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Disaster-related prenatal maternal stress explains increasing amounts of variance in body composition through childhood and adolescence: Project Ice Storm

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ABSTRACT

Background: The increasing prevalence of childhood obesity worldwide has become a public health issue. While many factors are involved in the development of obesity, stress during pregnancy has been linked to adiposity. However, research involving stressors that are independent of pregnant women's socioeconomic and psychological characteristics is rare. The present study made use of a natural disaster (1998 Quebec ice storm) to determine which aspect of the women's disaster experience (objective hardship, subjective stress, and/or cognitive appraisal) were associated with body mass index levels and/or waist to height ratio across childhood and adolescence.
Methods: Measure of objective hardship, subjective stress, and cognitive appraisal were obtained following the 1998 Quebec ice storm. We measured height, weight, and waist circumference in children at ages 5½, 8½, 11½, 13½, and 15½.
Results: Our results show that higher prenatal maternal stress was associated with higher body mass index levels and central adiposity in children of ages 5½, 8½, 13½, and 15½. The effects of prenatal maternal stress on anthropometric measurements tend to increase as the children grew older.
Discussion: The findings of this study highlight the long-lasting effect of prenatal stress on body composition, and are compatible with the current theory of fetal programming. Hopefully, our increased knowledge of the effects of prenatal stress on the fetus will lead to improved awareness and the creation of early intervention programs, ultimately improving women's and children's health in the future.

1. Introduction

The continuing rise in obesity worldwide has become a pressing public health issue among both children and adults. For instance, a survey in 2009 estimates that 61% of Canadian adults and 26% of Canadian children suffer from either overweight or obesity (Statistics Canada, 2011). The regulation of body composition is complex and multifactorial. The increasingly sedentary lifestyle that developed with the advancement of technology is often cited as the most prominent factor for the modern obesity epidemic (Carroll and Dudfield, 2004; Huizink et al., 2008). Furthermore, a large body of research on the Developmental Origins of Health and Disease (DOHaD) (Barker, 2004; Gluckman et al., 2009) now shows that adverse conditions experienced by the pregnant female, such as inadequate nutrition, alters fetal programming and has lasting effects on the offspring. In the Dutch Hunger Winter study, nutritional restriction as the result of a famine predicted increased incidence of obesity (Ravelli et al., 1976). Prenatal maternal stress (PNMS) might have similar programming effects. Existing studies suggest that higher PNMS predicts increased body mass index (BMI) in children (Dancause et al., 2012), adolescents (Hohwu et al., 2014), and later in life (Schulz, 2010). Another study revealed that young adults whose mothers were exposed to bereavement in pregnancy showed increased risk of overweight and obesity (Hohwu et al., 2014); previously a similar linkage was also found in children aged 12–15 years old (Li et al., 2010).

The current body of PNMS research is limited in several ways.

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Table 1
Sample description.

Age	n	Child's sex		Timing of exposure			
		Males	Females	Preconception	1st trimester	2nd trimester	3rd trimester
5½	111	56	55	24	34	26	27
8½	90	46	44	22	29	22	17
11½	67	35	32	21	16	17	13
13½	66	37	29	16	15	18	17
15½	52	30	22	15	17	13	7

In animal research, rats or non-human primates can be randomly assigned to stressors in a controlled environment, allowing for causal conclusions to be made; this is not possible in human research. However, animal studies cannot tease apart elements of the human stress response including the degree of the mother's exposure, her cognitive appraisal of the event, and her subjective distress levels. In addition, the timing of PNMS exposure in gestation may moderate the effect of PNMS on offspring cortisol levels and the effect of cortisol levels on anthropometric measurements, respectively. Animals go through different pre- and post-natal developmental processes at different stages than do humans, making direct comparisons difficult. Human studies have their own limitations. Most human PNMS studies, usually retrospective, use everyday life event stressors such as job loss and marital discord. These stressors may not be considered "independent stressors" because they are often subject to personal influences, and personal traits may be heritable, creating genetic confounds. Thus, disentangling the objective, subjective, and cognitive aspects of the stressor, and finding the "active ingredient", would be almost impossible in most human PNMS designs. Furthermore, it is often difficult to assess the timing of these events during pregnancy with precision. It would not be ethically, nor logistically, feasible to conduct a human PNMS study in which randomly assigned stress is applied to a large group of women in different stages of their pregnancies. The use of a natural disaster as a stressor circumvents these limitations. Natural disasters are independent, random, can affect a large population, and their timing can be precisely identified.

