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Effects of maternal exposure to acute stress on birth outcomes: a quasi-experiment study

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Abstract

Numerous studies have shown associations between maternal stress and poor birth outcomes, but evidence is unclear for causal inference. Natural disasters provide an opportunity to study effects of quasi-randomized hardship with an accurate measure of onset and duration. In a population-based quasi-experimental study, we examined the effect of maternal exposure to the January 1998 Québec ice storm on birth outcomes by comparing pregnant mothers who lived in an area hard hit by the ice storm with those in two unaffected regions. In a total of 147,349 singleton births between 1995 and 2001, we used a difference-in-differences method to estimate the effects of the ice storm on gestational age at delivery (GA), preterm birth (PTB), weight-for-gestational-age *z*-scores (BWZ), large for gestational age (LGA), and small for gestational age (SGA). After adjusting for maternal and sociodemographic characteristics, there were no differences between the exposed and the unexposed mothers for birth outcomes. The estimated differences (exposed vs. unexposed) were 0.01 SDs (95% CI: −0.02, 0.05) for BWZ; 0.10% point (95% CI: −0.95%, 1.16%) for SGA; 0.25% point (95% CI: −0.78%, 1.28%) for LGA; −0.01 week (95% CI: −0.07, 0.05) for GA; and 0.16% point (95% CI: −0.66%, 0.97%) for PTB. Neither trimester-specific nor dose–response associations were observed. Overall, exposure to the 1998 Québec ice storm as a proxy for acute maternal stress in pregnancy was not associated with poor birth outcomes. Our results suggest that acute maternal hardship may not have a substantial effect on adverse birth outcomes.

Introduction

Studies have reported links between maternal stress to several health problems in offspring, such as cognitive and behavioral problems, autistic disorders, and attention deficit hyperactivity disorder.[1–7] A positive link between maternal stress during pregnancy and poor birth outcomes has also been reported in some[8–13] but not all studies.[14–17] Previous research has also described positive associations between maternal exposure to stress in preconception and adverse outcomes in offspring, including prematurity,[18] low birth weight,[12,13] and early mortality.[19,20] Studies have considered several forms of stress, including job-related stress,[21] domestic violence,[22,23] neighborhood stress,[24,25] self-reported perceived stress,[8,9] chronic and cumulative stress,[10,11] and stressful life events.[9,12,13] In addition to heterogenous measures of maternal stress, other methodological and conceptual issues of the literature make our understanding limited. First, most previous studies were observational, and using convenience samples, making it difficult to draw causal conclusions as exposure to stress conditions among pregnant women were not random and thus subject to confounding bias. Second, most have relied on self-reported stress symptoms[8–11,14,21] that could be highly subjective and vulnerable to recall bias and confounding by maternal personality trait and health status. Third, many of these studies did not differentiate between acute and chronic stress, nor did they consider dose–response effects. Finally, studies rarely obtained accurate measures of the onset and duration of stress, and it is unclear whether the effect of maternal stress is confined to certain sensitive time windows in pregnancy.

Natural disasters provide a unique opportunity to study effects of sudden-onset, quasi-randomized stressors that often affect large numbers of individuals.[4] These natural experiments also enable investigators to identify the exposed time during gestation sensitive to the exposure with accurately measured onset and duration of the event.[4] Although some studies have exploited the natural experiment design to assess the effects of acute maternal stress on birth outcomes, many were either based on small samples (n ≈ 70–170) [26,27] or lacking a control group for comparison.[26–31] In addition, results are inconsistent across studies.[26–29,32–34]

Using exposure to the 1998 Québec ice storm as a proxy measure of acute maternal stress, we aimed to determine the effect of exposure to acute maternal stress on birth outcomes in a population-based natural experiment study. Our aims were threefold: (1) to estimate overall effects of the exposure, (2) to examine whether there is specific time in gestation particularly vulnerable to the exposure, and (3) to examine the magnitude of dose–response effects of the exposure.

Methods

Settings

This study utilizes one of the worst and costliest natural disasters in Canadian history. Between January 4 and 10 in 1998, a severe ice storm hit parts of the southern region of the province of Québec, Canada, leaving more than 1.4 million households without power for up to 6 weeks during one of the coldest months of the year.[35–37] The Montérégie region of Québec (MRQ) was one of the hardest-hit regions and experienced the longest power outages (up to 45 days). In this study, we compared population-level birth data between the MRQ and two regions in Québec similar in demographics to the MRQ, but unaffected by the ice storm or other disaster during that time: the Lower Saint Lawrence (LSL) and the Québec Capital Region (QCR). MRQ is primarily a rural area with some small cities, towns, and suburban communities, with a total population of 1,603,232 in 2020.[38] The LSL is also mainly a rural area (with two cities; 2020 population was 197,987), whereas the QCR includes the greater Quebec City area, small towns, and rural areas (2020 population was 757,065).[38] The population in these three areas was stable between 1995 and 2001 (lost approximately <2% of their citizens each year), and they had a similar distribution of income, occupation, and education.[39] We identified all singleton live births (n = 147,695) born in the three regions in 1995–2001 and obtained their birth records via the Institut de Statistique du Québec (ISQ). Ethics approval was received from the Douglas Mental Health University Institute Research Ethics Board at McGill University.

Exposure

Based on gestational age (GA; completed weeks) and date of birth recorded on birth records, we identified conception week (birth week minus GA at birth in weeks). All births conceived up to 42 weeks before the first week of January 1998 were considered exposed to the ice storm at any time in gestation (Fig. 1). We defined trimester-specific exposures according to the conception week relative to the first week of January 1998 – first, second, and third trimester exposures were defined as births conceived 0–12, 13–28, and 29–42 weeks before the first week of January 1998, respectively, and preconception exposure included births conceived in the first 12 weeks of 1998. All births between 1995 and 2001 conceived outside this exposure window were considered unexposed.

