians at participants' prenatal care visits, so there was not a standardized timing of or procedure for the collection of these data.

Statistical Analyses

We first performed analyses on the entire sample of participants ($N = 136$). Because the sample included women who had labor induced for various reasons, including planned births, it was not clear if the effects of the flood on length of gestation would be evident. Therefore, in analyses of the entire sample we statistically controlled for whether a labor was spontaneous or induced. Then, we repeated analyses with a subsample including only women who had spontaneous or augmented labors ($N = 84$) to rule out effects of labor induction in outcomes. Sociodemographic characteristics significantly correlated with outcome variables were included in these analyses as control variables (covariates) along with age, socioeconomic status (SES), body mass index, nulliparity, medical risk score, and nicotine use during pregnancy. Adjusted income and a dichotomized education variable (−1: ≤high school, 1: >high school) were highly correlated ($r = .40$, $p < .001$), so a SES index was created by z scoring and then averaging the two variables for following inferential analyses. Hierarchical regression analyses (Aiken & West, 1991) tested whether pregnancy outcomes were predicted by distance from areas of flooding or GA at the time of the flood crest.

Also, to examine if the effect of distance from flooding depended on the gestational timing of the flood, we tested an interaction between distance and GA at the time of crest. We reported the effect size of significant interactions as the proportion of variability in outcome (birth weight or GA) uniquely accounted for by the interaction (ΔR^2) followed by simple slopes analyses that indicate the change in outcome associated with a 1 *SD* change in distance from evacuation points for participants earlier (–1 *SD*) and later (+1 *SD*) in pregnancy (Aiken & West, 1991).

To examine the amount of variance in pregnancy outcomes explained by psychological, physical, evacuation, and financial strains, we performed regression analyses including all of the strain measures as well as separate regressions for each measure. The results of the latter analyses did not differ from those that included all of the strain measures, so only the results of the full model are presented here. If any of these measures predicted an outcome and the effects of distance or timing were reduced, this would suggest that the flood-related strain explains, at least in part, why distance or timing was associated with pregnancy outcome.

Results

Correlational analyses

Table 3 presents the bivariate correlations among all study variables for the sample. Consistent with previous research on the psychological effects of disasters during pregnancy (Glynn et al., 2004), there was a negative correlation between gestation age at flooding and psychological stress. So, women later in pregnancy at the time of the flood reported being less stressed. Interestingly, deliveries in which forceps or vacuum were used ("assisted" or "instrumental" deliveries) were significantly associated with lower birth weight (see Table 3). Therefore, we controlled for whether a birth was instrument assisted or not in following analyses.

Predicting pregnancy outcomes

Regressions showed that living closer to the flooding ($\beta = 0.05$) and the flood cresting earlier in gestation ($\beta = .06$, $ps > .40$) were not independently associated with birth weight. However, a distance by timing interaction significantly predicted birth weight

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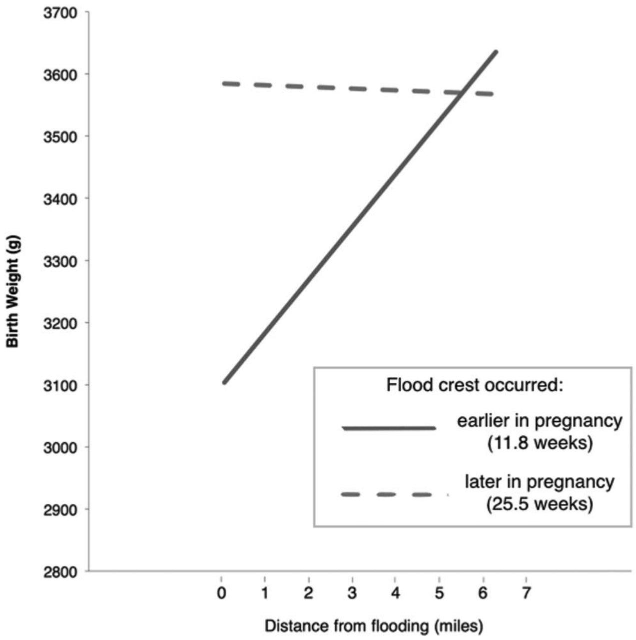

Figure 1. The interaction effect of distance from flooding by gestational timing of the flood crest on birth weight. Values are calculated for 1 *SD* above and below the mean of distance ($M = 3.7$ mi; $SD = 3.5$) and timing ($M = 18.6$ weeks; $SD = 6.8$). The solid line represents those who experienced the flood crest earlier in pregnancy (11.8 weeks) and the broken line represents those who experienced the flood crest later in pregnancy (25.5 weeks). SI conversion to km = mi × 1.6.

when controlling for GA (fetal growth), $\Delta R^2 = .05$, $\beta = -.22$, $p < .01$. The interaction is depicted in Figure 1.