Project Ice Storm was launched after the devastating 1998 Quebec ice storm to study measures of stress exposure among women who were pregnant during the disaster, and their children's development. Analyses of participant characteristics showed low correlations between severity of the exposure to the ice storm and sociodemographic measures (Laplante et al., 2016), supporting the independent nature of the exposure.

In a previous Project Ice Storm analysis, objective stress was found to predict childhood obesity at age 5½ years (Dancause et al., 2012). However, it is unknown whether the association between PNMS and adiposity varies as the children grow older; which aspect of the maternal stress response predicts body composition in adolescence; and the extent to which that association is moderated by the timing of stress exposure in utero and by sex.

Our goal was to determine how associations between PNMS and adiposity change with age. Specifically, we tested the following hypotheses: (1) PNMS predicts anthropometric measurements (BMI and waist-to-height ratio) at ages 5½, 8½, 11½, 13½, and 15½; (2) the effect of PNMS on anthropometric measurements are moderated by the sex of the child and the timing in utero of the disaster.

2. Materials and method

The ice storm is counted as among the worst natural disasters in Canadian history (Insurance Bureau of Canada, 2012) and left 3 million people without electricity for as long as 6 weeks during the coldest month of the year. In June of the same year, mothers who were pregnant during the ice storm, or who became pregnant in the three months after the storm, were recruited for a study of PNMS and child development. The initial survey isolated objective hardship and subjective distress; the women's cognitive appraisal of the event as positive, neutral, or negative, was also assessed. Periodic mail-in questionnaires and face-to-face assessments have been used to track the development of their children.

2.1. Participants

Following the ice storm, we contacted obstetricians associated with the four major hospitals in the Montérégie, a region southeast of Montreal that endured the longest power losses from the storm. These obstetricians identified patients who were pregnant during, or conceived within 3 months of, the storm and who were at least 18 years old. The first questionnaire, "Reactions to the storm," was mailed on 1 June 1998 to 1440 women. Of 224 respondents, 178 consented to follow-up and were sent a second questionnaire, "Outcomes of the pregnancy," 6 months after their pregnancy due date. Of these, 177 returned the second questionnaire. Level of education was higher for respondents than in the Montérégie in general: 61.0% of respondents had a college degree or higher compared to regional figures of 45.3%, for women aged 20–44 in the 2001 census (http://www12.statcan.ca/english/census01/home/index.cfm).

Body composition data (height and weight), were obtained by a trained research assistant when the children were aged 5½, 8½, 11½, and 15½ years. The sample sizes range from 52 at age 15½ to 111 at 5½; these data were available for at least one age for 123 children. A description of the participants at each age is reported in Table 1 as a function of child sex and period of exposure. Comparisons between families who participated in at least one assessment and those who did not indicated that participating families had higher socio-economic status ($p = 0.03$). Significant group differences were not observed for the PNMS measures nor maternal age.

The protocols for each assessment were reviewed and approved by the Research Ethics Board of the Douglas Institute Research Center. Mothers provided informed written consent for each assessment. Youth provided informed written assent from the assessment at age 11½ years onward.

2.2. Outcome measures

Body Mass Index (BMI) was defined as the children's total body mass (kilograms) divided by the square of their body length (meters). Standing height was measured without shoes to the nearest 0.1 cm and weight to the nearest 0.1 kg at each age of assessment. Waist-to-Height Ratio (WHtR), an index of central adiposity, was defined as the children's waist circumference (cm) divided by their height (cm). This measure was obtained at each assessment period starting when the children were 8½ years of age. All physical data were obtained by trained research assistants.