For dose–response analysis in the exposed births, we used the number of days of power outage that was calculated by the ISQ using algorithms according to data on the impacts of the ice crisis from three sources – *Enquête sur la santé des populations de 1998* by the Québec government, and Project Ice Storm surveys in 1998 and 2018.[40,41] (see Fig. S1 for further details). The number of days without power was originally provided by ISQ in ten categories (Fig. S1), which we then simplified into eight categories to ensure enough numbers in each category (Table 1).

Birth outcomes

Our birth outcomes included: GA at birth in completed week based on the first-trimester ultrasound[42]; preterm birth (PTB, <37 weeks of gestation); sex-specific birthweight-for-gestational-age *z*-scores (BWZ) based on a Canadian reference[43]; and small for gestational age (SGA) and large for gestational age (LGA) births defined as weighing less than 10% and greater than 90% of the birthweight of infants of the same sex and GA, respectively, classified according to the Canadian reference.[43]

Covariates

Covariates included in our study were: child's sex, maternal age in years, parity (number of previous live births categorized as primiparous, 1, 2, or 3 or more), mother's education (no high school diploma (<11 years), Québec high school diploma (11 years), some postsecondary (12–13 years), some university or more (>14 years), or missing), mother's marital status at birth (single, married or living with a partner, or other (widowed, divorced, or separated)), mother's province or country of birth (Québec, elsewhere in Canada, outside Canada, or unknown), mother's native language (French, English, other, or missing), father's age (<25, 25–29, 30–34, 35–39, 40+ years, or missing), and father's native language (French, English, other, or unknown). All covariates were obtained from birth records.

Statistical analysis

We estimated the association between maternal exposure to the Québec 1998 ice storm and birth outcomes using the difference-in-differences (DD) analysis, a quasi-experimental method that is typically used to evaluate the effect of a policy change on health outcomes while accounting for unmeasured secular trends.[44] Instead of comparing the rate of adverse birth outcomes in MRQ before and after the ice storm (i.e., a pre-post design in the affected region only), the DD analysis uses an external control region (LSL/QCR) to provide a counterfactual for what would have happened to the exposed region in the absence of the exposure to the ice storm. The DD analysis compares the *difference* in a given birth outcome between the exposed and the unexposed regions before and after the exposure (*differences*), that is, changes in birth outcomes between regions potentially brought by the exposure, rather than time-invariant exposures that differs across regions.[45] It estimates changes in the exposed region (MRQ) that is above and beyond changes occurring in the control regions (LSL/QCR) during the same period, assuming those changes would have remained identical between regions had there been no ice storm.[46] This method uses information from all regions (MRQ and control regions) to estimate a common time trend in birth outcomes that is subtracted from the changes in birth outcomes in the exposed region (MRQ) (see Fig. 2 for illustration).[46] By comparing *changes* in birth outcomes between the unexposed period vs. 1998 (the exposed) in the MRQ to *changes* between the two time periods in the control regions (LSL/QCR), the DD model removes bias due to (a) temporal trends in birth outcomes, (b) time-invariant differences between the exposed (MRQ) and the control regions, and (c) potential confounders common to all regions.[47] We ensured the homogeneity of the two regions (LSL and QCR) to combine as a single control group by comparing in population characteristics over time (Table S1).

For the primary analysis, we used births that occurred in the 3 years before the ice storm as the unexposed (i.e., births in 1995–

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Table 1. Characteristics of the study sample and by region and period (n = 147,349)

		Montérégie region			Control regions (LSL and QCR)		
Characteristic	Total sample	1995–1997	1998	1999–2001	1995–1997	1998	1999–2001
Number of births	147,349	43,761	13,074	37,279	24,738	7384	21,113
Birth weight, μ (SD)	3385.7 (536.8)	3370.7 (535.4)	3384.1 (540.2)	3396.4 (532.0)	3380.0 (539.8)	3388.5 (545.0)	3404.2 (538.3)
Birthweight *z*-score, μ (SD)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.1 (1.0)
Small for gestational age (SGA)							
No	133,597 (90.7)	39,237 (89.7)	11,807 (90.3)	34,071 (91.4)	22,292 (90.1)	6712 (90.9)	19,478 (92.3)
Yes	13,752 (9.3)	4524 (10.3)	1267 (9.7)	3208 (8.6)	2446 (9.9)	672 (9.1)	1635 (7.7)
Large for gestational age (LGA)							
No	133,802 (90.8)	40,054 (91.5)	11,898 (91.0)	33,703 (90.4)	22,545 (91.1)	6678 (90.4)	18,924 (89.6)
Yes	13,547 (9.2)	3707 (8.5)	1176 (9.0)	3576 (9.6)	2193 (8.9)	706 (9.6)	2189 (10.4)
Gestational age, μ (SD)	39.0 (1.8)	39.1 (1.8)	39.0 (1.8)	39.0 (1.8)	39.0 (1.8)	39.0 (1.8)	38.9 (1.8)
Preterm birth							
No	138,308 (93.9)	41,084 (93.9)	12,281 (93.9)	35,024 (94.0)	23,242 (94.0)	6932 (93.9)	19,742 (93.5)
Yes	9044 (6.1)	2677 (6.1)	793 (6.1)	2255 (6.0)	1496 (6.0)	452 (6.1)	1371 (6.5)
Child's sex							
Male	75,619 (51.3)	22,395 (51.2)	6685 (51.1)	19,149 (51.4)	12,673 (51.2)	3814 (51.7)	10,903 (51.6)
Female	71,730 (48.7)	21,366 (48.8)	6389 (48.9)	18,130 (48.6)	12,065 (48.8)	3.570 (48.4)	10,210 (48.4)
Maternal age, μ (SD)	28.4 (5.1)	28.3 (5.1)	28.3 (5.2)	28.3 (5.2)	28.4 (5.0)	28.5 (5.1)	28.5 (5.1)
Maternal age							
<20	6024 (4.1)	1986 (4.5)	571 (4.4)	1610 (4.3)	866 (4.6)	249 (3.4)	742 (4.8)
20–24	28,382 (19.3)	8233 (18.8)	2545 (19.5)	7489 (20.1)	4613 (22.9)	1410 (19.1)	4092 (24.9)
25–29	51,786 (35.1)	15,439 (35.3)	4488 (34.3)	12,871 (34.5)	8790 (34.8)	2639 (35.7)	7559 (36.5)
30–34	43,444 (29.5)	13,236 (30.2)	3888 (29.7)	10,503 (28.2)	7662 (27.8)	2143 (29)	6012 (24.2)
35+	17,713 (12.0)	4867 (11.1)	1582 (12.1)	4806 (12.9)	2807 (9.9)	943 (12.8)	2708 (9.6)
Mother's years of education							
No high school diploma (<11 years)	14,994 (10.2)	5228 (11.9)	1547 (11.8)	3873 (10.4)	2146 (8.6)	562 (7.6)	1638 (7.8)
High school diploma (11 years)	15,732 (10.7)	4882 (11.1)	1354 (10.4)	3560 (9.6)	2189 (8.9)	1077 (14.6)	2670 (12.7)
Some post-secondary (12–13 years)	32,144 (21.8)	11,283 (25.8)	2966 (22.7)	7935 (21.3)	5623 (22.6)	1220 (16.5)	3117 (14.8)
Some university or more (>14 years)	74,753 (50.7)	20,574 (47.1)	6502 (49.7)	19,014 (51)	12,130 (48.8)	4238 (57.4)	12,295 (58.2)
Missing	9726 (6.6)	1794 (4.1)	705 (5.4)	2897 (7.8)	2650 (11.1)	287 (3.9)	1393 (6.6)
Mother's marital status							
Single	84,317 (57.2)	22,694 (51.9)	7413 (56.7)	22,274 (59.7)	13,619 (55.2)	4538 (61.5)	13,779 (65.3)