Simple slope analyses showed that when the flood crested later in pregnancy (+1 $SD = 25.5$ weeks), the distance from flooding areas did not significantly predict birth weight, $\beta = -0.17$, $p > .10$ (Aiken & West, 1991). In contrast, when the flood crested earlier in pregnancy (−1 $SD = 11.8$ weeks), living 1 *SD* (3.5 mi) closer to flooding (−1 $SD = 0.2$ mi) was associated with a 148-g decrease in birth weight $\beta = 0.28$, $p < .01$.

When we added psychological, physical, evacuation, or financial strains as covariates in regression analyses the distance by timing interaction remained significant (see Table 4). None of these variables accounted for a significant amount of variance in birth weight. Therefore, these variables did not independently contribute to the prediction of birth weight and they did not meaningfully mediate the effects of objective flooding conditions on birth weight. Length of gestation was not significantly associated with distance from flooding, timing of the flood in gestation, or their interaction (*p*s >.13).

Subsample Analyses ($n = 84$)

In analyses of a subsample of women whose labors were not induced by means of medical intervention we found similar associations among flood timing, flood distance, and pregnancy outcomes.

The flood cresting earlier in gestation and distance from flooding did not independently predict birth weight controlling for GA, *p*s > .10. The distance by timing interaction was statistically significant $\Delta R^2 = .07$, $\beta = -.27$, $p < .01$ and the pattern of this interaction was similar to that depicted in Figure 1. Follow-up simple slope analyses confirmed that when the flood crest occurred earlier in pregnancy (−1 $SD = 12$ weeks), living 1 *SD* (3.31 mi) closer to flooding was associated with a 153-g decrease in birth weight, $\beta = .38$; $p < .01$. For women who experienced the flood crest later in pregnancy (+1 $SD = 26$ weeks), distance from flooding was not associated with birth weight, $\beta = -.15$; $p = .30$.

When we controlled for psychological, physical, evacuation, or financial strains as covariates in regression analyses, none of these variables accounted for the distance by gestational timing effect on fetal growth (see Table 4). As in the total sample, in the subsample length of gestation was not significantly associated with flooding (*p*s >.17).

Biparietal Growth Analysis

As a supplementary analysis, we examined a direct measure of fetal growth by analyzing ultrasound measures of fetal biparietal diameter over the course of pregnancy. We included data from participants who had more than one prenatal visit during which biparietal diameter was measured with ultrasound (psychosocial and outcome data were not required, $n = 169$). We controlled for medical risk, body mass index, and SES.

Because participants did not have the same number of ultrasounds or ultrasounds at the same times during pregnancy, we used multilevel modeling, which is robust to random missing data (Singer & Willett, 2003). Multilevel modeling allows for Level 1 units, here, ultrasound visits, to be nested within Level 2 units, here, participants.

The Level 1 predictors of biparietal diameter were date of ultrasound (time), time^2, time by pre/post crest (coded 0 for before the crest and 1 after the crest), and time^2 by pre/post crest. Time and time^2 were centered such that 0 was the crest of the river (i.e., March 28, 2009). A pre/post main effect was not included to allow for a common intercept. The Level 2 predictor was weeks gestation at crest. This variable was grand mean centered (Enders & Tofighi, 2007). Finally, the following cross-level interactions were included in the model: crest by time, crest by time^2, crest by time by pre/post, and crest by time^2 by pre/post. We predicted that biparietal diameter growth would change as a function of when the crest happened during the pregnancy.

There was a significant effect of time ($\gamma = .1909$, $t = 6.98$, $p < .001$), suggesting that as expected, biparietal diameter increased linearly over time. There was also a significant interaction between time ($\gamma = .1083$, $t = 2.68$, $p < .001$) and time^2 ($\gamma = -.0032$, $t = -2.70$, $p < .001$) and pre/post indicating that after the crest, growth continued linearly but decreased quadratically. More importantly there was a significant crest by time^2 by pre/post interaction ($\gamma = -.0002$, $t = 4.84$, $p < .001$) indicating that the change in growth following the flood crest depended on when during pregnancy the crest occurred.