2.3. Predictor variables

On June 1, 1998 postal questionnaires were sent to the women from their own doctors' offices. Among other measures, the questionnaires included measures of the women's ice storm experiences. Objective hardship was estimated using the mothers' responses to questionnaire items tapping into categories of exposure used in other disaster studies: Threat, Loss, Scope, and Change (Bromet and Dew, 1995). Because each natural disaster presents unique experiences, questions pertaining to each category must be tailor-made (see Laplante et al. (2007) for the questions). An algorithm was devised such that each of the four dimensions was scored on a scale of 0–8, ranging from no exposure to high exposure. We computed a total objective hardship score by summing scores from all four dimensions using McFarlane's approach (McFarlane, 1988).

Subjective distress was assessed using the French version (Brunet et al., 2003) of the widely used Impact of Event Scale – Revised (Weiss and Marmar, 1997). The 22-item scale describes symptoms from three categories relevant to post-traumatic stress disorder: Intrusive Thoughts, Hyperarousal, and Avoidance. The IES-R instructions for respondents allow investigators or clinicians to “write in” the traumatic event in question. Participants, thus, responded on a 5-point Likert scale, from *Not at all* to *Extremely*, the extent to which each item described how they felt over the preceding seven days in response to the ice storm crisis. We used the total score in all analyses. We published validity data on the French version, which demonstrated good internal consistency for the total score with the current sample ($\alpha = .93$) and three-month test-retest validity with a post-disaster sample from France ($r = .76$) (Brunet et al., 2003).

Cognitive appraisal was assessed by asking the women to rate the overall consequences of the ice storm on them and on their families using a 5-point Likert scale that ranged from very negative (−2) to neutral (0) to very positive (+2). Scores were recoded into ‘negative’ and ‘neutral/positive’.

The trimester of pregnancy during which the women were exposed to the ice storm was determined using the difference in days between the mothers' anticipated due date and January 9, 1998, the date corresponding to the peak of the ice storm. Specifically, 3rd trimester exposure corresponds to due dates between 0 and 93 days following January 9; 2nd trimester of exposure corresponds to between 94 and 186 days; 1st trimester of exposure corresponds to between 187 and 279 days between January 9 and the due date; Preconception exposure corresponded to postnatal days 1 through 93.

Socioeconomic status (SES) was computed using the Hollingshead Social Position criteria (Hollingshead, 1973) and was based on parental education and occupation; higher scores represent lower SES.

2.4. Statistical analyses

Data were cleaned and examined for normality. Preliminary associations were assessed by correlating the three PNMS variables with BMI and WHtR at each age. To get a better understanding of how the different PNMS variables influence the overall BMI and WHtR across all ages and to determine if they also influence how the outcomes change with age, multilevel modeling, or mixed model, analyses were conducted with age as the first level and participants as the second level. The multiple steps used to analyze the mixed models were proposed by Hox (2002). First, an intercept-only model was analyzed allowing the intercept to enter as a random effect in order to determine if a significant amount of the variance in the outcome was explained by the difference between the participants, which makes the mixed model analyses necessary. The intraclass correlation, that is, the percentage of variance in the outcome due to the difference between subjects, was also computed based on that model. Age of the child at assessment, the only first-level variable, was then entered in the model as a fixed effect. It was then allowed to enter as a random effect to determine if the children's outcomes changed differently from one age to the other as they got older. The second-level variables, namely objective hardship, subjective distress, cognitive appraisal, sex of the child, and timing of ice storm exposure *in utero,* were then entered in the model. The interaction terms between all variables were then tested in separate models. Three-way interactions, always including age of the child, were also tested in order to determine if the interaction terms changed across different ages. At each step, any non-significant variables were trimmed out of the model in order to increase efficiency and statistical power.

