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A Potential Psychological Mechanism Linking Disaster-Related Prenatal Maternal Stress With Child Cognitive and Motor Development at 16 Months: The QF2011 Queensland Flood Study

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Fetal exposure to prenatal maternal stress can have lifelong consequences, with different types of maternal stress associated with different areas of child development. Fewer studies have focused on motor skills, even though they are strongly predictive of later development across a range of domains. Research on mechanisms of transmission has identified biological cascades of stress reactions, yet links between psychological stress reactions are rarely studied. This study investigates the relationship between different aspects of disaster-related prenatal maternal stress and child cognitive and motor development, and proposes a cascade of stress reactions as a potential mechanism of transmission. Mothers in the Queensland Flood Study (QF2011) exposed to a major flood during pregnancy completed questionnaires assessing flood exposure, symptoms of peritraumatic distress, dissociation, and posttraumatic stress (PTSD), and cognitive appraisal of the overall flood consequences. At 16 months post-partum, children's ($N = 145$) cognitive and motor development was assessed using the Bayley-III. Flood exposure predicted child cognitive development and maternal PTSD symptoms and negative cognitive appraisal were significantly negatively related to child motor development, with all relationships moderated by timing of exposure. Together, a cascade of stress reactions linked maternal flood exposure to poorer fine motor development. These findings suggest that the way stress reactions operate together is as important as the way they operate in isolation, and identifies a potential psychological mechanism of transmission for the effects of prenatal stress. Results have implications for conceptualizing prenatal stress research and optimizing child development in the wake of natural disasters.

Keywords: child development, prenatal maternal stress, timing in utero, sex, natural disasters

Different types of stress during pregnancy, such as natural disasters, life events, perceived stress, work stress and daily hassles, have been associated with different areas of child development, including birth outcomes, play, cognition, language, temperament, behavior, and motor (Bergman, Sarkar, O'Connor, Modi, & Glover, 2007; Cao, Laplante, Brunet, Ciampi, & King, 2014; Chuang et al., 2011; Dancause et al., 2011; Grace, Bulsara, Robinson, & Hands, 2015; Gutteling et al., 2005; Huizink, De Medina, Mulder, Visser, & Buitelaar, 2002; King, Dancause, Turcotte-Tremblay, Veru, & Laplante, 2012; Laplante et al., 2004; Laplante, Brunet, & King, 2016; Laplante, Zelazo, Brunet, & King, 2007; Slykerman et al., 2005). Few prenatal stress studies focus on child motor development (Sandman & Davis, 2010), even though early motor development predicts later development in a range of areas and delays in motor development can result in delays elsewhere (Bornstein, Hahn, & Suwalsky, 2013). It is essential to better understand the relationship between prenatal maternal stress and subsequent child development, given the potent influence of pre-

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natal stress (Graignic-Philippe, Dayan, Chokron, Jacquet, & Tordjman, 2014; Sandman, Davis, Buss, & Glynn, 2012) and the importance of early skills to later child development (Bornstein et al., 2013). Furthermore, theories of the biological mechanisms of transmission (Glover, 2014; O'Connor, Monk, & Fitelson, 2014) suggest it would be beneficial to explore whether maternal psychological reactions exert combined, and not just unique, influences on child development. This study aims to investigate the extent to which different aspects of disaster-related prenatal maternal stress relate to child cognitive and motor development at 16 months, and tests a novel cascade of stress reactions as a potential psychological mechanism of transmission.

Prenatal Maternal Stress and Child Development

Defining Stress

Stress is the emotional, behavioral, and physiological response to a situation that is appraised as exceeding a person's coping resources and threatening their well-being (Carver, 1997; Lazarus & Folkman, 1984; Levy-Shiff, Dimitrovsky, Shulman, & Har-Even, 1998). Stress is associated with adverse impacts on both physical and mental health (Holahan & Moos, 1985; Kessler, Price, & Wortman, 1985; Razurel, Kaiser, Sellenet, & Epiney, 2013). When stress occurs during pregnancy it can also influence the developing fetus, resulting in lifelong consequences (Barker et al., 1993; Martin & Brantley, 2004; Sandman & Davis, 2010).

The Differential Effects of Maternal Stress

However, this picture is more nuanced than simply saying that stress during pregnancy is harmful. Some studies have found positive or curvilinear effects, with low to moderate amounts of stress predicting better development (e.g., DiPietro, Novak, Costigan, Atella, & Reusing, 2006; King et al., 2012). Other studies have found differential effects, where stressors are associated with one area of development but not another. For example, prenatal anxiety and depression are associated with different areas of development (Keim et al., 2011; van Batenburg-Eddes et al., 2009), and the same is true for prenatal stress. For example, Laplante et al. (2004) found that at 2 years of age the severity of objective prenatal exposure to an ice storm predicted cognitive development, language and play, yet the posttraumatic distress-like symptoms associated with the storm only predicted play. In a national cohort study, Tegethoff, Greene, Olsen, Schaffner, and Meinlschmidt (2011) also found that although there was some overlap, exposure to prenatal life stress and emotional stress predicted different health outcomes in later childhood (3.6 years old to 8.9 years old). Other studies show a similar pattern (e.g., Davis & Sandman, 2010; DiPietro et al., 2006; Huizink et al., 2002), demonstrating that prenatal stress has differential effects on child development.

The Influence of Timing and Sex

Potential explanations for differential effects are the timing of stress exposure during gestation and the sex of the child. Fetal organs and systems mature at different times throughout pregnancy, suggesting that periods of vulnerability vary, and this may be one reason why stress at a particular time can influence one area of development and not another (O'Donnell & Glover, 2008). Several prenatal stress studies have found trimester effects (Davis & Sandman, 2010; Ellman et al., 2008; Glynn, Wadhwa, Dunkel-Schetter, Chicz-DeMet, & Sandman, 2001). For example, in Project Ice Storm, King et al. (2012) reported that stress exposure during the first and second trimester of pregnancy was associated with poorer cognitive development, whereas third trimester exposure was key for motor development (Cao et al., 2014), but no timing effects were observed for internalizing and externalizing behavior. In prenatal stress studies where results have been nonsignificant for some areas of child development, this may have been because these areas were not in a critical stage of development at the time of stress exposure.

