Brief Report

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# Prenatal Maternal Stress Affects Motor Function in 5½-Year-Old Children: Project Ice Storm

***ABSTRACT:*** *Evidence suggests that prenatal maternal stress (PNMS) has long-term effects on several outcomes, yet effects on neuromotor function are relatively unknown. We aimed to determine whether disaster-related PNMS predicts motor functioning in young children and whether timing of exposure and sex of the child moderate these effects. Objective and subjective PNMS levels were assessed among pregnant women exposed to a natural disaster. Their children's bilateral coordination, balance, and visual motor integration (VMI) were assessed at 5½ years. Girls performed better than boys. Objective stress exposure and subjective distress interacted such that when subjective distress was high, no added effect of objective hardship was observed; when subjective distress was low, objective hardship showed a negative effect. In girls, late pregnancy exposure was associated with poorer outcomes. In conclusion, disaster-related PNMS is associated with relatively lower motor functions in exposed offspring. Exposure timing, sex, and type of stress influenced the effects.*  Dev Psychobiol 56: 117–125, 2014.

***Keywords:*** *natural disaster; prenatal maternal stress; motor function*

## INTRODUCTION

Animal and human research has demonstrated that prenatal maternal stress (PNMS) may have long-term effects on brain structure and function (Charil, Laplante, Vaillancourt, & King, 2010). It is believed that PNMS results in the production of excess circulating maternal stress hormones, which can affect fetal neuronal development and lead to cognitive, behavioral, neuroendocrine, and neuroanatomical effects in exposed offspring (Maccari et al., 2003; Weinstock, 2008). However, the effect of PNMS on neuromotor function has received little attention. Studies with non-human primates found that high PNMS resulted in reduced motor activity and maturity, lower muscle tone and coordination, slower reaction time, and poorer balance in the exposed offspring (Schneider & Coe, 1993; Schneider, Coe, & Lubach, 1992; Schneider, Roughton, Koehler, & Lubach, 1999). Only three neonatal and two infant studies have so far examined the relationship between PNMS and indices of motor functioning. In general, this research suggests that increased PNMS and/or maternal cortisol levels during pregnancy are associated with poorer motor outcomes at birth (Ellman et al., 2008; Rieger et al., 2004) and during early development (Buitelaar, Huizink, Mulder, de Medina, & Visser, 2003; Chuang et al., 2011). Interestingly, the influence of PNMS on sex differences in neuromotor functioning has not been studied.

The present study examined the extent to which in utero exposure to PNMS resulting from a natural disaster (the 1998 Quebec Ice Storm) influenced motor functioning during childhood. Because the ice storm was a random act of nature, we were able to obtain both objective and subjective measures of PNMS that were independent of other maternal characteristics from a relatively large number of pregnant women 5–6 months following the storm. In addition, because the exact

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parameters of the ice storm are well documented (e.g., specific dates when electrical power was lost and reestablished), we were able to pinpoint the exact week or weeks of exposure during pregnancy.

The goal of the present study was to determine the extent to which disaster-related objective and/or subjective PNMS predicted motor functioning in the Project Ice Storm cohort of children at age 5½ years, and the role of timing of the exposure and sex of the child.

## METHODS

### Participants

The present study included 5½-year-old children ($n = 89$; 42 boys and 47 girls) of women who were in their first ($n = 35$), second ($n = 27$), or third ($n = 27$) trimester of pregnancy on January 9, 1998, the peak of the ice storm. Details pertaining to the identification and recruitment of subjects have been presented elsewhere (Laplante et al., 2007). The research protocol was approved by the Research Ethics Board of the Douglas Mental Health University Institute, a McGill University teaching hospital.

### Outcome Variables

***Bilateral Coordination and Balance.*** We administered two subtests of the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978). The 8-item bilateral coordination subtest measures the ability to sequence precise movement and simultaneous coordination movements on both sides of the body. Raw scores were converted to standard scores ($M = 15$; $SD = 5$). Data from one participant were missing.

The 8-item balance subtest measures postural control. Raw scores were converted to standard scores ($M = 15$; $SD = 5$).

***Visual Motor Integration.*** The Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI; Beery & Beery, 2004) assesses the coordination of visual and fine motor skills by having a participant copy a series of geometric figures. Raw scores were converted to standard scores ($M = 100$; $SD = 15$). Data from one participant were missing.

### Predictor Variables

***Objective Hardship.*** Our objective PNMS scale assessed the severity of specific storm-related events experienced by the pregnant women (e.g., number of days without electricity, whether they stayed in a shelter). The objective PNMS questionnaire, sent in June 1998, included items for each of four categories commonly assessed following natural disasters: threat, loss, scope, and change (Bromet & Dew, 1995). Questions pertaining to each of the four categories were tailor-made (see Laplante, Zelazo, Brunet, & King, 2007) and scored on a scale of 0–8, ranging from no exposure to high exposure. We computed a total objective hardship score (Storm32) by summing scores from all four dimensions using McFarlane's approach (McFarlane, 1988).

***Subjective Distress.*** Our subjective PNMS scale assessed the pregnant women's psychological distress in response to the storm, measured in June 1998 using a French adaptation (Brunet, St-Hilaire, Jehel, & King, 2003) of the widely used Impact of Event Scale—Revised (IES-R; Weiss & Marmar, 1997). This 22-item scale describes symptoms from three categories relevant to posttraumatic stress disorder: intrusive thoughts, hyperarousal, and avoidance. Scale items were written to reflect the mothers' symptoms relative to the ice storm. The extent of behavior felt by participants during the preceding 7 days was measured on a five-point Likert scale, from ''not at all'' (0) to ''extremely'' (4) and the total score was used for analyses.