3. Results

3.1. Descriptives

Descriptions of the samples available at all ages (5½, 8½, 11½, 13½, and 15½) are presented in Table 2. As can be seen, despite

Table 2
Sample descriptions at each age: M (SD) or n (%).

Age of assessment	5½	8½	11½	13½	15½
Sample size (n)	111	90	67	66	n2
BMI	15.9 (1.7)	17.2 (3.1)	19.6 (5.2)	21.6 (5.3)	23.7 (6.4)
WHtR	N/A	0.46 (0.05)	0.44 (0.07)	0.44 (0.07)	0.47 (0.08)
Child age	5.6 (0.1)	8.5 (0.1)	11.6 (0.1)	13.6 (0.1)	15.6 (0.3)
Objective hardship	10.5 (4.3)	11.1 (4.7)	11.4 (4.6)	11.5 (4.6)	11.0 (4.5)
Subjective stress	1.8 (1.1)	1.9 (1.1)	1.9 (1.1)	1.9 (1.2)	1.9 (1.1)
Cognitive appraisal (0=negative)	72 (64.9%)	56 (62.2%)	43 (64.2%)	41 (62.1%)	34 (65.4%)
Sex (boys)	56 (50.5%)	46 (51.1%)	35 (52.2%)	37 (56.1%)	30 (57.7%)
Timing of exposure (days)	104. 6 (98.1)	90.1 (93.2)	87.6 (100.4)	107.3 (101.7)	76.9 (92.4)
Maternal age at birth	29.9 (4.9)	29.8 (4.9)	29.7 (4.8)	29.8 (4.8)	29.6 (5.0)
SES	27.7 (12.2)	27.1 (11.6)	28.4 (12.2)	28.6 (11.8)	28.7 (10.2)
Cigarettes (number/day)	2.1 (1.1)	2.0 (1.2)	2.5 (5.6)	1.7 (4.4)	1.7 (3.9)
Number of children at birth	1.3 (1.2)	1.2 (1.2)	1.2 (1.0)	1.5 (1.3)	1.1 (1.0)
Notes:	n=109 for cognitive appraisal	n=88 for WHtR	n=66 for maternal age	n=64 for maternal age; 61 for WHtR	n=50 for WHtR

BMI=body mass index.
WHtR=waist-to-height ratio.
SES=socioeconomic status.

Table 3
Correlations between prenatal stress and body composition measures at each age.

Predictor variables	Age at assessment									
	5½	*p*	8½	*p*	11½	*p*	13½	*p*	15½	*p*
	Body mass index									
Objective hardship	**0.23**	***0.02***	**0.21**	***0.05***	**0.24**	***0.05***	0.23	*0.06*	**0.34**	***0.02***
Subjective distress	0.10	*0.31*	0.16	*0.14*	0.16	*0.19*	0.20	*0.10*	**0.28**	***0.05***
Cognitive appraisal (0=negative)	0.06	*0.50*	0.12	*0.19*	0.09	*0.42*	0.09	*0.30*	0.14	*0.26*
Timing of exposure	−0.11	*0.26*	−0.22	*0.04*	−0.09	*0.47*	−0.11	*0.36*	−0.06	*0.41*
Maternal age at birth	−0.02	*0.88*	−0.10	*0.35*	−0.11	*0.36*	−0.04	*0.73*	−0.04	*0.91*
Socioeconomic status	0.06	*0.55*	0.01	*0.95*	0.01	*0.94*	0.02	*0.90*	0.05	*0.33*
Cigarettes (number/day)	0.07	*0.49*	0.10	*0.40*	0.10	*0.10*	0.11	*0.44*	0.08	*0.60*
Number of children at birth	−0.05	*0.61*	−0.17	*0.11*	−0.21	*0.08*	−0.16	*0.21*	−0.22	*0.12*
	Waist to height ratio									
Objective hardship			**0.23**	***0.03***	**0.29**	***0.02***	**0.32**	***0.01***	**0.44**	***<0.01***
Subjective distress			0.05	*0.67*	**0.25**	***0.04***	**0.32**	***0.01***	**0.29**	***0.04***
Cognitive appraisal (0=negative)			0.01	*0.78*	0.09	*0.50*	0.05	*0.42*	0.08	*0.45*
Timing of exposure			−0.06	*0.56*	−0.04	*0.70*	−0.17	*0.19*	**−0.28**	***0.05***
Maternal age at birth			−0.04	*0.74*	−0.03	*0.79*	−0.01	*0.93*	−0.10	*0.48*
Socioeconomic status			0.05	*0.67*	0.05	*0.72*	<0.01	*0.99*	−0.07	*0.61*
Cigarettes (number/day)			0.06	*0.63*	0.12	*0.38*	0.16	*0.26*	0.09	*0.58*
Number of children at birth			−0.10	*0.36*	−0.23	*0.06*	−0.22	*0.09*	−0.25	*0.08*