The relationship between prenatal stress and child development can also differ according to the sex of the child (Glover & Hill, 2012). Both animal and human studies show that male and female fetuses respond differently to prenatal adversity, laying the foundation for sexually dimorphic trajectories of development (Ellman et al., 2008; Sandman & Davis, 2010; Sandman et al., 2012). It is theorized that ". . . males are more vulnerable to developmental insults, including prenatal adversity" (Sandman & Davis, 2010, p. 682), yet females experience increased variability in developmental trajectories (Sandman, Glynn, & Davis, 2013). This may be due to different responses to elevated glucocorticoids by male and female placentae (Clifton, 2010). However, some prenatal stress studies have failed to find sex differences in the relationship between prenatal maternal stress and child development (e.g., DiPietro et al., 2006). Despite some mixed results, studies that do not account for the sex of the child may overlook important relationships.

Disaster-Related Prenatal Maternal Stress

Studies of prenatal maternal stress have typically relied on stressors such as daily hassles and pregnancy-specific anxiety as ethical considerations preclude random assignment of pregnant mothers to stressful conditions (King et al., 2012; Sandman & Davis, 2010). However, these types of stress often do not have a defined onset, which makes it difficult to pinpoint the timing of exposure during gestation, and it is also difficult to separate the influence of shared genetics from the influence of maternal stress on child development (DiPietro, 2012; King et al., 2012). In contrast, natural disasters can function as natural experiments. They enable measurement of objective hardship, which is independent of maternal factors, as well as subjective distress, comparable to other prenatal stress studies (King et al., 2012; Sandman & Davis, 2010). In addition, disasters typically have a clear and distinct onset, enabling accurate pinpointing of stress exposure during gestation (King et al., 2012; Sandman & Davis, 2010).

Two cohort studies have used a natural disaster to investigate the influence of prenatal stress on child development. In Project Ice Storm, higher disaster-related objective hardship predicted lower cognitive development at 2 years of age and lower IQ and motor development at 5.5 years of age, and higher objective hardship and subjective distress predicted lower motor development at 5.5 years of age; sex and timing effects were evident (Cao et al., 2014; Laplante et al., 2004; Laplante, Brunet, Schmitz, Ciampi, & King, 2008) In the Queensland Flood Study (QF2011), Simcock et al. (2016) found that maternal appraisal of the overall consequences of a major urban flood predicted better maternal-rated infant motor development at 2 months and poorer infant motor development at 6 and 16 months, with effects moderated by timing at 6 and 16 months. Subjective distress was not significant, although objective hardship predicted development at 6 months.

In the wake of disasters, it is estimated that up to 17% to 20% of people will develop psychological morbidity (McFarlane, 1990; Rubonis & Bickman, 1991). However, because not all people who experience a disaster go on to develop symptoms like PTSD, ". . . the mechanisms by which disasters lead to mental health effects warrant more extensive consideration. For example, higher levels of dissociative reactions in the initial aftermath of some events . . . may heighten individuals' likelihood for psychopathology" (Bromet & Dew, 1995, p. 117). Experiencing distress during or immediately after a traumatic event is a potent risk factor for developing PTSD symptoms, and dissociation predicts symptom persistence (Brunet et al., 2001; Thomas, Saumier, & Brunet, 2012). This model suggests a cascade of stress reactions that can link traumatic event exposure to later symptom occurrence and is a potential psychological mechanism for transmitting the effects of maternal stress to the developing fetus. However, this model has not yet been tested in the prenatal stress literature.

The Present Study

The overall aims of this study were to (a) investigate the relationship between different aspects of disaster-related stress and child cognitive and motor development at 16 months, moderated by timing and sex and (b) to test a potential psychological mechanism of transmission by exploring how different stress reactions work together to predict development. In January 2011, the state of Queensland, Australia experienced a flood that saw 78% of the state declared a disaster area, 29,000 homes and business inundated, 2.5 million people affected and 33 people killed (Queensland Floods Commission of Inquiry, 2012). The QF2011 Queensland Flood Study used this flood as a source of objective hardship and, in addition, measured the severity of three different types of subjective stress reaction: peritraumatic distress, peritraumatic dissociation, posttraumatic stress symptoms, as well as a cognitive appraisal of the overall consequences of the flood.

We hypothesized that the severity of objective hardship and subjective stress reactions would predict different aspects of child development. We anticipated that relationships with child development would be moderated by timing and sex. Last, we hypothesized that a cascade of maternal stress reactions would link flood exposure with child development, with higher flood exposure related to worse development.

Method

Participants. The participants in the present study were part of the QF2011 Study, an ongoing prospective longitudinal study on maternal stress and child development (King et al., 2015). Eligibility criteria included being pregnant during the flood, singleton birth, aged 18 years or older, fluent in English, and able to provide informed consent. At recruitment, 227 women provided informed consent. The sample for the present study includes the 145 mother–infant dyads with gestation of at least 36 weeks who completed a face-to-face developmental assessment at 16 months (M = 16.48 months, SD = 0.57 months, range = 14.78–18.10 months). Three infants were excluded for birth prior to 36 weeks gestation as per previous research on the effects of prenatal maternal stress (Davis & Sandman, 2010; DiPietro et al., 2006; O'Connor et al., 2003).