(*Continued*)

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Table 1. (*Continued*)

Characteristic	Total sample	Montérégie region			Control regions (LSL and QCR)		
		1995–1997	1998	1999–2001	1995–1997	1998	1999–2001
Married	58,402 (39.6)	19,405 (44.3)	5220 (39.9)	13,809 (37.1)	10,418 (42.0)	2663 (36.1)	6887 (32.6)
Other	4630 (3.1)	1662 (3.8)	441 (3.4)	1196 (3.2)	701 (2.8)	183 (2.5)	447 (2.1)
Parity							
0	67,544 (45.8)	18,837 (43.1)	5689 (43.5)	17,051 (45.7)	11,786 (47.6)	3648 (49.4)	10,533 (49.9)
1	54,910 (37.3)	16,439 (37.5)	5030 (38.5)	14,063 (37.7)	8938 (36.1)	2730 (37.0)	7710 (36.5)
2	18,359 (12.5)	6298 (14.4)	1728 (13.2)	4492 (12.1)	3021 (12.2)	721 (9.8)	2099 (9.9)
3+	6536 (4.4)	2187 (5.0)	627 (4.8)	1673 (4.5)	993 (4.0)	285 (3.9)	771 (3.7)
Mother's country of birth							
Quebec	133,249 (90.4)	38,799 (88.7)	11,601 (88.7)	33,191 (89)	23,163 (93.6)	6903 (93.5)	19,592 (92.8)
Elsewhere in Canada	4350 (3.0)	1621 (3.7)	475 (3.6)	1351 (3.6)	364 (1.5)	117 (1.6)	422 (2.0)
Outside Canada	8454 (5.7)	2752 (6.3)	933 (7.1)	2618 (7)	839 (3.4)	333 (4.5)	979 (4.6)
Unknown	1296 (0.9)	589 (1.3)	65 (0.5)	119 (0.3)	372 (1.5)	31 (0.4)	120 (0.6)
Mother's native language							
French	132,134 (89.7)	37,562 (85.8)	11,355 (86.9)	32,392 (86.9)	23,541 (95.2)	7073 (95.8)	20,211 (95.7)
English	8202 (5.6)	3711 (8.5)	1004 (7.7)	2813 (7.6)	352 (1.4)	99 (1.3)	223 (1.1)
Other	5352 (3.6)	2155 (4.9)	609 (4.7)	1704 (4.6)	464 (1.9)	84 (1.1)	336 (1.6)
Unknown	1661 (1.1)	333 (0.8)	106 (0.8)	370 (1.0)	381 (1.6)	128 (1.7)	343 (1.6)
Father's age, μ (SD)	31.1 (5.7)	31.0 (5.6)	31.1 (5.8)	31.1 (5.9)	31.3 (5.5)	31.3 (5.6)	31.4 (5.7)
Father's age							
<25	15,735 (10.7)	4673 (10.7)	1515 (11.6)	4453 (11.9)	2306 (11.3)	688 (9.3)	2100 (12.6)
25–29	41,151 (27.9)	12,464 (28.5)	3521 (26.9)	10,379 (27.8)	6781 (27.4)	2104 (28.5)	5902 (30.1)
30–34	49,281 (33.4)	15,150 (34.6)	4361 (33.4)	11,770 (31.6)	8700 (34.7)	2443 (33.1)	6857 (30.5)
35–39	25,335 (17.2)	6962 (15.9)	2268 (17.3)	6555 (17.6)	4369 (16.9)	1317 (17.8)	3864 (16.7)
40+	10,205 (6.9)	2738 (6.3)	890 (6.8)	2772 (7.4)	1621 (6.3)	539 (7.3)	1645 (6.6)
Missing	5642 (3.8)	1774 (4.1)	519 (4.0)	1350 (3.6)	961 (3.4)	293 (4.0)	745 (3.5)
Father's native language							
French	126,536 (85.9)	148,727 (82)	10,826 (82.8)	123,895 (83)	22,639 (91.5)	6800 (92.1)	19,479 (92.3)
English	8199 (5.6)	3703 (8.5)	984 (7.5)	2868 (7.7)	292 (1.2)	103 (1.4)	249 (1.2)
Other	5653 (3.8)	2230 (5.1)	664 (5.1)	1824 (4.9)	498 (2)	87 (1.2)	350 (1.7)
Unknown	6961 (4.7)	1961 (4.5)	600 (4.6)	1662 (4.5)	1309 (5.3)	394 (5.3)	1035 (4.9)
Number of days without electricity, Montérégie region, 1998 births (n = 13,019)[a]	–	–	–	–	–	–	–

Table 1. (*Continued*)

< 4 days	1383 (10.6)
4.1–7 days	2195 (16.9)
7.1–10 days	2115 (16.2)
10.1–13 days	1677 (12.9)
13.1–16 days	1178 (9.0)
16.1–21 days	1826 (14.0)
21.1–26 days	1746 (13.4)
>26 days	899 (6.9)

[a]Power outage associated with the ice storm did not occur in the control regions and in other time period than the ice storm year.