reductions in sample size with age, the sample characteristics remain stable across assessments in terms of levels of objective and subjective PNMS, cognitive appraisal, and maternal age at birth, SES, number of cigarettes smoked per day during pregnancy, and number of children in the household.

3.2. Correlations

Correlations between the, BMI and WHtR, and the PNMS variables, timing in utero, and control variables are presented in Table 3. These results show that greater objective hardship from the ice storm predicted greater BMI and WHtR at every age. The correlations between body composition and maternal subjective distress tended to increase with age such that the correlation between subjective stress and BMI was significant at 15 years, and was significant for WHtR ratio at ages 11½, 13½, and 15½. Maternal cognitive appraisal of the storm was not associated with either child measure at any age. Number of older children tended to be negatively correlated with WHtR ratio at ages 11½ through 15½ years. The remaining control variables were not significantly related to BMI or WHtR ratio.

3.3. Longitudinal analyses for BMI

Results of the mixed-model analysis are presented in Table 4. Results of the intercept-only model indicated that a significant proportion of the variance was attributed to the difference between the subjects ($p < 0.001$), with an intra-class correlation of 50.27%. Age of the child was then added to the model as a fixed effect, and had a significant positive effect on BMI ($p < 0.001$), indicating that the children's BMI increased as they got older. The random effect of children's age was then tested and found to be significant ($p < 0.001$), as was the covariance between the intercept and children's age ($p = 0.002$), indicating that the change in BMI as they grew older differs from one child to the other. Second-level variables were then entered in the model which was then trimmed of all non-significant predictor or covariate variables. Objective stress was not significantly associated with children's BMI level, but was kept in the model as a control variable. In the next step, a significant interaction between child age and objective hardship was detected ($p = 0.027$). To retain statistical power, timing of exposure was removed from the model, since its association with BMI was no longer significant. The interaction

Table 4
Results of the estimates of the fixed effects of the mixed-model analyses for body mass index and waist to height ratio.

Predictor variables	Estimate	Standard error	df	t	p	95th confidence interval	
						Lower	Upper
	Body mass index						
Intercept	12.688	0.699	98.274	18.160	< 0.001	11.302	14.075
Objective hardship	−0.059	0.059	105.231	−0.999	0.320	−0.175	0.058
Child's age	**0.401**	**0.124**	**108.226**	**3.242**	**0.002**	**0.156**	**0.646**
Objective hardship × child's age	**0.023**	**0.010**	**110.148**	**2.226**	**0.027**	**0.003**	**0.043**
	Waist to height ratio						
Intercept	0.365	0.062	256.203	5.919	< 0.001	0.244	0.487
Objective hardship	0.010	0.006	255.794	1.697	0.091	−0.002	0.021
Subjective distress	0.044	0.027	258.061	1.614	0.108	−0.010	0.097
Child's age	0.006	0.005	205.416	1.114	0.267	−0.004	0.016
Objective hardship × subjective distress	**−0.005**	**0.002**	**256.960**	**−2.055**	**0.041**	**−0.004**	**< −0.001**
Objective hardship × child's age	−0.001	0.001	200.786	−1.685	0.094	−0.002	< 0.001
Subjective distress × child's age	**−0.004**	**0.002**	**198.399**	**−1.988**	**0.048**	**−0.009**	**< −0.001**
Objective hardship × subjective distress × child's age	**0.001**	**< 0.001**	**196.728**	**2.755**	**0.006**	**< 0.001**	**0.001**