To interpret this interaction as it related to our hypotheses we used regression equations to predict growth curves for those who experienced the crest early in pregnancy (i.e., week 11, −1 *SD*) and those who experienced it at the later, average time in pregnancy for the sample (Peacher, Curran, & Bauer, 2006). As shown in Figure 2, for participants who experienced the flood earlier in

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Table 4
Summary of Hierarchical Regression Analyses Predicting Birth Weight Controlling for GA (Fetal Growth) in the Full Sample and Spontaneous Labor Subsample

	Full sample (n = 136)			Spontaneous labor subsample (n = 84)		
Variable	*B*	*SE B*	β	*B*	*SE B*	β
Step 1						
Age	−27.54	47.30	−.05	−97.25	51.95	−.23^
SES	−3.74	44.07	−.01	12.50	51.94	.03
BMI	42.11	39.73	.08	25.84	41.52	.06
Parity[a]	28.00	44.16	.06	2.67	56.96	.01
Medical risk	11.38	46.41	.02	−2.03	42.39	−.01
Nicotine during[b]	−8.81	37.52	−.02	17.05	44.81	.04
Length of gestation	344.70	40.89	.62**	203.57	42.83	.51**
Assist labor/delivery[c]	−58.21	37.05	−.11	−98.07	38.05	−.24*
R^2		.42			.37	
F change		10.82**			5.32**	
Step 2						
Psychological strain	38.21	37.96	.08	−43.11	44.19	−.11
Evacuation strain	−9.56	38.87	−.02	−20.22	58.15	−.04
Physical strain	−32.74	36.85	−.07	−26.08	42.90	−.06
Financial strain	22.42	44.95	.04	44.61	41.53	.11
R^2		.43			.39	
F change		.55			.60	
Step 3						
Distance from flooding	34.59	44.44	.07	67.34	51.13	.17
GA at crest	27.32	40.86	.05	53.40	42.42	.13
R^2		.43			.42	
F change		.52			1.57	
Step 4						
Distance × GA at Crest	−128.85	39.27	−.23**	−104.92	37.96	−.27**
R^2		.48			.48	
F change		10.77**			7.64**	

Note. GA = gestational age; SES = socioeconomic status; BMI = body mass index. All predictors were z scored.
[a] 0 = nulliparous, 1 = multiparous. [b] 0 = no use during pregnancy, 1 = use during pregnancy. [c] 0 = noninduced labor and unassisted delivery (only the latter for the subsample), 1 = induced labor and/or instrumental delivery (only the latter for the subsample).
^ $p < .10$. * $p < .05$. ** $p < .01$.

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their pregnancies a previously steady growth in biparietal diameter slowed. Experiencing the flood crest at 18 weeks gestation was associated with a continuous, steady increase in biparietal growth before and after the flood crest.

Discussion

This is the first study to show that, closer residential proximity to a major flood predicted lower birth weight when accounting for medical risk factors (Danziger, Silverwood, & Koupil, 2011). In particular, flooding was a stronger risk factor for decreased fetal growth in pregnancies that were in earlier stages of gestation. This effect held up with birth weight and ultrasound growth parameters as outcomes.

Confirming evidence from ultrasound readings revealed that, on average, fetal biparietal growth was slowed postflood crest for women who were relatively early in pregnancy (11 weeks) during the crest, but not for those who were later in pregnancy (18 weeks). These findings are consistent with the evidence that experiences of a catastrophe earlier in pregnancy have greater maternal and pregnancy outcome impacts, and extend this literature to flooding, a disaster not previously studied (Glynn et al., 2004). The ultrasound analyses show that the flood crest clearly preceded the reduction in biparietal growth. Also, contrary to expectations, we found no evidence that flood distance or timing were associated with length of gestation. Together, our results provide convincing evidence that the flood caused a decrease in fetal growth.

We examined four specific pathways by which major flooding could have influenced fetal growth—by creating physical, financial, or evacuation strain, or by leading to an increase in nicotine use (Parslow & Jorm, 2006). We also considered whether general stress, which would likely be affected by flooding, could explain the effects of distance on outcomes. Because these data were reported by women who had very recently experienced and, in many cases, still were experiencing the effects of the historic flood, we were fairly confident in the reliability of the self-report data.