1997), and all births exposed to the ice storm at any time *during pregnancy* as the exposed (i.e., births conceived in the 42 weeks preceding the week of the ice storm (first week of January 1998)). We used linear regression models for all outcomes (i.e., linear probability models for binary outcomes) of the form:

$$Y_{irp} = \beta_0 + \beta_1 * \text{MRQ} + \beta_2 * \text{Period} + \beta_3 * \text{MRQ} * \text{Period} + \beta_4 * X_{irp} + \varepsilon_{irp},$$

where Y_{irp} is the birth outcome for individual i in region r during period p. β_0 represents the mean outcome (mean prevalence for binary outcomes) before the ice storm in the control regions; β_1 represents the difference in outcomes between the exposed and control regions in the pre-ice storm period; β_2 represents the difference in outcome between 1998 births and the pre-1998 births in the control regions; β_3 is the parameter of interest for which birth is within the exposure period (exposed births to the ice storm in 1998) in the exposed region (MRQ); X_{irp} represents a vector of individual-level covariates.

A key underlying assumption of the DD analysis is that the pre-post differences in outcomes would have been stable over time and similar between exposed and control regions in the absence of the ice storm (i.e., changes in birth outcomes that are due to factors other than the ice storm do not differ between the exposed and control regions).[48,49] To assess the validity of this assumption, we visually examined annual, seasonal, and monthly trends in birth outcomes during the pre-ice storm period (1995–1997) in the exposed and control regions.

To identify the trimester-specific associations, we performed the DD analysis stratified by the timing of exposure shown in Fig. 1. For the dose–response analysis, our analysis was restricted to all births in the MRQ region only over the 7-year period. Using standard multivariable regression analyses, we estimated mean differences in outcomes using linear regression for continuous outcomes and risk ratios using log-binomial regression for binary outcomes across categories of the number of days without power.

We carried out several additional analyses to examine the robustness of primary analysis results. First, we used births between 1999 and 2001 (i.e., the post-ice storm births) as the unexposed to compare outcomes with the exposed births in 1998. Second, we repeated the DD analysis in births from all years (1995–2001) with the birth year as the time indicator, assuming that all births in 1998 in MRQ were exposed to the ice storm either in pregnancy or in preconception. We also repeated the DD analysis using log-binomial regression analysis for binary outcomes to calculate risk ratios. Finally, we examined associations with birthweight in grams among term births only (>37 completed weeks), minimizing the effect of GA on the association with birth weight. All statistical analyses were conducted using Stata version 14.2 (StataCorp, College Station, TX, USA).

Results

Sample characteristics

After excluding births with missing information on birthweight or GA (n = 204) and births with implausible birthweight and GA combination identified based on the Alexander method (n = 142),[50] our analytical sample included 147,349 births. Of the 13,074 births in MRQ in 1998, 3072 were exposed in their first trimester, 4346 exposed in second trimester, and 2715 in third

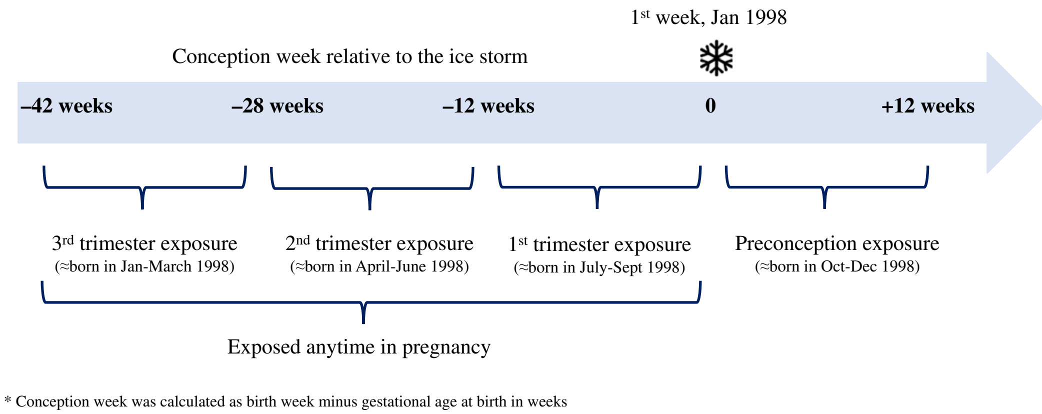
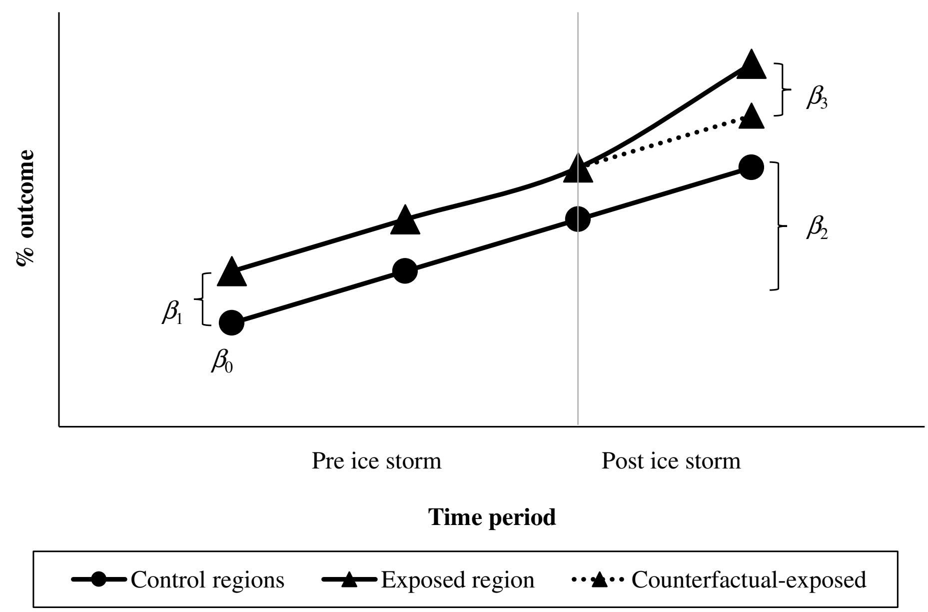


Fig. 1. Exposure definition according to conception week.