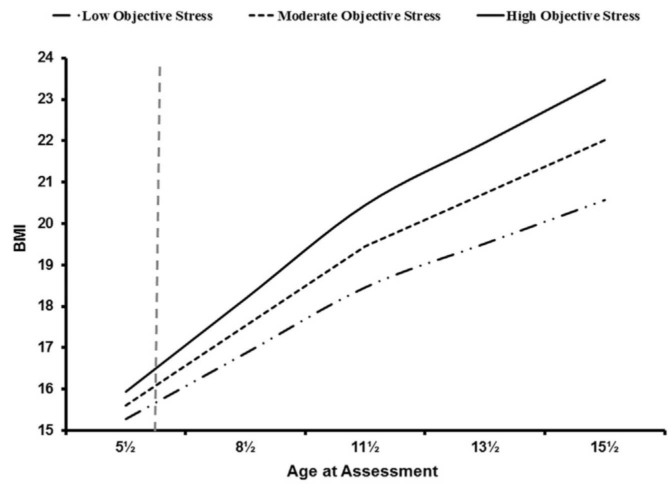

Fig. 1. The significant interaction between age of child and severity of objective stress in predicting child BMI. Low and High objective hardship lines represent slopes for lowest and highest 10% values of Storm32 for illustrative purposes.

between child age and objective hardship indicated that, on average, the older the child, the stronger the positive effect of mothers' objective hardship on children's BMI. This interaction also indicated that the higher the objective hardship score, the steeper the BMI increase with age (Fig. 1). This interpretation is for the average effect, however, since the child's age still has a significant random effect.

3.4. Longitudinal analyses for WHtR

Results of the estimates of the fixed effect of the analysis are presented in Table 4. The intercept-only model indicated that a significant proportion of the variance in WHtR was attributed to the between-subject differences ($p < 0.001$), with an intra-class correlation of 75.39%. Age of the child was not significantly associated with the outcome when entered as a fixed effect. However, its random effect on the outcome was found to be significant, indicating that the participants have a significantly different WHtR change as they get older. The second-level predictor and control variables were then entered in the model. Only objective hardship was found to be significant, such that mothers with higher objective stress during pregnancy had children with greater central adiposity. A significant three-way interaction between objective hardship, subjective distress and age of the child was detected ($p = 0.037$), indicating that the effect of subjective distress on the change in central adiposity with age depends on the mother's level of objective hardship during the ice storm. Probing the interaction revealed that, for women who were exposed to a low objective hardship, the effect of subjective stress on central adiposity did not vary with age, and that effect was never significant. However, for women with high levels of objective hardship, starting at an objective stress score of 12, the effect of subjective stress on central adiposity increased significantly as their children got older. As an example, if we consider a high objective stress score of 15.35 (M + 1SD), subjective stress has a marginally significant ($p < 0.10$) positive effect on central adiposity for children older than 13 years of age, which became significant when the children reached 15 years of age. (See Fig. 2a and b).

4. Discussion

The Quebec ice storm presented an opportunity to explore the role of PNMS on children's adiposity by exposing families in the region to varying degrees of objective hardship in quasi-random fashion. Given that there is no correlation between SES and our objective PNMS measure, we are confident that social class does not confound our results, although there may well be related, but unmeasured, psychosocial variables that could have moderated the effects of ice storm exposure. By having anthropometric measurements across a time span of ten years, and by using potential moderating variables such as sex and exposure timing, Project Ice Storm created a unique opportunity for exploring the dynamics of the anthropometric effects of PNMS, and for disentangling the relative effects of the mother's objective degree of exposure, or hardship, to the disaster from her level of subjective distress and her cognitive appraisal of the event.