***Timing of Exposure.*** The timing of the pregnant mother's exposure to the ice storm was defined as the number of days between January 9, 1998—the peak of the ice storm—and the infant's due date. Thus, larger numbers represent exposure earlier in pregnancy. Third trimester exposure corresponds to due dates falling between 0 and 93 days; 2nd trimester, 94–186 days; and 1st trimester, 187–279 days following January 9.

***Maternal Factors.*** Non-storm-related maternal anxiety was assessed with the widely used General Health Questionnaire-28 (GHQ; Goldberg, 1972), included in our June 1998 questionnaire and again when the children were 5½ years of age. Data from 16 mothers when the children were 5½ years of age were missing. Major life events were assessed using the Life Experiences Survey (LES; Sarason, Johnson, & Siegel, 1978) 6 months following delivery. In an effort to keep the total length of the questionnaire reasonable, we reduced this list to 29 events by eliminating items not likely to have occurred in this sample (e.g., ''combat experience''). Women were instructed to indicate events, other than the ice storm, that occurred in the preceding year. The LES was repeated during the assessment at age 5½, with questions pertaining to the year preceding the assessment. The total number of events from each of the two assessments was used in the analyses. Data from 16 mothers when the children were 5½ years of age were missing. Postpartum depression was assessed using the 10-item Edinburgh Postnatal Depression Scale (EDPS; Cox, Chapman, Murray, & Jones, 1996; Cox, Holden, & Sagovsky, 1987) 6 months following delivery. The total score was calculated by summing all of the items. Data from four mothers were missing. Socio-economic status (SES) was computed using the Hollingshead Index criteria using maternal and paternal education and occupation (Hollingshead, 1973). The number of obstetric complications (OC) and delivery type (vaginal or caesarean) were obtained from maternal reports and hospital records. Alcohol (drinks/week) and cigarette use (cigarettes/day) during pregnancy were obtained from maternal reports 6 months following delivery.

***Child Factors.*** The children's birth weight, birth length, gestational age, ponderal index (body weight/body length$^3$), head circumference-to-birth length ratio, and whether the child spent any time in the Neonatal Intensive Care Unit (NICU) after birth were obtained from maternal reports and hospital records. NICU status was missing for four children. The children's height and weight were measured when they were 5½ years old and their body mass index (BMI, kg/m$^2$) was calculated.

### Statistical Analyses

First, descriptive analyses were conducted on both the outcome and predictor variables. Second, we tested correlations between the outcome and predictor variables. For dichotomous variables, point-biserial correlations were used. Third, hierarchical multiple regression analyses were performed on each outcome variable using $p$-values of 0.1 as enter, and 0.2 as removal, criteria. Maternal factors were allowed to enter (stepwise) into the first block of the equation. Child factors were allowed to enter (stepwise) into the second block of the equation. Child sex, timing of the exposure, objective hardship, and subjective distress were forced to enter in subsequent blocks. Finally, all possible interaction terms between objective and subjective PNMS, timing of exposure, and sex of the child were allowed to enter (stepwise) in the final block of the equation.

# RESULTS

## Descriptive Analysis

The means and standard deviations of all variables are listed in Table 1. Compared to regional norms, mothers in the present sample were more likely to be college- or university-educated (67% vs. 47%) and to own their own home (75% vs. 65%) (www.stat.gouv.qc.ca). Seventy percent of the families were classified as upper or upper-middle class using the Hollingshead Index. On average, the children's scores on the three outcome variables were higher than the established norms.

## Correlations among the predictor and outcome variables

The three motor indices were intercorrelated (Tab. 1). Subjective distress was significantly associated with objective hardship. Subjective distress was negatively associated with bilateral coordination and VMI scores: higher levels of subjective distress were associated with lower scores. The timing of the exposure during pregnancy was positively correlated with VMI scores: exposure later in gestation was associated with lower scores. Among the predictor variables, taller children had lower scores on all three motor indices. Females had better balance and VMI scores than males. Children who spent time in a NICU after birth had lower bilateral coordination and balance scores.

## Hierarchical Multiple Regression Analysis

***Balance.*** Children who were in the NICU after birth had lower balance scores, explaining 9.8% of the variance (Tab. 2). Taller children had lower balance scores (6.8%). Girls had better balance scores than boys (11.8%). Together, these variables accounted for 28.4% of the variance in balance abilities. Neither objective nor subjective PNMS from the ice storm, nor any interaction terms, explained additional, unique variance in children's balance scores.

***Bilateral Coordination.*** Taller children had lower bilateral coordination scores, explaining 8.4% of the variance. Children who were in the NICU after birth had lower bilateral coordination scores (5.8%). Sex of the child (1.5%) and the timing of exposure to the ice storm during pregnancy (2.3%) did not significantly increase the amount of variance accounted for. Higher levels of objective hardship (6.0%) and subjective distress (6.8%) were associated with lower bilateral coordination scores. The interaction term of sex $\times$ timing of exposure accounted for an additional 3.7% of the variance: the boys' performance did not vary but the girls' performance declined as the exposure to the storm was closer to birth (Fig. 1A). Finally, the interaction term of objective hardship $\times$ subjective distress accounted for an additional 3.1% of the variance: although performance remained relatively low for children whose mothers experienced high levels of subjective distress regardless of the mothers' objective hardship ratings, performance declined with increasing maternal objective hardship levels in children whose mothers reported low levels of subjective distress (Fig. 1B). These variables accounted for 37.7% of the variance in the children's bilateral coordination scores.