Notes: This figure illustrates a hypothetical example of the difference-in-differences method. The solid line for the exposed region represents observed changes in adverse birth outcomes in the exposed region, assuming that exposure to the ice storm increases the risk of adverse birth outcomes. The dashed line represents changes in adverse birth outcomes that would have been observed in the exposed region "the counterfactual" if it was not exposed to the ice storm. The line for the control regions represents observed changes in adverse birth outcomes in control regions (unexposed to the ice storm). β_0 represents the mean birth outcome (mean prevalence for binary outcomes) before the ice storm in the control regions. β_1 represents the difference in birth outcomes between the exposed and control regions in the pre-ice storm period. β_2 represents the difference in outcome between births in the ice storm year (1998 births) and the pre-ice storm births in the control regions. β_3 is the parameter of interest for which birth is within the exposure period (exposed births to the ice storm in 1998) in the exposed region.

Fig. 2. Illustration of the difference-in-differences analysis.

trimester, and most of those exposed births were born in January–September 1998. Taken together with births exposed in the preconception (n = 2793 born in 1998), almost all births (~99%) in MRQ in 1998 were exposed either in pregnancy (78%) or in preconception (21%).

Table 1 shows the characteristics of the overall sample and by period (1998 vs. other years) and region. The mean birthweight for the whole sample was 3386 g (SD = 536.8) and mean GA at birth was 39.0 weeks (SD = 1.8). Approximately 6% of births were preterm, and this proportion was relatively stable across years and regions. Around 9% of all births were SGA or LGA, but rates of SGA births were declining over time in all regions while rates of LGA were gradually increasing across regions (see Table S1). The majority of women (71%) had at least some postsecondary

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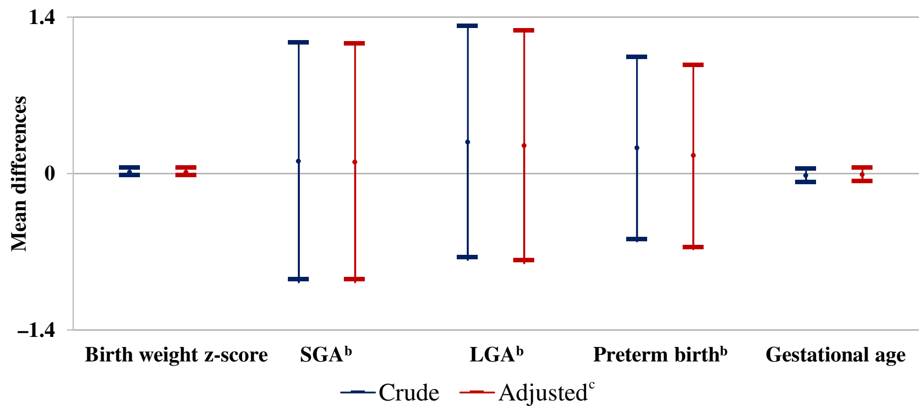

Notes
^a Values above represent the coefficients of the interaction term between mother giving birth in the area exposed to the ice storm (Montérégie region) and whether the year of birth is within the exposure period (exposed births in 1998). Analyses involved crude and multivariable linear models (i.e. linear probability models for binary outcomes).
^b Coefficients for binary outcomes were multiplied by 100 and therefore represent a change in percentage points.
^c Adjusted model include the following covariates: mother's education, age, parity, marital status, country of birth, and native language, father's age and native language, and infant's sex.

Fig. 3. Association of exposure to the 1998 Quebec Ice Storm with birth outcomes (n = 84,351).

education, and most of them (≈90%) were born in Québec, speaking French as their first language. Of those exposed to the ice storm in MLQ, more than half (≈57%) had power outage for less than 14 days, while 7% of women experienced more than 26 days without power.

Difference-in-differences model assumptions

Annual trends of birth outcomes during the pre-ice storm period (1995–1997) of exposed and control regions were roughly parallel for all outcomes except for PTB (Fig. S2). Nevertheless, monthly trends (smoothed using 3 months moving averages) of all outcomes including PTBs were overlapping between regions with no clear evidence of a violation of the parallel trend assumption (Fig. S3). We also examined monthly trends in birth outcomes by year and region for any seasonal variation in birth outcomes and found no systematic differences between regions (Fig. S4). Furthermore, observed characteristics were similar in the exposed and control regions over the years (Tables 1 and S1), which also indicate the violation of parallel trend assumption is unlikely.

Effects of exposure to the Québec 1998 ice storm on birth outcomes

Exposure to the ice storm during pregnancy was not associated with poor birth outcomes in either crude or adjusted analyses. Associations adjusted for sociodemographic characteristics were 0.01 SDs (95% CI: −0.02, 0.05) for birthweight *z*-scores; 0.10% point (95% CI: −0.95%, 1.16%) for SGA; 0.25% point (95% CI: −0.78%, 1.28%) for LGA; −0.01 week (95% CI: −0.07, 0.05) for GA; and 0.16% point (95% CI: −0.66%, 0.97%) for PTB (Fig. 3). Trimester-specific associations were also close to the null in both crude and adjusted analyses (Table 2). Although some associations for preconception exposure were statistically significant, their effect estimates were very small with minimal clinical importance. Results were similar in our sensitivity analyses using the post-ice storm period (1999–2001) or with the birth year as the time indicator as well as performing log-binomial regression analysis for binary outcomes (Tables S2–S4). Birthweight (g) was also not associated with the exposure among term births (Table S5).