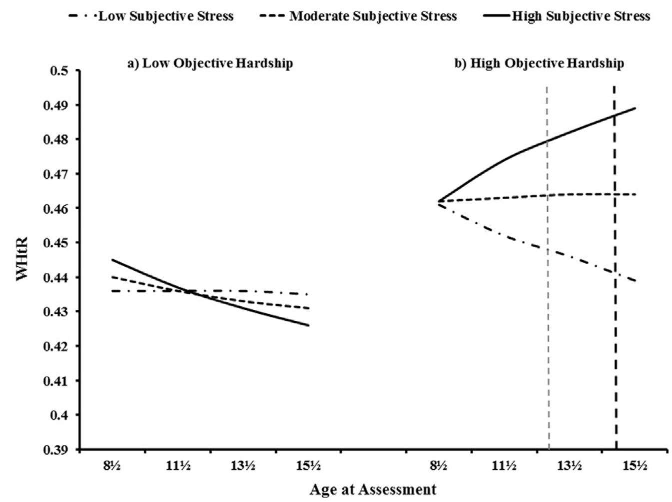

Fig. 2. The significant interaction among age of child, severity of maternal objective hardship, and severity of subjective stress in predicting child WHtR ratios. (a) depicts the lack of association between subjective stress and WHtR ratios when objective stress was low; (b) depicts the significant age-by-subjective stress interaction when objective hardship was high. Low and high subjective stress lines represent slopes for lowest and highest 10% values of IES-R for illustrative purposes. The vertical lines indicate regions of significance: subjective stress has a marginally significant positive effect on central adiposity for children older than 13 years of age ($p < 0.10$; gray horizontal dashed line), which became significant when the children reached 15 years of age ($p < 0.05$; black horizontal dashed line).

The results support the hypothesis of a dose-response relationship between objective hardship in the pregnant woman and her child's BMI and WHtR throughout childhood and early adolescence: in general, the greater the mother's objective degree of hardship from the ice storm, the higher the children's BMI and central adiposity. Subjective distress predicted greater BMI at 15 as well as greater WHtR at 11½, 13½, and 15½, which suggests that the emotional state of pregnant women also plays an important role in the fetal programming of body composition.

We anticipated that the effect of PNMS on anthropometric measurements would change as the children aged, although we expected that the effects of the prenatal environment would diminish with age as the postnatal environment would exert an ever-increasing influence on the young person's lifestyle. On the contrary, we found that the older the child, the stronger the positive association between the mother's objective stress during pregnancy and her child's body composition; the higher the objective stress, the greater the increase in BMI with age. With regard to central adiposity, we found that for children whose mothers experienced high objective stress, the effect of subjective distress had an increased effect on WHtR as the children grew older; on the other hand, maternal subjective distress from the ice storm had no effect on children's WHtR at lower levels of objective hardship.

The independent nature of our stressor, the ice storm of 1998, is a great strength of this study. A natural disaster is unlikely to have genetic or socioeconomic confounds that might affect teens' weight and body composition. Indeed, the objective degree of hardship from the ice storm is uncorrelated with family SES ($r < 0.10$). As such, our results pertaining to the objective stress measure strongly suggest that the dimensions of the hardship experienced by the mothers during the crisis - scope, threat, loss, and change - played a role in influencing the exposed children's BMI and central adiposity levels. The role of the mothers' subjective distress appears to be more nuanced. Our subjective stress measure, the IES-R, assesses the severity of the mother's PTSD-like symptoms during the week preceding the assessment which, in this case, was 4–6 months after the events of the ice storm crisis. Although it is relatively normal to experience such symptoms during a disaster, the failure of these symptoms to abate over time may reflect a failure of the mother's own hypothalamic-pituitary-adrenal (HPA) axis to return to baseline; alternatively, the persistence of a woman's PTSD-like symptoms may reflect a longstanding HPA axis profile that created a vulnerability for PTSD-like symptoms in the face of trauma. As illustrated in Fig. 2, however, high levels of enduring subjective distress are not sufficient on their own to influence the unborn child's future adiposity, but the highest central adiposity levels were seen in those children with a "double hit" of both objective hardship and maternal distress.