At recruitment, the majority of the sample was married or had a partner, with only 4.1% single. The sample was highly educated, with more than half (53.1%) having completed a tertiary degree and only 10.3% not completing any further study since high school. More than half were employed either full-time (37.2%) or part-time (20.0%), and most (82.8%) had pre-tax incomes of $1,000 AUD or more per week. Only 4.8% relied on a government benefit as the main income. The majority (96%) identified their cultural background as White/Caucasian. At the birth of the study child, mothers ranged in age from 19 to 47 years (M = 31.48 years, SD = 5.02 years) and half were primiparous (49.2%). There were slightly more boys (55.9%) than girls (44.1%). Flood exposure occurred in the first trimester for 38.6% of the dyads, second trimester for 36.6%, and third trimester for 24.8%.

Procedures. The QF2011 Study partnered with an existing randomized control trial on midwifery group care (the M@NGO study; see Tracy et al., 2011, 2014) and began recruitment in April 2011 at a large metropolitan hospital located in the flood zone (see King et al., 2015 for a detailed description of recruitment procedures and methodology). Measurement for the QF2011 study occurred at recruitment and/or 12 months postflood and at 16 months postpartum. The recruitment questionnaire included measures of objective hardship (flood exposure), subjective stress, maternal mental health, coping strategies, and demographics. The questionnaire at 16 months included measures of maternal mental health, life stress, parenting stress, coping, social support, and infant development. At 16 months, mothers were also invited to attend a lab-based assessment which commenced with measures of the child's cognitive, gross motor, and fine motor development. Participants received a $30 gift voucher at recruitment, and at the 16-month assessment mothers received a $30 gift voucher and children received a small toy. All phases of this study have received ethical approval from the Mater Hospital HREC (1709M, 1844M) and The University of Queensland (2013001236).

Measures.

Objective hardship. The severity of flood exposure (objective hardship) was assessed at recruitment and/or 12 months postflood using the Queensland Flood Objective Stress Scale (King et al., 2015). This survey was tailored to the events of the Queensland flood and is based on instruments used in other disaster studies (e.g., Laplante et al., 2007; Yong Ping et al., 2015). A total of 49 items assess four categories of objective hardship experienced during the flood: threat (e.g., "Were you physically hurt because of the flood?"), loss (e.g., ". . . please estimate the total value of all material loss and damage experienced because of the flood."), scope (e.g., "To what extent was your immediate community changed because of the flooding?"), and change (e.g., "How many times were you required to change homes because of the flood?"). The maximum score for each subscale is 50, with a total score ranging from 0 to 200. Higher scores indicate more severe hardship.

Subjective maternal stress reactions. Subjective stress reactions related to the flood were assessed at recruitment and/or 12 months postflood using three instruments. The Impact of Event

Scale–Revised (IES-R; Weiss & Marmar, 1997) is commonly used to measure trauma-related distress, particularly in disaster studies (Laplante et al., 2007), and assesses three categories of symptoms related to PTSD: intrusive thoughts and images, hyperarousal, and avoidance. Participants were asked to refer to the flood and respond to 22 items on a five-point Likert scale ranging from 0 (*not at all*) to 4 (*extremely*). The IES-R has high internal consistency (alpha coefficients from 0.79 to 0.94), and adequate test–retest reliability (correlation coefficients from 0.51 to 0.94; Creamer, Bell, & Failla, 2003; Weiss & Marmar, 1997).

The Peritraumatic Distress Inventory (PDI-Q; Brunet et al., 2001) is a 13-item scale that retrospectively assesses the emotional and physical reactions that occurred around the time of trauma. Respondents were asked to recall their reactions during and immediately after the flood, and to rate each item on a five-point Likert scale from 0 (*not at all true*) to 4 (*extremely true*). This measure is internally consistent (coefficient $\alpha = .76$), stable over time (Brunet et al., 2001), and predictive of PTSD (Guardia et al., 2013).

The Peritraumatic Dissociative Experiences Questionnaire (PDEQ; Marmar, Weiss, & Metzler, 1997) is a 10-item scale that measures dissociative reactions that can occur after a traumatic event. Respondents were asked to recall their reactions during and immediately after the flood, and to rate each item on a five-point Likert scale ranging from 0 (*not at all true*) to 4 (*extremely true*). It is internally consistent (Cronbach's $\alpha = .85$; Brunet et al., 2001), has a high correlation with PTSD symptoms, and is the most widely used measure of trauma-related dissociation (Brooks et al., 2009).

Cognitive appraisal. In addition, participants were asked to make a cognitive appraisal of the overall consequences of the flood. The single item read, "If you think about all of the consequences of the 2011 Queensland flood on you and your household, would you say the flood has been . . .", with responses rated on a five point Likert scale that was dichotomized into *negative/very negative* and *there were no consequences/positive/very positive*.

Postnatal covariates. Major life events, excluding the 2011 flood, were assessed at 16-months post-partum using a modified version of the Life Experiences Survey (Sarason, Sarason, Shearin, & Pierce, 1987). This questionnaire lists 26 categories of life events, such as divorce, illness, or changes in employment. Participants were asked to indicate whether they had experienced the event since the conception of the study child, to list the month and year the event occurred, and to rate its impact on a 7-point Likert scale ranging from −3 (*extremely negative*) to 3 (*extremely positive*). Events that occurred prior to conception or that related to flood events assessed by other measures were excluded. For this study, the total number of events and total impact were summed for postnatal events.

Parenting stress was measured at 16-months post-partum using the short form of the Parenting Stress Index (PSI-SF; Abidin, 1995). This 36-item questionnaire measures stress within the parent–child system and comprises three subscales. The Parental Distress subscale measures perceived competence, conflict, social support and role stress. The Parent–Child Dysfunctional Interaction subscale (PSIDI) measures the extent to which the child meets the parent's expectations, and the level of reward associated with interactions. The Difficult Child subscale measures the parent's perception of the child's temperament, compliance and demands. Most items are rated on a five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The PSI-SF correlates well with the longer Parenting Stress Index, is considered to have good construct validity, and is widely used in studies of parenting stress (Reitman, Currier, & Stickle, 2002).