Associations between the number of days without power and birth outcomes

Fig. 4 shows dose–response associations for continuous (mean differences) and binary (risk ratios) outcomes. Overall, analyses did not show any evidence of increased risks of poor birth outcomes with extended power outage in either crude or adjusted analyses among women exposed to the ice storm.

Discussion

We examined the effects of exposure to the 1998 ice storm in Québec as a proxy measure of acute maternal hardship on birth outcomes using the quasi-experimental DD analysis in a population-based sample of singleton live births in three regions over a 7-year period. We found that prenatal exposure to the ice storm was not associated with any of the birth outcomes examined in the study. In addition, neither trimester-specific effects nor dose–response associations were observed.

Consistent with our results, several studies of the effects of natural and human-made disasters have found no associations with poor birth outcomes.[28,32,33,51–53] For example, two large population-based cohort studies in the US comparing outcomes of births before and after the September 11 terrorist attacks found no increased risk of PTB in those exposed *in utero*.[51,52] Likewise, Hetherington *et al.*[33] found no increased risk of PTB or SGA in women exposed to the 2013 Calgary flood. However, some have reported an increased risk of adverse birth outcomes – mostly low birth weight – after exposure to natural disasters.[31,34,54,55] Two previous studies examined associations between the Québec 1998 ice storm and birth outcomes.[27,42] A population-based study by Auger *et al.*[42] examined rates of PTB in three

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Table 2. Trimester-specific associations of exposure to 1998 Quebec ice storm with birth outcomes[a]

Outcome	First trimester (n = 73,283)[b]		Second trimester (n = 75,275)[c]	
	Crude	Adjusted	Crude	Adjusted[d]
Gestational age	−0.04 (−0.15, 0.07)	−0.04 (−0.15, 0.07)	0.00 (−0.09, 0.09)	0.01 (−0.08, 0.10)
Preterm birth[e]	0.44 (−1.02, 1.90)	0.45 (−1.01, 1.90)	−0.21 (−1.44, 1.02)	−0.30 (−1.54, 0.93)
Birthweight *z*-score	−0.03 (−0.05, 0.02)	−0.01 (−0.07, 0.04)	0.03 (−0.02, 0.08)	0.03 (−0.02, 0.08)
SGA[e]	0.64 (−1.19, 2.47)	0.77 (−1.04, 2.59)	−0.14 (−1.63, 1.36)	−0.13 (−1.62, 1.36)
LGA[e]	−0.59 (−2.34, 1.15)	−0.69 (−2.42, 1.05)	1.15 (−0.35, 2.65)	1.10 (−0.39 2.60)
Outcome	Third trimester (n = 72,791)[f]		Preconception (n = 73,090)[g]	
	Crude	Adjusted	Crude	Adjusted
Gestational age	−0.01 (−0.10, 0.08)	0.00 (−0.09, 0.09)	0.15 (0.03, 0.26)	0.15 (0.04, 0.27)
Preterm birth[b]	0.66 (−0.49, 1.81)	0.51 (−0.65, 1.66)	−1.62 (−3.15, 0.08)	−1.61 (−3.15, 0.07)
Birthweight *z*-score	0.00 (−0.06, 0.06)	0.01 (−0.06, 0.07)	−0.03 (−0.09, 0.03)	−0.04 (−0.10, 0.02)
SGA[e]	0.08 (−1.98, 1.82)	−0.22 (−2.12, 1.67)	0.27 (−1.50, 2.03)	0.43 (−1.33, 2.19)
LGA[e]	−0.10 (−1.96, 1.75)	−0.04 (−1.88, 1.81)	−1.56 (−3.42, 0.30)	−1.72 (−3.57, 0.14)

[a]Values above represent the regression coefficients of the interaction term between mother giving birth in the area exposed to the ice storm (Montérégie region) and whether the year of birth is within the exposure period (exposed births in 1998). Analyses involved crude and multivariable linear models (i.e., linear probability models for binary outcomes).
[b]First-trimester exposure included births conceived 0–12 weeks before the ice storm (n = 4784). The reference included 1995–1997 births (n = 68,499).
[c]Second-trimester exposure included births conceived 13–28 weeks before the ice storm (n = 6776). The reference included 1995–1997 births (n = 68,499).
[d]Adjusted models include the following covariates: mother's education, age, parity, marital status, country of birth, and native language, father's age and native language, and infant's sex.
[e]Coefficients for binary outcomes were multiplied by 100 and therefore represent a change in percentage points.
[f]Third-trimester exposure excluded births conceived 29–42 weeks before the ice storm (n = 4292) The reference included 1995–1997 births (n = 68,499).
[g]Preconception exposure included births conceived 0–12 after the ice storm (n = 4591). The reference included 1995–1997 births (n = 68,499).

periods (1993–1997, 1998, 1999–2003) and five regions in Québec and found slightly increased odds of PTB in those born in the hardest-hit area (OR~ = 1.27; 95% CI: 0.81–2.02) than in areas less severely affected by the storm. Project Ice Storm is the longest cohort study of the Québec 1998 ice storm following up women from the Montérégie who were pregnant during the storm or who became pregnant in the following 3 months (n = 172) and their children. In this exposed cohort, Dancause found that mothers exposed to the storm in the first or second trimester of pregnancy had slightly shorter pregnancies and lighter babies compared to those exposed in the third trimester or in preconception (exposure timing explained 1.7% of the variance in birth weight and GA), and the lowest birth weights were for those with severe prenatal stress symptoms exposed in mid-pregnancy.[27]

Several explanations may account for the lack of associations observed in our study. Our definition of acute maternal stress based on the date of the ice storm assumes that all pregnant residents of the affected region were impacted equally by the event; however, it is plausible that some pregnant women would have taken refuge in safer places. Similarly, this acute, short-lived stressor may not have triggered high enough levels of distress in all women to affect birth outcomes, as long-term, chronic stressors may have more pronounced effects on birth outcomes.[11] Finally, some mitigation strategies were in place at the time of the ice storm: shelters and police forces visiting door to door to get people out of their houses.[37] These public and some private (e.g., moving in with families, relatives, or friends) resources may have alleviated the adverse effects of the disaster. Nevertheless, our results would be valid estimates of the average causal effects of the disaster to be observed at the population level, analogous to intent-to-treat based inference in randomized controlled trials.