***Visual Motor Integration.*** Taller children at 5½ years had lower VMI scores, explaining 6.4% of the variance in VMI scores. Children who were in the NICU after birth had lower VMI scores (3.1%). Sex of the child did not significantly increase the amount of variance explained. Children who were exposed to the effects of maternal PNMS later in pregnancy had lower scores (8.4%). Higher levels of objective hardship were associated with lower VMI scores (3.9%). The main effect of subjective distress was not significant, however the interaction terms of objective hardship $\times$ subjective distress, and sex $\times$ timing of exposure accounted for an additional 4.0% and 3.0% of the variance, respectively. Mirroring the patterns observed for Bilateral

**Table 1. Correlation Coefficients Between All Outcome and Predictor Variables and Number, Mean, and Standard Deviations of All Outcome and Predictor Variables**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | *N* | *M* | *SD* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outcome measures | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 Balance | — | | | | | | | | | | | | | | | | | | | | | | | | | 89 | 17.2 | 4.6 |
| 2 Bilateral coordination | .54$^{***}$ | — | | | | | | | | | | | | | | | | | | | | | | | | 88 | 20.3 | 3.8 |
| 3 Visual motor integration | .54$^{***}$ | .54$^{***}$ | — | | | | | | | | | | | | | | | | | | | | | | | 88 | 108.0 | 11.9 |
| Maternal variables | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 Age (years) | .00 | −.03 | .09 | — | | | | | | | | | | | | | | | | | | | | | | 89 | 30.2 | 4.9 |
| 5 Life events (6 months) | −.08 | −.03 | −.03 | .17 | — | | | | | | | | | | | | | | | | | | | | | 89 | 5.0 | 3.6 |
| 6 Anxiety (6 months) | −.03 | −.09 | −.05 | .15 | .08 | — | | | | | | | | | | | | | | | | | | | | 89 | .3 | .3 |
| 7 Obstetrical complications | −.15 | −.09 | .07 | .11 | .07 | .07 | — | | | | | | | | | | | | | | | | | | | 88 | 3.8 | 2.6 |
| 8 Postnatal depression | −.04 | −.15 | −.11 | −.12 | .17 | .17 | .05 | — | | | | | | | | | | | | | | | | | | 85 | 5.7 | 4.0 |
| 9 Cigarettes/day | −.14 | −.12 | −.10 | −.14 | .27$^{*}$ | .27$^{*}$ | .15 | .32$^{**}$ | — | | | | | | | | | | | | | | | | | 89 | 1.7 | 4.8 |
| 10 Alcoholic drinks/week | .01 | .04 | .16 | .26$^{*}$ | −.08 | −.08 | .22$^{*}$ | .07 | −.01 | — | | | | | | | | | | | | | | | | 89 | .02 | .5 |
| 11 Socioeconomic status | .03 | −.05 | −.05 | −.30$^{**}$ | .11 | .11 | −.11 | .22$^{*}$ | .51$^{***}$ | −.05 | — | | | | | | | | | | | | | | | 89 | 27.1 | 12.5 |
| 12 Education (years) | .11 | .14 | .07 | .19$^{\dagger}$ | −.01 | −.01 | .13 | −.13 | −.32$^{**}$ | .14 | −.64$^{***}$ | — | | | | | | | | | | | | | | 89 | 15.2 | 2.5 |
| 13 Life events (5½ years) | −.07 | −.06 | −.14 | −.09 | .05 | .05 | .11 | .23$^{\dagger}$ | −.04 | −.19 | .02 | .13 | — | | | | | | | | | | | | | 73 | 4.4 | 2.8 |
| 14 Anxiety (5½ years) | .06 | −.18 | −.12 | −.01 | .16 | .16 | .01 | .29$^{*}$ | .15 | −.14 | .10 | .05 | .21$^{\dagger}$ | — | | | | | | | | | | | | 73 | .2 | .3 |
| Child variables | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 Sex of child (male) | .47$^{***}$ | .24$^{*}$ | .21$^{\dagger}$ | .03 | −.01 | .07 | −.01 | −.20$^{\dagger}$ | −.22$^{*}$ | .04 | −.06 | .15 | −.02 | −.07 | — | | | | | | | | | | | | 47.2% | |
| 16 Gestational age (weeks) | .09 | .08 | .04 | −.02 | .03 | −.03 | −.19$^{\dagger}$ | .05 | .01 | −.33$^{**}$ | .12 | −.15 | .16 | .12 | .05 | — | | | | | | | | | | 89 | 39.5 | 1.8 |
| 17 Birth weight (kg) | .11 | .12 | .03 | −.12 | .02 | −.10 | −.24$^{*}$ | .05 | −.03 | −.23$^{*}$ | .13 | −.19$^{\dagger}$ | .14 | .13 | .04 | .68$^{***}$ | — | | | | | | | | | 89 | 3.4 | .5 |
| 18 Birth length (cm) | .08 | .06 | −.02 | .01 | .04 | −.06 | −.08 | .08 | −.08 | −.15 | .02 | .01 | .27$^{*}$ | .03 | .02 | .46$^{***}$ | .64$^{***}$ | — | | | | | | | | 89 | 50.0 | 2.5 |
| 19 Neonatal intensive care unit | −.31$^{**}$ | −.26$^{*}$ | −.19$^{\dagger}$ | .10 | .08 | .01 | .17 | −.04 | −.03 | .11 | −.20$^{\dagger}$ | .07 | −.12 | .02 | −.24$^{*}$ | −.41$^{***}$ | −.41$^{***}$ | −.33$^{**}$ | — | | | | | | | 85 | 17.6% | |
| 20 Weight (5½ years) (kg) | −.18 | −.17 | −.10 | .01 | .16 | −.09 | .08 | .05 | .12 | −.01 | .09 | −.08 | .20$^{\dagger}$ | −.06 | −.14 | .15 | .30$^{**}$ | .24$^{*}$ | .07 | — | | | | | | 89 | 20.4 | 3.2 |
| 21 Height (5½ years) (cm) | −.27$^{*}$ | −.29$^{**}$ | −.25$^{*}$ | −.03 | .17 | .04 | .13 | .16 | .17 | .06 | .11 | .01 | .27$^{*}$ | .01 | −.15 | .05 | .18$^{\dagger}$ | .35$^{**}$ | −.07 | .73$^{***}$ | — | | | | | 89 | 113.0 | 4.1 |
| 22 Body mass index (5½ years) | −.07 | −.04 | .03 | .03 | .11 | −.16 | .02 | −.03 | .06 | −.05 | .06 | −.13 | .11 | −.08 | −.10 | .17 | .30$^{**}$ | .10 | −.13 | .90$^{***}$ | .35$^{**}$ | — | | | | 89 | 15.9 | 1.8 |
| Ice Storm variables | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 23 Objective hardship | −.11 | −.25$^{*}$ | −.13 | .10 | .21$^{*}$ | .06 | −.02 | −.05 | .04 | −.09 | −.01 | −.03 | .03 | .16 | −.17 | .07 | −.04 | −.23$^{*}$ | .21$^{\dagger}$ | .22$^{*}$ | .10 | .26$^{*}$ | — | | | 89 | 10.7 | 4.5 |
| 24 Subjective distress | −.09 | −.37$^{***}$ | −.21$^{*}$ | −.02 | .11 | .36$^{**}$ | .03 | .21$^{\dagger}$ | .31$^{**}$ | .02 | .17 | −.09 | .11 | .22$^{\dagger}$ | −.07 | −.06 | −.12 | −.16 | .06 | .15 | .19$^{\dagger}$ | .07 | .34$^{**}$ | — | | 89 | 10.5 | 12.8 |
| 25 Timing of exposure (days) | .01 | .12 | .25$^{*}$ | .01 | −.17 | −.11 | −.02 | −.10 | −.10 | .15 | −.19$^{\dagger}$ | −.01 | −.13 | −.11 | −.09 | −.14 | −.20$^{\dagger}$ | −.29$^{**}$ | .16 | .10 | −.04 | .17 | .21$^{\dagger}$ | −.03 | — | 89 | 142.3 | 81.6 |