The short form of the Depression, Anxiety and Stress Scale (Lovibond & Lovibond, 1995) was administered at 16-months post-partum to assess maternal mental health. It is a 21-item measure broken into three subscales, one each for stress, anxiety and depression. Respondents rate each item on a four-point Likert scale ranging from 0 (*did not apply to me at all*) to 3 (*applied to me very much, or most of the time*).

Birth outcome data (birth weight, gestation) were extracted from the hospital database. Birth weight was subsequently standardized by gestational age and sex and all three variables were treated as continuous covariates.

Child development. The Cognitive and Motor scales of the Bayley Scales of Infant Development (3rd ed. [BSID-III]; Bayley, 2006a) were administered at 16 months of age by Bayley-accredited researchers who were blind to the mother's stress status. The Bayley is a standardized assessment of developmental functioning and is widely used in studies of child development. The BSID-III has high internal consistency and has been extensively validated, with average reliability coefficients of 0.91 for the Cognitive Scale, 0.86 for the Fine Motor Scale, and 0.91 for the Gross Motor Scale (Bayley, 2006b). Scaled scores ($M = 10$, $SD = 3$) can be calculated by referencing raw scores against norms for developmental ages as per the user manual (Bayley, 2006a).

Statistical analyses. Analyses were performed using SPSS (Version 21; IBM Corp, 2012). First, attrition analyses were conducted. Second, missing data from the PSI at 16 months (9%) were imputed via a regression model that used PSI, anxiety and depression data from other time points within the QF2011 study as predictors. Scores for flood-related variables were finalized by integrating ratings provided at recruitment, 12 months postflood, or both.

Third, descriptive analyses were conducted on all study variables. Predictors and covariates were transformed as required to correct non-normality and reduce the influence of outliers. Outcome variables were not transformed as this would reduce interpretability of standardized scores; instead, the single outliers on the cognitive and motor scales were recoded to a value that was 3 standard deviations below the mean. This process maintains the participant's rank order but reduces the influence on the normality of the distribution (Ghosh & Vogt, 2012).

Fourth, bivariate correlations were calculated to explore relationships between predictor variables, covariates and child development. Pearson's r was used for continuous and dichotomous variables and Spearman's rho for categorical variables.

Fifth, a series of moderation analyses was conducted using the PROCESS macro (Hayes, 2013), to explore whether the child's sex or the timing of flood exposure during gestation moderated the relationships between child development and objective hardship, peritraumatic distress, peritraumatic dissociation, PTSD symptoms, or cognitive appraisal. Models controlled for flood exposure and were run separately for cognitive, fine and gross motor development. Covariates that were correlated with the outcome variable at $p < .10$ were included in the models. Simple slopes and the Johnson-Neyman (J-N) technique were used to probe significant interactions. Traditionally, the pick-a-point approach to simple slopes uses one standard deviation above and below the mean to contrast high and low values. However, these values may fall outside the sample, particularly if the data are skewed (Hayes, 2013). An alternative approach is to plot the values at the 10th, 25th, 50th, 75th, and 90th percentiles (Hayes, 2013). In our sample, these percentiles corresponded to the 4th, 9th, 17th, 26th, and 35th week of pregnancy. For continuous moderators, the J-N technique adopts a region of significance approach, identifying the values of the moderator at which the effect of the predictor on the outcome becomes significant (i.e., where the 95% confidence interval for the effect does not contain 0 and $p < .05$).

Finally, moderated serial mediations were conducted to test the sequence of objective hardship > peritraumatic distress > PTSD symptoms > child development, moderated by timing. Models controlled for covariates correlated at $p < .10$ and used 10,000 bootstraps to generate 95% bias-corrected confidence intervals, using the procedure described in Hayes (2015). All regression coefficients are unstandardized.

Results

Maternal stress. Separate variance *t*-tests showed that participants who did ($N = 145$) and did not ($N = 79$) attend the 16-month assessment differed on only one flood related variable: Participants present at 16 months reported slightly higher objective hardship on average ($M_{\log} = 2.83$) than did the participants who did not attend ($M_{\log} = 2.62$), $t(222) = -2.02$, $p = .045$.

Scores on the flood-related variables indicate a wide range of objective hardship within the sample and variability in subjective stress reactions (see Table 1). Flood-related variables were all significantly correlated (see Table 2). The stability of these measures over time was calculated for participants with data at both recruitment and 12 months postflood ($n = 75$). Paired samples correlations were high and significant for peritraumatic distress ($r = .620$, $p < .001$), peritraumatic dissociation ($r = .760$, $p < .001$), and PTSD symptoms ($r = .779$, $p < .001$), suggesting high stability.

Associations between maternal stress and child cognitive development. The majority of children were in the average range on the Cognitive Scale, with 19 children scoring above and 1 child scoring below average. The mean for the Cognitive Scale was slightly above the normed average (see Table 1). Maternal flood-related variables were not correlated with cognitive development (see Table 1). The timing of flood exposure showed a negative trend with children's cognitive scores ($p = .085$), suggesting that cognitive development worsened as flood exposure occurred closer to birth. Postnatal maternal stress and maternal demographics were also uncorrelated with cognitive development, with the exception of the Dysfunctional Interaction subscale (PSIDI) of the PSI, suggesting that higher levels of dysfunction within the mother-child relationship were

Table 1
Descriptives of Key Predictors/Covariates and Correlations with Child Development