The validity of the DD analyses relies on the assumption that post-exposure trends in birth outcomes in control regions accurately depict what would have been observed in the exposed region had there been no exposure to the ice storm. We observed no clear evidence that the annual and monthly trends in outcomes were systematically different (i.e., violating the parallel trend assumption) across regions in the 3 years before the ice storm. Importantly, we also found that characteristics were similar in the exposed and control regions over time. To our knowledge, there were also no programs or major policy changes, nor other natural disasters, occurring in Québec during the study period that would have impacted birth outcomes.

Strengths of our study include the use of quasi-experimental DD analysis, which better controls for confounding due to underlying secular trends in birth outcomes and unmeasured confounders and overcomes limited inference made in studies using a pre-post design (comparison of births before and after the disaster) only among the exposed region.[26,42,56–58] A large representative sample of pregnant women with information on several sociodemographic characteristics of both the mother and the father is another strength. We exploited a large-scale natural disaster that affected a large number of women in a randomized fashion that allowed us to accurately measure the start and duration of stress and enabled us to examine the effects of exposure to the ice storm overall, trimester-specific exposures, and the length of power outage, on the risk of poor birth outcomes.

Several limitations of this study should also be noted. We used exposure to the ice storm as a proxy measure of acute maternal stress, but we lacked detailed information about individual experiences beyond estimates of power outages in the affected region. Nevertheless, the use of the ice storm provides an objective way to measure exposure to sudden environmental upheaval, which reduces biases related to recall and confounding by factors such as socioeconomic factors, maternal personality, and mental health. The use of administrative data to ascertain our birth outcomes may result in misclassification, albeit likely nondifferential with respect to the exposure to the ice storm, which may have contributed to the lack of associations observed in the study. Exposure

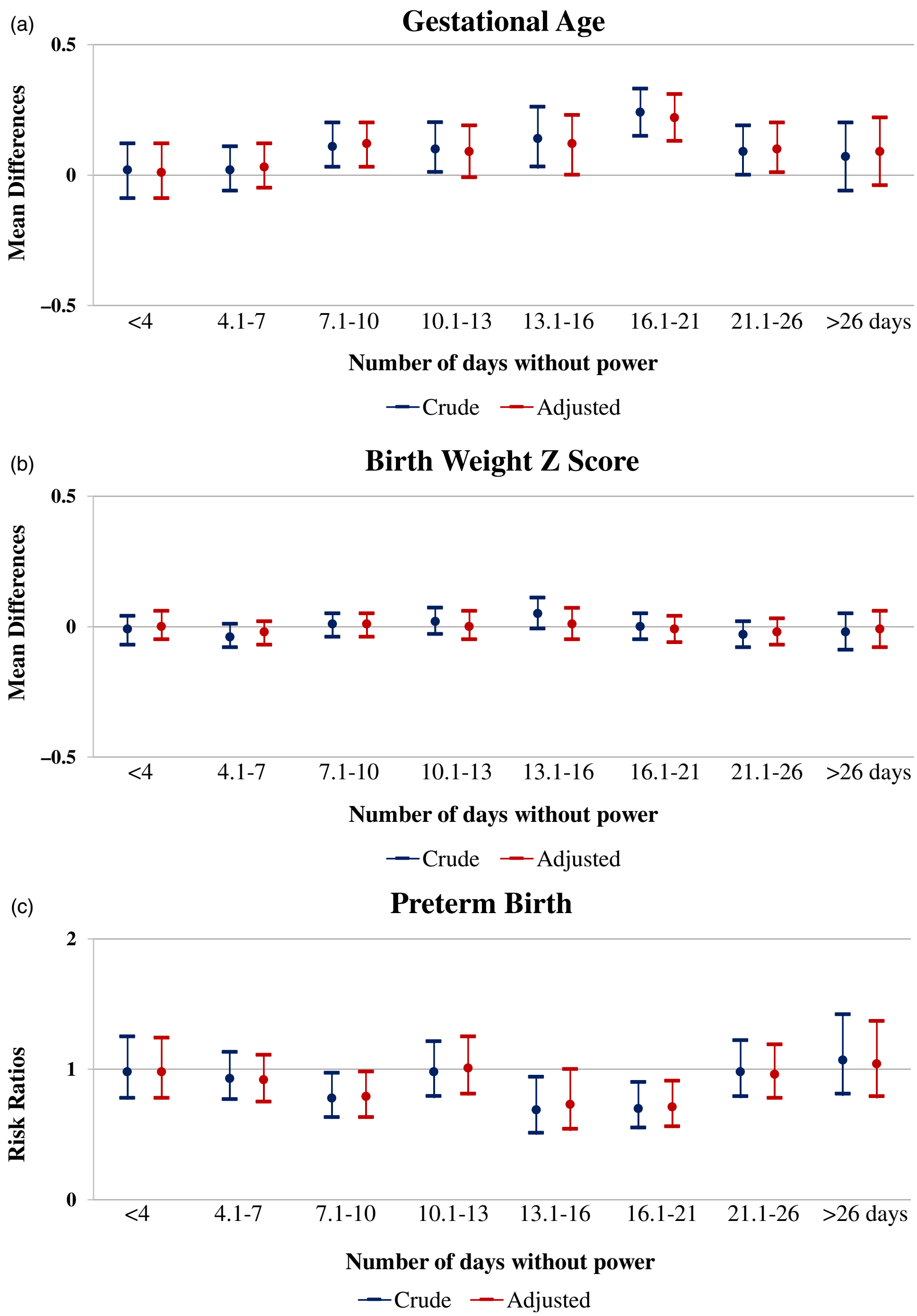

Fig. 4. Associations of the number of days without power and birth outcomes among study participants exposed to the 1998 Quebec Ice Storm.