In terms of the mechanisms that translate PNMS into child adiposity, one possibility is the fetal programming of the HPA axis in response to high levels of maternal stress hormones, the alteration of which has been linked to the regulation of body composition and energy expenditure (Amugongo and Hlusko, 2014). Another possibility is epigenetics. We recently reported other results from Project Ice Storm demonstrating that objective, but not subjective, maternal stress correlated significantly with the methylation level of a large number of CpG sites on the genome-wide level (Cao-Lei et al., 2014). As well, DNA methylation of CpG sites on genes implicated in Type I and II diabetes mediated the effects of the objective stress on the children's BMI and central adiposity at age 13, the same age at which the epigenetic assessments were conducted (Cao-Lei et al., 2015). The importance of objective hardship from the ice storm, but not the mother's degree of distress, in the epigenetic mediation of PNMS on child BMI and central adiposity suggests that these two components of the human stress experience may activate different biological pathways.

In Project Ice Storm, we have noted low correlations among our three stress measures (objective hardship, subjective distress and cognitive appraisal) (generally $r < 0.30$ depending on the sample). As such, whether women appraised the consequences of the ice storm crisis to be negative, neutral, or positive was disconnected from both the objective reality of their situation and their subjective distress. In the current analyses, we see no evidence that the mother's cognitive appraisal of this severe weather event in pregnancy is predictive of her child's future adiposity. On the other hand, as we have also reported elsewhere (Cao-Lei et al., 2015), these same mothers' cognitive appraisal was an even stronger predictor of genome-wide DNA methylation profiles than objective stress. Preliminary results are suggesting, in fact, that maternal cognitive appraisal may exert an influence on the child's metabolic function (i.e., insulin secretion) via an effect on methylation sites of diabetes-related genes (unpublished data). Ultimately, we may find that each aspect of PNMS programs the fetus in different ways with implications for different patterns of outcomes.

The present study has some limitations. First, no control group exists, so comparisons cannot be made between children in this sample and those whose mothers did not experience a natural disaster; rather than taking a case-control approach, Project Ice Storm studies dose-response relationships between the severity of PNMS and child outcomes. Second, the present sample was skewed to the middle-upper and upper classes, making it impossible to generalize our findings to the population in general. Finally, the relatively small sample size precluded our ability to assess whether the observed influence of PNMS on BMI and central adiposity was influenced by the timing of the disaster-related stress on the developing fetus. As such, we were unable to address whether the observed effect was limited to individuals exposed during a particular period of pregnancy or those exposed in the preconception period as suggested by new research findings (Hohwu et al., 2014).

Regardless of these limitations, and despite the literature showing that obesity rates are lowest in families from upper-middle class and higher SES classes (Oliver and Hayes, 2005; Orsi et al., 2011), our results showed that higher PNMS was associated with higher BMI levels and central adiposity in children of ages 5½, 8½, 13½, and 15½. The effects of PNMS on anthropometric measurements tend to increase as the children grew older. Future studies are needed to clarify the dynamics of the association between PNMS and anthropometric measurements. The findings of this study highlight the vulnerability of the fetus to prenatal maternal stress, and are compatible with the current theory of fetal programming. The findings also illustrate the long-lasting effects of PNMS. Hopefully, advancements in understanding PNMS will lead to improved awareness and the creation of early intervention programs, ultimately improving women's and children's health in the future.

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