				Correlation with child development		
Measure	*N*	*M* (*SD*)	Range	Cognitive	Fine motor	Gross motor
Maternal stress/appraisal						
Objective hardship	145	21.28 (17.26)	2–81	−.014	−.134	−.013
Peritraumatic distress	145	12.26 (8.74)	0–42	.058	−.005	.010
Peritraumatic dissociation	145	6.13 (7.79)	0–32	.025	−.033	.045
PTSD symptoms	145	6.86 (11.99)	0–66	−.072	−.180*	−.122
Cognitive appraisal[a]	144	36% negative 64% neutral/positive		.072	.096	.138
Child development						
Cognitive	145	11.23 (2.20)	5–18		.369**	.411**
Fine motor	143	12.98 (1.94)	7–18	.369**	–	.355**
Gross motor	145	9.40 (2.23)	4–16	.411**	.355**	
Moderators						
Timing of flood (weeks gestation)	145	18.09 (11.10)	.14–38.28	−.144[b]	−.122	−.153[b]
Sex of child[c]	145	56% male 44% female		.110	.126	.146[b]
Covariates						
Anxiety	132	3.15 (4.13)	0–18	−.112	−.058	−.029
Stress	132	10.89 (7.56)	0–34	.006	−.113	−.113
Depression	132	4.80 (5.81)	0–26	.038	.055	.142
Parent distress	145	26.75 (8.64)	12–50	−.117	−.047	.044
Dysfunctional interaction	145	16.48 (5.33)	12–46	−.166*	−.203*	−.166*
Difficult child	145	23.99 (8.01)	12–50	−.101	−.048	−.045
Number of postnatal events	129	3.83 (2.77)	0–15	.036	.069	.072
Impact postnatal events	129	−1.78 (5.46)	−23–12	.045	−.014	−.035
Gestational age (weeks)	145	39.37 (1.10)	36–42	.039	.050	.044
Birthweight (grams)	144	3567.67 (447.56)	2,712–5,050	.114	.152[b]	.044
Standardized weight[d]	144	.28 (.80)	−1.5–3	.132	.152[b]	.042

Note. PTSD = posttraumatic stress disorder.
[a] Coding for cognitive appraisal: 0 = *negative/very negative*, 1 = *neutral/positive/very positive*. [b] $p = .051$–.99. [c] Coding for sex: 0 = male, 1 = female. [d] Birthweight standardized by gestational age and sex.
* $p < .05$. ** $p < .001$.

Table 2
Correlations Among Maternal Flood-Related Variables

Variable	1	2	3	4	5
1. Objective hardship	—				
2. PTSD symptoms	.592**	—			
3. Peritraumatic distress	.428**	.588**	—		
4. Peritraumatic dissociation	.388**	.458**	.672**	—	
5. Cognitive appraisal[a]	−.533**	−.442**	−.293**	−.217*	—
6. Timing of exposure	.008	.105	.006	−.026	.060

Note. PTSD = posttraumatic stress disorder.
[a] Coding for cognitive appraisal: 0 = *negative/very negative*, 1 = *neutral/positive/very positive*.
* $p < .05$. ** $p < .001$.

associated with lower cognitive development scores. As such, the PSIDI was included as a covariate in all further analyses of cognitive scores.

Moderation analyses revealed a significant interaction between objective hardship and timing, explaining 4.4% of the variance in cognitive scores (the total variance explained was 9.0%; see Table 3). Controlling for the PSIDI, the J-N technique indicated that the conditional effect of objective hardship on cognitive scores was significant prior to 5 weeks gestation and after 30 weeks gestation. Simple slopes analysis of percentiles (see Figure 1) showed that when flood exposure occurred at 4 weeks gestation, cognitive development scores were higher (1.68 points) in children of mothers with more severe objective hardship, compared to children of mothers with less severe objective hardship. In contrast, when flood exposure occurred at 34 weeks gestation, cognitive development scores were lower (−1.99 points) in children of mothers with more severe objective hardship, compared to children of mothers with less severe objective hardship.

No significant interactions were found between timing and peritraumatic distress, peritraumatic dissociation, PTSD symptoms or cognitive appraisal. No significant interactions were found between child sex and any of the maternal flood-related variables.

Associations between maternal stress and child fine motor development. The majority of children were in the average range on the overall Motor Composite Scale (fine and gross motor combined), with 13 children scoring above and 2 children scoring below average. The mean for the Fine Motor Scale was one normed standard deviation above the normed average (see Table 1). Bivariate correlations showed that maternal PTSD symptoms were significantly negatively correlated with child fine motor scores, with higher PTSD symptoms associated with lower development (see Table 1). There was a trend for birth weight (standardized and unstandardized, *p*s = .071). Objective

Table 3
Ordinary Least Squares Regression Coefficients for the Moderation by the Timing of Flood Exposure During Pregnancy of the Relationship Between Maternal Stress Variables and Child Development at 16 Months Old

	Coefficient	95% CI	*SE*	*t*	*p*
Objective hardship and cognitive scores (N = 145)[a]					
Constant	9.83	[6.96, 12.70]	1.45	6.78	<.001
Objective hardship	1.02	[.11, 1.94]	.46	2.21	.028
Timing of flood	.14	[.01, .28]	.07	2.15	.033
PSIDI	−.07	[−.14, −.00]	.03	−2.08	.040
Objective Hardship × Timing (ΔR^2 = .044, p = .010)	−.06	[−.10, −.01]	.02	−2.60	.0
PTSD symptoms and fine motor scores (N = 142)[b]					
Constant	16.11	[12.14, 20.09]	2.01	8.25	<.001
PTSD symptoms	.24	[−.29, .77]	.27	1.01	.371
Timing of flood	.02	[−.03, .07]	.02	.88	.382
Objective hardship	−.13	[−.63, .38]	.26	−.72	.618
PSIDI	−2.45	[−5.41, .52]	1.45	−1.66	.105
Birthweight (standardized by gestational age)	.39	[.01, .78]	.20	2.01	.047
PTSD × Timing (ΔR^2 = .026, p = .048)	−.02	[−.05, −.0002]	.01	−2.02	.048
Cognitive appraisal and gross motor scores (N = 144)[c]					
Constant	12.36	[7.98, 16.73]	2.21	5.59	<.001
Cognitive appraisal[d]	−.67	[−2.13, .79]	.74	−.90	.367
Timing of flood	−.09	[−.14, −.03]	.03	−3.06	.003
Objective hardship	.28	[−.27, .83]	.28	1.01	.314
Sex	.49	[−.23, 1.21]	.36	1.35	.179
PSIDI	−2.51	[−5.70, .68]	1.61	−1.56	.122
Cognitive Appraisal × Timing (ΔR^2 = .040, p = .013)	.09	[.02, .15]	.03	2.51	.013