Physical, evacuation, and financial strains (to a lesser extent) were associated with distance from flooding and psychological stress was associated with the timing of flooding. However, none of these flood-related strain variables were associated with pregnancy outcomes, and therefore they did not explain how flood distance or timing affected fetal growth. Also, we found no associations between nicotine use and flooding or pregnancy outcomes,

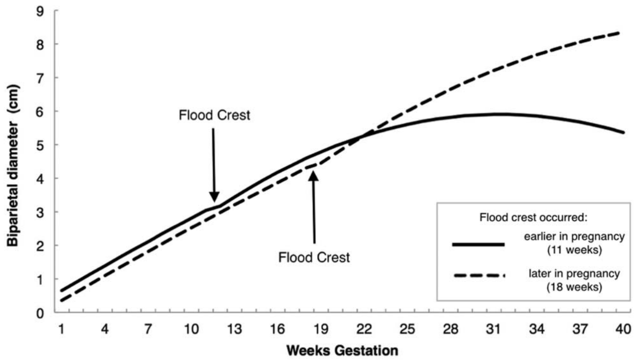

Figure 2. Biparietal growth trajectories modeled using multivariate linear modeling techniques before and after flood crest for women at 11 weeks gestation and 18 weeks gestation during the crest. The solid line represents those who experienced the flood crest earlier in gestation (11 weeks) and the broken line represents those who experienced the flood crest later in gestation (18 weeks).

perhaps due to a low number of prepregnancy smokers in the sample ($n = 11$).

Research on stress and pregnancy has shown that domain-specific stresses can differentially predict pregnancy outcomes. For instance, stress about the particular pregnancy is a potent predictor of gestation length, and experiences of racism have predicted fetal growth for African American women (Hilmert et al., 2014). It is possible that a measure of major disaster-specific stress that asks, for example, "How worried are you that the flood will affect your pregnancy?" or "How confident are you in your ability to cope with the effects of the flood?" could explain some of the flood impact on pregnancy outcome. Also, there may be a critical moment(s) when a disaster has its greatest impact on pregnancy; psychosocial status may be most predictive of pregnancy outcomes during the anticipation of a natural disaster, during the disaster, after the disaster, or a combination of these in a cumulative fashion, perhaps depending on the disaster.

Of note, this study did not consider clinically classified low birth weight (<2,500 g; $n = 5$, 2.7%) or preterm birth (<37 weeks gestation; $n = 15$, 7.7%). Instead, we used continuous measures of birth weight and length of gestation, which even in the normal range have been associated with adverse developmental outcomes (Danziger et al., 2011). Because participants were all receiving prenatal health care, the sample was relatively low risk. By using continuous variable outcomes and accounting for medical risk factors in a low risk sample we were able to focus on the impact of the disaster on pregnancy outcomes. The pregnancies of women who are at higher risk of adverse pregnancy outcomes, perhaps due to a lack of access to prenatal care, may be more severely affected by a stressful natural disaster than those in this study.

An important objective of health care disaster management is to identify populations put at risk by the disaster to employ appropriate and effective health care and recovery plans (McCaughrin & Mattammal, 2003). Our study suggests that being closer to areas of flooding while in the first or early second trimester of pregnancy may characterize one such population. Furthermore, our study suggests that physical exertion, evacuation and financial strains associated with the disaster, and general stress did not account for the effects of flooding on birth weight. Further research is needed. In particular, we believe that future research should focus on the moderating role of subjective stress on disaster, pregnancy health associations. Also, our sample was from a relatively low-risk, healthy population receiving prenatal care. Research needs to consider the impact of a major flood on an at-risk population or on women with high-risk pregnancies, which may be much more severe.

In this study, flooding had an impact on birth weight, but not on length of gestation. Therefore, it appears that the underlying biopsychosocial variables affected by the flood were independent of stress-related variables associated with length of gestation (e.g., stress-related hormones; Sandman et al., 2006). Our previous work has implicated cardiovascular functioning as a potential pathway linking stress to fetal growth (Hilmert et al., 2014; Hilmert et al., 2008). Perhaps the consequences of being near a flood early in pregnancy were more cardiovascular than neuroendocrine in nature. Stress physiology during natural disasters could be an enlightening avenue for future research.

At this point, our results suggest that focusing on reducing physical exertion and evacuation or financial strains and stress in general may not avoid the adverse impact of a disaster on fetal growth. Future studies can focus on other important resources that may be compromised by a major flood, including the presence and support of others who are instead focused on coping with an unavoidable disaster. Also, disaster-specific education and coping skills may alleviate pressures that were not detected in the current study.

Flooding adversely affects pregnancy outcomes and has a nondiscriminating global presence. The biopsychosocial impacts a natural disaster can have on a person affords many potential pathways by which the disaster can affect a pregnancy. It is important that we continue to search for factors that link catastrophic events like this to decreased fetal growth so that we might be able to better target those factors and protect pregnancies.

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