$^{\dagger}p = <.1$.
$^{*}p = <.05$.
$^{**}p = <.01$.
$^{***}p < 0.01$.

**Table 2. Summary of Hierarchical Linear Regression Analyses**

| | Values in Final Model | | | | Values After Entry of Each Variable | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Predictor Variables | $B$ | SE $B$ | $\beta$ | $B$, $p$-Value | $R^2$ | $\Delta R^2$ | $F^*$ | $\Delta F$ | $\Delta F$, $p$-Value |
| Balance ($n = 85$) | | | | | | | | | |
| Constant | 38.704 | 12.038 | | | | | | | |
| Neonatal intensive care unit | −2.476 | 1.130 | −.212 | .031 | .098 | | 9.044** | | |
| Height at 5½ years | −.228 | .104 | −.209 | .031 | .166 | .068 | 8.184** | 6.702 | .011 |
| Sex of child | 3.188 | .872 | .358 | <0.001 | .284 | .118 | 10.729*** | 13.355 | <0.001 |
| Bilateral coordination ($n = 84$) | | | | | | | | | |
| Constant | 53.160 | 11.651 | | | | | | | |
| Height at 5½ years | −.229 | .094 | −.241 | .017 | .084 | | 7.537** | | |
| Neonatal intensive care unit | −1.840 | .978 | −.183 | .064 | .142 | .058 | 6.717** | 5.484 | .022 |
| Sex of child | −2.361 | 1.535 | −.306 | .128 | .158 | .015 | 4.987** | 1.453 | .232 |
| Timing of exposure (days) | −.023 | .015 | −.488 | .129 | .180 | .023 | 4.347** | 2.201 | .142 |
| Objective hardship | −.299 | .128 | −.336 | .022 | .241 | .060 | 4.941** | 6.177 | .015 |
| Subjective distress | −.269 | .095 | −.902 | .006 | .309 | .068 | 5.735*** | 7.611 | .007 |
| Sex × timing of exposure (days) | .021 | .009 | .761 | .030 | .346 | .037 | 5.741*** | 4.300 | .041 |
| Objective hardship × subjective distress | .014 | .007 | .692 | .058 | .377 | .031 | 5.665*** | 3.703 | .058 |
| Visual motor integration ($n = 84$) | | | | | | | | | |
| Constant | 194.664 | 37.282 | | | | | | | |
| Height at 5½ years | −.624 | .299 | −.217 | .040 | .064 | | 5.613* | | |
| Neonatal intensive care unit | −4.790 | 3.130 | −.156 | .130 | .095 | .031 | 4.260* | 2.784 | .099 |
| Sex of child | −6.202 | 4.995 | −.263 | .218 | .106 | .011 | 3.160* | .964 | .329 |
| Timing of exposure (days) | −.038 | .050 | −.258 | .452 | .190 | .084 | 4.623** | 8.162 | .005 |
| Objective hardship | −1.010 | .405 | −.377 | .015 | .229 | .039 | 4.635** | 3.984 | .049 |
| Subjective distress | −.793 | .302 | −.872 | .011 | .245 | .016 | 4.159** | 1.604 | .209 |
| Objective hardship × subjective distress | .051 | .023 | .831 | .029 | .285 | .040 | 4.321*** | 4.242 | .043 |
| Sex × timing of exposure (days) | .056 | .031 | .663 | .072 | .315 | .030 | 4.314*** | 3.334 | .072 |

*$p < .05$.
**$p < .01$.
***$p < .001$.