Note. PSIDI = Dysfunctional Interaction subscale of the Parenting Stress Index; PTSD = posttraumatic stress disorder symptoms.
[a] R^2 = .090, *MSE* = 4.53, $F(4, 140)$ = 3.48, p = .010. [b] R^2 = .111, *MSE* = 3.45, $F(6, 135)$ = 3.02, p = .014. [c] R^2 = .135, *MSE* = 4.53, $F(6, 137)$ = 3.55, p = .003. [d] Coding for cognitive appraisal: 0 = *negative/very negative*, 1 = *neutral/positive/very positive*.

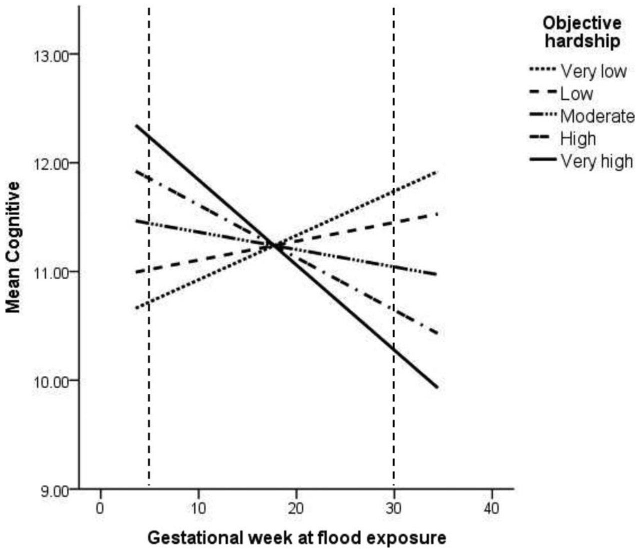

Figure 1. The moderating effect of timing (i.e., the week of flood exposure during gestation) on the relationship between objective hardship (log transformed) and child cognitive scores. The region of significance is to the left of the first and to the right of the second vertical dashed line.

hardship, peritraumatic distress and peritraumatic dissociation were not correlated with child fine motor development. Postnatal maternal stress and maternal demographics were also uncorrelated with motor development, with the exception of the PSIDI. This significant negative correlation suggests that higher levels of dysfunction within the mother-child relationship were associated with lower fine motor development scores. As such, the PSIDI was included as a covariate in all further analyses of fine motor scores.

Moderation analyses revealed a significant interaction between PTSD symptoms and timing, explaining 2.6% of the variance in fine motor scores (the total variance explained was 11.1%; see Table 3). Controlling for objective hardship, standardized birth weight, and the PSIDI, the J-N technique indicated that the conditional effect of PTSD symptoms on fine motor scores was significant from 26 weeks gestation onward. Simple slopes analysis of percentiles (see Figure 2) showed that when flood exposure occurred at 34 weeks gestation, average fine motor development was close to one standard deviation lower (1.77 points) in children of mothers with more severe PTSD symptoms, compared to children of mothers with no PTSD symptoms. Overall, fine motor scores were lower in children whose mothers reported more severe PTSD symptoms, but only when flood exposure occurred from 26 weeks gestation onward.

No significant interactions were found between timing and objective hardship, peritraumatic distress, peritraumatic dissociation or cognitive appraisal. No significant interactions were found between sex and any of the maternal flood-related variables.

Associations between maternal stress and child gross motor development. The mean for the Gross Motor Scale was slightly below the normed average (see Table 1). Bivariate correlations showed that objective hardship, peritraumatic distress, peritraumatic dissociation, and PTSD symptoms were not correlated with child gross motor development. The timing of flood exposure showed a negative trend with gross motor scores ($p = .066$), suggesting that motor development worsened as flood exposure occurred closer to delivery. Sex showed a positive trend with gross motor scores ($p = .082$), suggesting that scores were higher for girls, so sex was included as a covariate in all further analyses. Birth outcomes, maternal postnatal stress, and maternal demographics were not correlated with child gross motor development, with the exception of the PSIDI. This significant negative correlation suggests that higher levels of dysfunction within the mother-child relationship were associated with lower gross motor scores. The PSIDI was included as a covariate in all further analyses.

Moderation analyses revealed a significant interaction between cognitive appraisal and timing, explaining 4.0% of the variance in gross motor scores (the total variance explained was 13.5%; see Table 3). Controlling for objective hardship, sex and the PSIDI, there was no significant relationship between timing and gross motor scores when mothers appraised the impact of the flood as neutral or positive. However, when mothers appraised the flood as negative, gross motor scores worsened as flood exposure occurred later in pregnancy (see Figure 3). The J-N technique showed that the conditional effect of cognitive appraisal on gross motor scores transitioned to significance at 17 weeks gestation. Simple slopes analysis based on percentiles shows that when flood exposure occurred at 34 weeks gestation, average gross motor development was just over one standard deviation lower (2.30 points) in children whose mother appraised the impact of the flood as negative, compared to neutral or positive. Overall, gross motor scores were lower in children whose mothers rated the experience of the flood as negative, compared to neutral or positive, but only when flood exposure occurred from 17 weeks gestation onward.