misclassification – both overall and trimester-specific – may have occurred for some women as GA at delivery was only available in completed weeks. For example, some pregnancies conceived in the first week of January 1998 might have been exposed to the ice storm in the first trimester, rather than preconception (e.g., those conceived between January 1–4, 1998). Furthermore, we only considered the week of the ice storm in the classification of trimester-specific exposures, without incorporating the timing into the power outage duration as exposure because the period without electricity varied considerably among women. Hence, some women may have been exposed to the ice storm, or the power outage caused by it, in more than one trimester, for example, the end of first trimester and beginning of the second trimester. Pregnancies that ended early were less likely to be exposed to the ice storm than pregnancies that continued to term; therefore, associations for PTB and GA might have been attenuated (particularly for third-trimester exposure). Nevertheless, associations for GA specific outcomes (i.e., SGA, LGA, and BWZ) would not have

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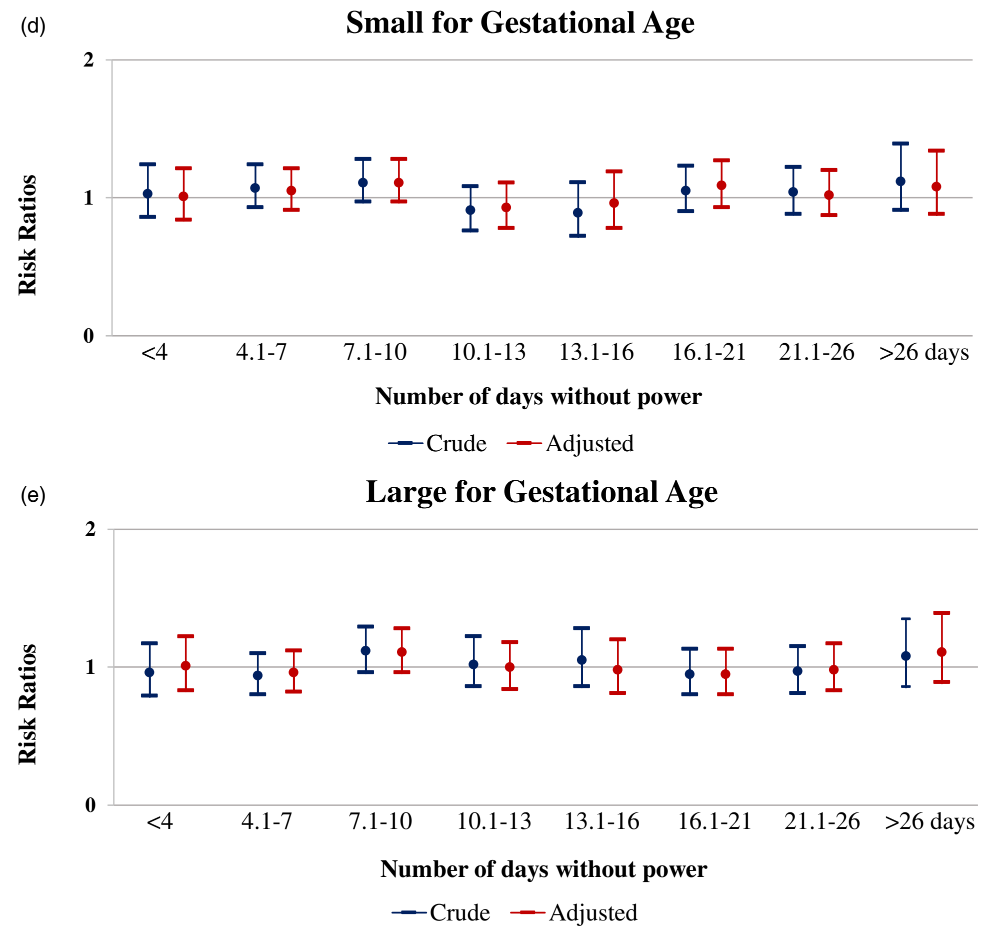

Notes: Graphs shows differences in mean gestational age at birth in weeks (a) and birth weight-Z scores (b) and risk ratios for (c) preterm birth, (d) small for gestational age, and (e) large for gestational age according to the number of days without power for births in Montérégie region exposed to the 1998 ice storm in Quebec. The reference category includes all births in the Montérégie region (1995-2001) unexposed to the 1998 Quebec ice storm. Adjusted model include the following covariates: mother's education, age, parity, marital status, country of birth, and native language, father's age and native language, and infant's sex.

Fig. 4. (Continued).

been affected. For births delivered shortly after the ice storm, there would have been insufficient time for fetal growth-related outcomes (BWZ, SGA, LGA) to be affected by the exposure, particularly for third-trimester exposure. Nevertheless, our results that were restricted to exposures in the preconception period or in the first or second trimester also showed no association.

Though we found no evidence of the parallel trend assumption of DD methods in our data, the relatively short non-exposed time periods (i.e., 3 years before and after the exposure) would have been insufficient to ensure the exchangeability between the exposed and the control groups. We did not account for stillbirths or early pregnancy losses, which may be linked to maternal exposure to stress.[47,48] We were unable to consider subcategories of PTB (<28 weeks, 28–31 weeks, and 32–36 weeks) owing to the small number of exposed births in each category. We have only considered birth outcomes in this paper, but exposure to the ice storm might affect other long-term outcomes in offspring – such as psychological and neurodevelopmental outcomes – that have been linked to maternal stress.[1–7] Future analyses with the same data will use the same analytic approach with childhood physical and mental health conditions.

Conclusions

Our large population-based quasi-experiment study found no increased risk of adverse birth outcomes among women who experienced acute hardship — Québec 1998 ice storm — during pregnancy. Further studies of more extreme natural events with greater or more direct effects on pregnant women or with detailed measures of distress experienced by pregnant women at the time of adversity that employ rigorous study designs are needed to better understand the causal role of acute maternal stress exposure in perinatal outcomes. Further work is also needed to assess how stress related to ice storms and similar natural disasters may influence other maternal–child health outcomes.

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Conflicts of Interest. None.

Ethical Standards. This study was approved by the Douglas Mental Health University Institute Research Ethics Board at McGill University.

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