Coordination, boys' performance did not vary as a function of the timing of the exposure, but girls' performance declined as the exposure to the crisis was closer to birth (Fig. 1C). Next, performance remained relatively low for children whose mothers experienced high levels of subjective distress regardless of their objective hardship ratings, but performance declined with increasing maternal objective hardship levels in children whose mothers reported low levels of subjective distress (Fig. 1D). Together, these variables accounted for 37.7% of the variance in the children's VMI scores.

## DISCUSSION

Project Ice Storm has demonstrated that the objective and/or subjective PNMS from the ice storm, among the worst disasters in Canadian history (Insurance Bureau of Canada: www.ibc.ca), had significant effects on birth outcomes (Dancause et al., 2011), and on the children's cognitive and language development (Laplante et al., 2004; Laplante, Brunet, Schmitz, Ciampi, & King, 2008), physical development (Dancause et al., 2012; Dancause, Veru, Andersen, Laplante, & King, under review; King et al., 2009), and behavioral development (unpublished data). The goal of the present study was to determine whether disaster-related objective hardship and subjective distress explained variance in motor functioning in children at 5½ years of age. These analyses provide a particularly important contribution to our understandings of the effects of prenatal adversity from environmental events on central nervous system functioning, since it has been suggested that motor outcomes are probably less affected by current and past social factors than are cognition and academic success (Dietrich, Berger, & Succop, 1993). The present findings clearly indicate that high levels of objective hardship and/or subjective distress were associated with lower motor scores on two of the three motor indices that were assessed. These findings are similar to those from studies conducted with infants (Buitelaar et al., 2003; Chuang et al., 2011) and in animals (Schneider & Coe, 1993; Schneider et al., 1992, 1999).