No significant interactions were found between timing and objective hardship, peritraumatic distress, peritraumatic dissociation or posttraumatic stress. No significant interactions were found between sex and any of the maternal flood-related variables. However, an

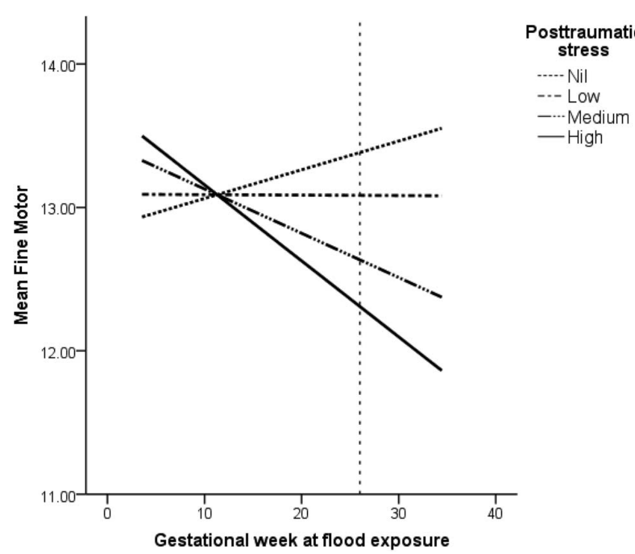

Figure 2. The moderating effect of timing (i.e., the week of flood exposure during gestation) on the relationship between maternal PTSD symptoms and child fine motor scores. The region of significance is to the right of the vertical dashed line.

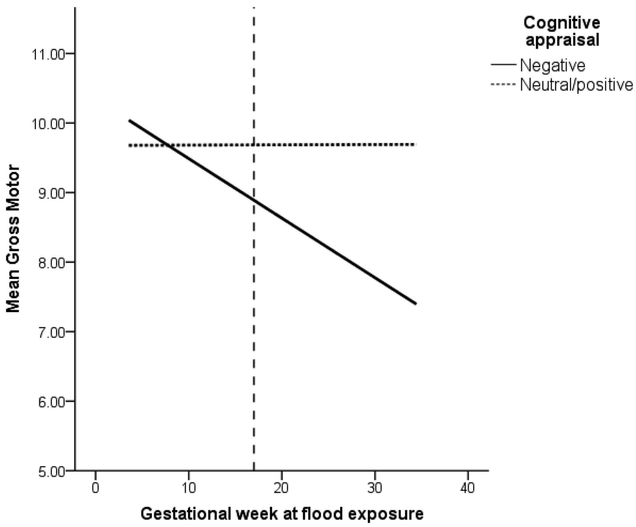

Figure 3. The moderating effect of timing (i.e., the week of flood exposure during gestation) on the relationship between maternal cognitive appraisal and child gross motor scores. The region of significance is to the right of the vertical dashed line.

interesting trend was evident. The overall interaction between cognitive appraisal and sex was not significant ($p = .084$), but the conditional effect was significant for girls ($p = .012$), suggesting that gross motor scores were lower for girls than for boys when cognitive appraisal was negative compared to neutral or positive.

Testing a cascade of maternal stress reactions as a potential psychological mechanism of transmission. The literature on potentially traumatic events suggests that peritraumatic reactions link traumatic exposures to PTSD symptoms, yet this cascade of stress reactions has not been tested in the prenatal stress literature. Partial correlations, controlling for the influence of objective hardship, were significant between PTSD symptoms and both peritraumatic distress ($pr = .460$, $p < .001$) and peritraumatic dissociation ($pr = .307$, $p < .001$). This suggests that there is a relationship between peritraumatic reactions and PTSD symptoms that cannot be fully accounted for by the common cause of objective hardship. This association may be spurious, may be due to a variable not measured, or may indicate that one of these variables influences the other (Hayes, 2013). This suggests a serial mediation from objective hardship > peritraumatic reactions > PTSD symptoms. Regression analyses showed that peritraumatic dissociation became nonsignificant as a predictor of PTSD symptoms when controlling for peritraumatic distress ($B = .04$, $p = .639$), whereas peritraumatic distress remained significant when controlling for peritraumatic dissociation ($B = 0.61$, $p < .001$). This suggests that peritraumatic dissociation was not a significant independent predictor of PTSD symptoms, and this variable was therefore dropped from the model. Child motor development was added to this cascade to test the indirect relationship between objective hardship and motor development (see Figure 4). Cognitive development was not tested due to a lack of association with maternal subjective stress.

In the model testing fine motor development, timing was included as a moderator of the pathway between PTSD symptoms and motor development, based on the moderation analyses described above. Controlling for standardized birth weight and the PSIDI, serial mediation analyses showed that higher objective hardship predicted higher peritraumatic distress (a_1), which predicted more severe PTSD symptoms (d_{21}), which in turn predicted poorer fine motor scores, moderated by timing (b_4; see Table 4). This model met the criteria for moderated mediation proposed by Hayes (2015), because the bias-corrected bootstrapped confidence interval for the index of moderated mediation did not contain 0 (index $= -0.006$, 95% CI $[-0.015, -0.0003]$). Overall, objective hardship was not directly related to fine motor development, but was indirectly related via peritraumatic reactions and PTSD symptoms acting in serial. This moderated serial mediation was not significant for gross motor scores.

Discussion

This study supports the differential results from other prenatal stress research, with different aspects of flood-related stress predicting different areas of child development. This study further identifies a cascade of maternal stress reactions to a natural disaster that, for the first time, sheds light on the potential psychological mechanisms by which prenatal stress may relate to child motor development.