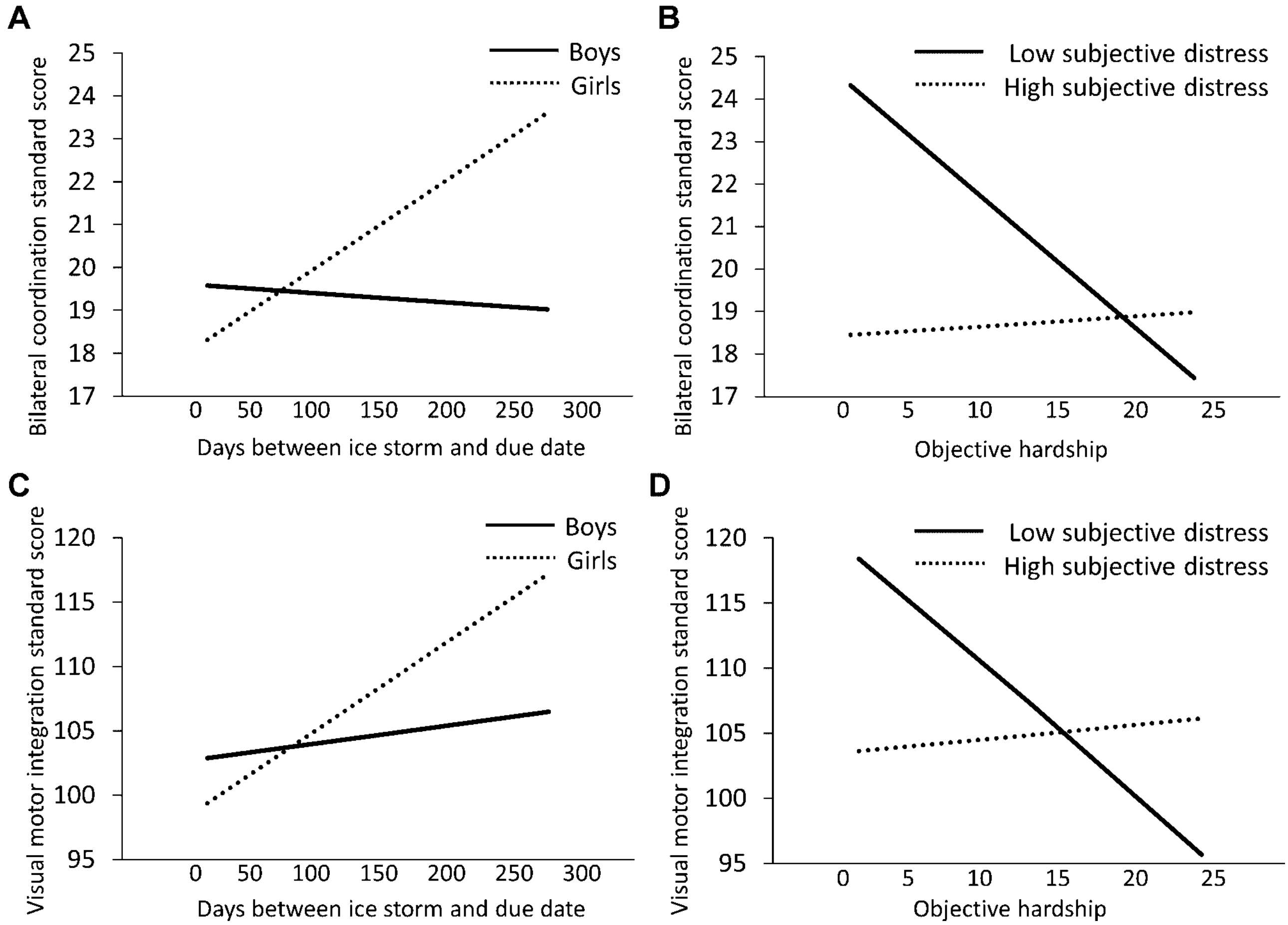


**FIGURE 1** The function of sex × timing of exposure and the objective hardship × subjective distress interaction terms on bilateral coordination and visual motor integration (VMI). Boys' performance on this task did not vary as a function of the timing of the exposure but girls' performance declined as the exposure to the crisis was closer to birth (**A** and **C**). While performance remained low for children whose mothers experienced high levels of subjective distress regardless of the mothers' objective hardship ratings, performance declined with increasing maternal objective hardship levels in children whose mothers reported low levels of subjective distress (**B** and **D**).

Unlike previous research with human cohorts, we were able to separate the PNMS measure into objective hardship and subjective distress. The results indicate that both stress measures adversely affected the children's motor functioning. However, present findings suggest that a high level of subjective distress had a universally harmful impact on the children's motor functioning whereas negative effects of objective hardship were seen only when subjective distress was low. A similar finding was observed in this cohort where both objective hardship and subjective distress predicted birth outcomes (Dancause et al., 2011). Moreover, the interaction of objective hardship and subjective distress suggests that when subjective distress is high, motor performance scores were lower with no added effect of objective hardship. However, when subjective distress is low, objective hardship had a negative effect on motor functioning.

The results suggest that late term in utero exposure was associated with decreased motor functioning, however this timing effect was seen only in girls. Animal studies provide some support that late gestation PNMS might negatively impact brain structures involved in motor functioning. Prenatal stress in rodents results in an 11% reduction in volume fraction of granule cell nuclei in granular layers, a 50% reduction of synaptic density in the cerebellum, and a decrease in the cerebellar granule-to-Purkinje cell ratio in rodents prenatally stressed late in gestation (Ulupinar & Yucel, 2005; Ulupinar, Yucel, & Ortug, 2006). Thus, it is possible that in utero exposure to high levels of PNMS may be linked to cerebellar dysfunction in humans. However, this hypothesis has yet to be tested directly.

Sex differences might be explained in part by differences in maternal cortisol levels depending on fetal sex. Similar to previous findings (Davis & Sandman, 2010), DiPietro and colleagues (DiPietro, Costigan, Kivlighan, Chen, & Laudenslager, 2011) found that maternal cortisol levels increased during normally progressing pregnancies in healthy women, but these levels vary depending on gestational week and sex of the fetus. In early pregnancy, maternal cortisol levels were higher in women carrying a male fetus; however, around 30 weeks gestation a cross-over occurred and cortisol levels were higher in women carrying a female fetus until near the end of pregnancy when maternal cortisol levels were similar regardless of fetal sex. Thus, the cortisol levels of women pregnant with a female fetus are naturally higher in late pregnancy when the fetus' cerebellum is developing. Since increases in maternal cortisol levels result in exponential increases in fetal cortisol (Gitau, Cameron, Fisk, & Glover, 1998), additional increases in maternal cortisol levels late in pregnancy may have greater impact on cerebellar development in female fetuses. Thus, during late pregnancy, the increased perturbations caused by the ice storm, coupled with carrying a female fetus, might have been sufficient to increase the production of maternal cortisol to levels high enough to affect the underlying structures involved in bilateral coordination and VMI.

A positive relation also exists between fetal cortisol and testosterone levels (Sarkar, Bergman, Fisk, O'Connor, & Glover, 2007). Thus, increased fetal cortisol levels triggered by increased maternal cortisol levels could escalate the fetus' exposure to testosterone. Increased fetal testosterone levels are associated with alteration in the asymmetry of the posterior corpus callosum (Chura et al., 2010), which is known to influence cognitive functioning such as mental imagery (Zacks, 2008) and visuospatial cognition (Hanggi et al., 2010). As such, the decrease in bilateral coordination and VMI among the girls in our sample may have been the result of increased testosterone levels. While the potential role of both cortisol and testosterone in explaining the interaction of sex-by-timing of exposure observed in the present study are speculative, they are plausible, and require further investigation.

Only two of the potential confounding variables, NICU status at birth and the child's height at age 5½, were associated with the children's motor functioning. Although it is well known that preterm newborns who have spent time in the NICU are at an elevated risk of later developmental problems (Dombkowski, Leung, & Gurney, 2008; Karimi, Fallah, Dehghanpoor, & Mirzaei, 2011), research has also reported that full-term infants admitted to the NICU for a variety of medical reasons exhibit more neurosensory, motor, and learning problems in early childhood relative to healthy controls (Schiariti et al., 2008). Why taller children in our cohort exhibited lower motor functioning is hard to explain, particularly since previous research reports contrary findings (Franjoine, Darr, Held, Kott, & Young, 2010; Habib & Westcott, 1998).

A recent review of the influence of environmental factors on motor functioning in early childhood (Venetsanou & Kambas, 2010) found that familial SES was positively related to motor functioning. While it remains unclear exactly what familial SES represents in terms of motor functioning (e.g., nutritional status, more opportunities to engage in motor activities, other factors), the research strongly suggests that motor functioning improves with increases in SES. However, we observed negative effects of PNMS on motor functioning despite the current cohort's elevated SES and overall superior motor functioning relative to established norms.

Some study limitations exist. In particular, the relatively small sample, which was not representative of the population, limits the generalizability of the results. Furthermore, due to initial and continued funding limitations, no non-stress cohort is available for direct comparisons. However, our study is the first to demonstrate that disaster-related PNMS negatively affects aspects of motor functioning in 5½-year-old children. Prenatal exposure to the ice storm was associated with lowered bilateral coordination and visual motor integration, but not balance, abilities. The timing of exposure and sex of the child influence these effects. Although the ice storm met all the criteria for a natural disaster, it may be considered as a less traumatic event than other more recent natural (Hurricane Katrina, South-East Asian Tsunami) or man-made (World Trade Center attack) disasters. Thus, Project Ice Storm could be considered a small-scale model of PNMS resulting from major catastrophic events.

## NOTES

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## REFERENCES

Beery, K. E., & Beery, N. A. (2004). The Beery-Buktenica Developmental Test of Visual-Motor Integration with Supplemental developmental tests of visual motor integration and motor coordination and stepping stones age norms from birth to age six: Administration, scoring and teaching manual (5th ed.). Minneapolis: NCS Pearson, Inc.

Bromet, E., & Dew, M. A. (1995). Review of psychiatric epidemiologic research on disasters. Epidemiologic Reviews, 17(1), 113–119.

Bruininks, R. H. (1978). Bruininks-Oseretsky test of motor proficiency. Circle Pines, MN: American Guidance Service.

Brunet, A., St-Hilaire, A., Jehel, L., & King, S. (2003). Validation of a French version of the Impact of Event Scale—Revised. Canadian Journal of Psychiatry, 48, 55–60.

Buitelaar, J. K., Huizink, A. C., Mulder, E. J., de Medina, P. G., & Visser, G. H. (2003). Prenatal stress and cognitive development and temperament in infants. Neurobiology of Aging, 24(Suppl. 1), S53–S60; discussion S67–S68.

Charil, A., Laplante, D. P., Vaillancourt, C., & King, S. (2010). Prenatal stress and brain development. Brain Research Reviews, 65(1), 56–79.

Chuang, C.-H., Liao, H.-F., Hsieh, W.-S., Jeng, S.-F., Su, Y.-N., & Chen, P.-C. (2011). Maternal psychosocial factors around delivery on development of 2-year-old children: A prospective cohort study. Journal of Paediatrics and Child Health, 47(1–2), 34–39. DOI: 10.1111/j.1440-1754.2010.01887.x

Chura, L. R., Lombardo, M. V., Ashwin, E., Auyeung, B., Chakrabarti, B., Bullmore, E. T., & Baron-Cohen, S. (2010). Organizational effects of fetal testosterone on human corpus callosum size and asymmetry. Psychoneuroendocrinology, 35, 122–132.

Cox, J. L., Chapman, G., Murray, D., & Jones, P. (1996). Validation of the Edinburgh postnatal depression scale (EPDS) in non-postnatal women. Journal of Affective Disorders, 39, 185–189.

Cox, J. L., Holden, J. M., & Sagovsky, R. (1987). Detection of postnatal depression: Development of the 10-item Edinburgh Postnatal Depression Scale. British Journal of Psychiatry, 150, 782–786.

Dancause, K. N., Laplante, D., Oremus, C., Fraser, S., Brunet, A., & King, S. (2011). Disaster-related prenatal maternal stress influences birth outcomes: Project Ice Storm. Early Human Development, 87, 813–820. DOI: 10.1016/j.earlhumdev.2011.06.007

Dancause, K. N., Laplante, D. P., Fraser, S., Brunet, A., Ciampi, A., Schmitz, N., & King, S. (2012). Prenatal exposure to a natural disaster increases risk for obesity in 5½ year old children. Pediatric Research, 71, 126–131.

Dancause, K. N., Veru, F., Andersen, R. E., Laplante, D. P., King, S. (under review). Prenatal stress predicts insulin secretion in adolescence. Journal of Adolescent Health, Submitted 23 July 2012.

Davis, E. P., & Sandman, C. A. (2010). The timing of prenatal exposure to maternal cortisol and psychosocial stress is associated with human infant cognitive development. Child Development, 81, 131–148.

Dietrich, K. N., Berger, O. G., & Succop, P. A. (1993). Lead exposure and the motor development status of urban six-year-old children in the Cincinnati Prospective Study. Pediatrics in Review, 91, 301–307.

DiPietro, J. A., Costigan, K. A., Kivlighan, K. T., Chen, P., & Laudenslager, M. L. (2011). Maternal salivary cortisol differs by fetal sex during the second half of pregnancy. Psychoneuroendocrinology, 36(4), 588–591.

Dombkowski, K. J., Leung, S. W., & Gurney, J. G. (2008). Prematurity as a Predictor of Childhood Asthma among Low-Income Children. Annals of Epidemiology, 18(4), 290–297. DOI: 10.1016/j.annepidem.2007.11.012

Ellman, L. M., Schetter, C. D., Hobel, C. J., Chicz-DeMet, A., Glynn, L. M., & Sandman, C. A. (2008). Timing of fetal exposure to stress hormones: Effects on newborn physical and neuromuscular maturation. Developmental Psychobiology, 50(3), 232–241.

Franjoine, M. R., Darr, N., Held, S. L., Kott, K., & Young, B. L. (2010). The performance of children developing typically on the pediatric balance scale. Pediatric Physical Therapy, 22(4), 350–359.

Gitau, R., Cameron, A., Fisk, N. M., & Glover, V. (1998). Fetal exposure to maternal cortisol. The Lancet, 352, 707–708.

Goldberg, D. P. (1972). The detection of psychiatric illness by questionnaire; a technique for the identification and assessment of non-psychotic psychiatric illness. London, New York: Oxford University Press.

Habib, Z. P. P. T., & Westcott, S. P. P. T. (1998). Assessment of anthropometric factors on balance tests in children. Pediatric Physical Therapy Fall, 10(3), 101–109.

Hanggi, J., Buchmann, A., Mondadori, C. R., Henke, K., Jancke, L., & Hock, C. (2010). Sexual dimorphism in the parietal substrate associated with visuospatial cognition independent of general intelligence. Journal of Cognitive Neuroscience, 22, 139–155.

Hollingshead, A. B. (1973). Four-factor index of social status. New Haven: Yale University Press.

Karimi, M., Fallah, R., Dehghanpoor, A., & Mirzaei, M. (2011). Developmental status of 5-year-old moderate low birth weight children. Brain and Development, 33(8), 651–655. DOI: 10.1016/j.braindev.2010.10.022

King, S., Mancini-Marïe, A., Brunet, A., Walker, E., Meaney, M. J., & Laplante, D. P. (2009). Prenatal maternal stress from a natural disaster predicts dermatoglyphic asymmetry in humans. Development and Psychopathology, 21, 343–353.

Laplante, D. P., Barr, R. G., Brunet, A., Galbaud du Fort, G., Meaney, M., Saucier, J.-F., . . . King, S. (2004). Stress during pregnancy affects intellectual and linguistic functioning in human toddlers. Pediatric Research, 56, 400–410.

Laplante, D. P., Brunet, A., Schmitz, N., Ciampi, A., & King, S. (2008). Project Ice Storm: Prenatal maternal stress affects cognitive and linguistic functioning in 5½-year-old children. Journal of the American Academy of Child and Adolescent Psychiatry, 47(9), 1063–1072.

Laplante, D. P., Zelazo, P. R., Brunet, A., & King, S. (2007). Functional play at 2 years of age: Effects of prenatal maternal stress. Infancy, 12(1), 69–93.

Maccari, S., Darnaudery, M., Morley-Fletcher, S., Zuena, A. R., Cinque, C., & Van Reeth, O. (2003). Prenatal stress and long-term consequences: Implications of glucocorticoid hormones. Neuroscience and Biobehavioral Reviews, 27, 119–127.

McFarlane, A. C. (1988). Relationship between psychiatric impairment and a natural disaster: The role of distress. Psychological Medicine, 18(1), 129–139.

Rieger, M., Pirke, K. M., Buske-Kirschbaum, A., Wurmser, H., Papousek, M., & Hellhammer, D. H. (2004). Influence of stress during pregnancy on HPA activity and neonatal behavior. Annals of the New York Academy of Sciences, 1032, 228–230.

Sarason, I. G., Johnson, J. H., & Siegel, J. M. (1978). Assessing the impact of life changes: Development of the Life Experience Survey. Journal of Consulting & Clinical Psychology, 46(5), 932–946.

Sarkar, P., Bergman, K., Fisk, N. M., O'Connor, T. G., & Glover, V. (2007). Amniotic fluid testosterone: Relationship with cortisol and gestational age. Clinical Endocrinology, 67(5), 743–747. DOI: 10.1111/j.1365-2265.2007.02955.x

Schiariti, V., Klassen, A. F., Houbé, J. S., Synnes, A., Lisonkova, S., & Lee, S. K. (2008). Perinatal characteristics and parents' perspective of health status of NICU graduates born at term. Journal of Perinatology, 28(5), 368–376.

Schneider, M. L., & Coe, C. L. (1993). Repeated social stress during pregnancy impairs neuromotor development in the primate infant. Journal of Developmental & Behavioral Pediatrics, 14(2), 81–87.

Schneider, M. L., Coe, C. L., & Lubach, G. R. (1992). Endocrine activation mimics the adverse effects of prenatal stress on the neuromotor development of the infant primate. Developmental Psychobiology, 25(6), 427–439.

Schneider, M. L., Roughton, E. C., Koehler, A. J., & Lubach, G. R. (1999). Growth and development following prenatal stress exposure in primates: An examination of ontogenetic vulnerability. Child Development, 70, 263–274.

Ulupinar, E., & Yucel, F. (2005). Prenatal stress reduces interneuronal connectivity in the rat cerebellar granular layer. Neurotoxicology and Teratology, 27(3), 475–484. DOI: S0892-0362(05)00027-9. [pii] 10.1016/j.ntt.2005.01.015

Ulupinar, E., Yucel, F., & Ortug, G. (2006). The effects of prenatal stress on the Purkinje cell neurogenesis. Neurotoxicology and Teratology, 28(1), 86–94. DOI: S0892-0362(05)00145-5. [pii] 10.1016/j.ntt.2005.10.003

Venetsanou, F., & Kambas, A. (2010). Environmental factors affecting preschoolers' motor development. Early Childhood Education Journal, 37(4), 319–327.

Weinstock, M. (2008). The long-term behavioural consequences of prenatal stress. Neuroscience and Biobehavioral Reviews, 32(6), 1073–1086.

Weiss, D. S., & Marmar, C. R. (1997). The Impact of Event Scale—Revised. New York: Guilford.

Zacks, J. M. (2008). Neuroimaging studies of mental rotation: A metaanalysis and review. Journal of Cognitive Neuroscience, 20, 1–19.