A cascade of maternal stress reactions. As hypothesized, individual stress reactions operated together, linking objective hardship to child motor development via a novel cascade of

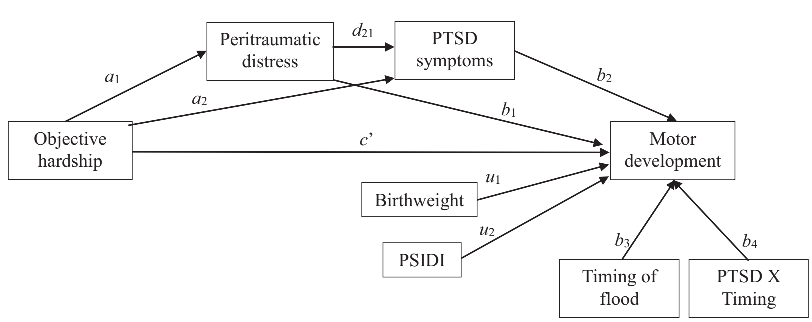

Figure 4. Path model for the moderated serial mediation. The relationship between maternal objective hardship and child motor development is indirect, mediated by peritraumatic distress and PTSD symptoms acting in serial, with the relationship between PTSD symptoms and motor development moderated by the timing of flood exposure during gestation. PSIDI = Dysfunctional Interaction subscale of the Parenting Stress Index.

Table 4
Ordinary Least Squares Regression Coefficients for the Moderated Serial Mediation (Standard Errors in Parentheses; N = 142)

	Outcome								
	Peritraumatic distress			PTSD symptoms			Fine motor		
Predictor	Path	Coefficient	p	Path	Coefficient	p	Path	Coefficient	P
Intercept		1.16 (.22)	<.001		−2.00 (.30)	<.001		15.17 (2.15)	<.001
Objective hardship	a_1	.42 (.08)	<.001	a_2	.64 (.10)	<.001	c'	−.16 (.26)	.535
Peritraumatic distress				d_{21}	.62 (.11)	<.001	b_1	.31 (.26)	.232
PTSD symptoms							b_2	.13 (.28)	.657
Timing								.02 (.02)	.383
PTSD × Timing								−.02 (.01)	.051
PSIDI[a]								−2.10 (1.53)	.172
Birthweight (standardized by gestational age and sex)								.39 (.20)	.048
Model R^2		.177	<.001		.475	<.001		.120	.015

Note. PTSD = posttraumatic stress disorder.
[a] Dysfunctional Interaction subscale of the Parenting Stress Index.

maternal stress reactions. The risk of developing PTSD symptoms is increased by the experience of peritraumatic reactions during or after trauma (Bromet & Dew, 1995; Brunet et al., 2001; Thomas et al., 2012). The model in Figure 4 tested the indirect relationship between objective prenatal maternal stress and child motor development via peritraumatic distress and PTSD symptoms acting in serial, proposing a potential psychological mechanism of transmission for the effects of prenatal maternal stress. We found that more objective flood stress predicted increased distress, which in turn predicted more severe PTSD symptoms, which predicted poorer fine motor scores in children exposed to the flood from midgestation onward. Previous studies have explored biological mechanisms for the negative effects of prenatal stress on child development, including cortisol and DNA methylation (e.g., Cao-Lei et al., 2015, 2014; Sandman et al., 2012). It is likely that biological and epigenetic mechanisms such as these here (Cao-Lei et al., 2015) underlie the psychological mechanism identified in this study, but in the wake of a natural disaster, psychological measures are easier for clinicians to administer and interpret. These findings suggest that it is not only the events of disasters but how mothers react to them that can predict later child development (Harville, Xiong, & Buekens, 2010; Tees et al., 2010) and emphasizes the importance of exploring whether subjective stress reactions operate together.

Different types of stress reaction. As hypothesized, different types of maternal stress reactions predicted different aspects of child development.

Objective hardship. Objective hardship predicted child cognitive development, but the nature of the relationship differed by the timing of exposure during gestation: For children exposed to the flood prior to 5 weeks gestation, more severe objective hardship predicted better development. For children exposed to the flood from 30 weeks gestation, more severe objective hardship predicted worse development. These results are similar to others showing either negative or positive relationships between prenatal maternal stress and child cognitive development (e.g., DiPietro et al., 2006; Huizink et al., 2002; Laplante et al., 2004). Although objective hardship triggered the cascade of stress reactions discussed above, there was no direct relationship between objective hardship and child motor development. These findings are different to those of Cao et al. (2014), who reported several direct relationships. This may be due to age differences, as Cao et al. (2014) measured motor development at 5.5 years of age and the present study included much younger children. It may also be due to differences in the area of motor development: Cao et al. (2014) studied balance, bilateral coordination, and visual motor integration, and the present study focused on broader measures of fine and gross motor development. In addition, the ice storm used as the source of objective hardship in the Cao et al. (2014) study was different than the flood used as the source of objective hardship in the present study. Using maternal ratings of child development, Simcock et al. (2016) found that objective hardship predicted gross motor development, but only at 6 months of age.

Cognitive appraisal and subjective stress reactions. Cognitive appraisal significantly predicted gross motor scores, with negative appraisal associated with poorer motor development, and PTSD symptoms predicted fine motor scores, with more severe symptoms related to poorer motor development. These results are similar to Cao et al. (2014), who found that maternal PTSD symptoms predicted one area of motor development (poorer bilateral coordination) but not others (visual motor integration and balance), and Simcock et al. (2016), who found that cognitive appraisal predicted maternal-rated child motor development at different ages in early childhood. The findings also support other studies which have found that relationships with child motor development were significant for some types of prenatal maternal stress and not others (e.g., Buitelaar, Huizink, Mulder, de Medina, & Visser, 2003; DiPietro et al., 2006). Different types of stress have different underlying physiological mechanisms (King et al., 2012), which may explain this differential susceptibility. Also, fine and gross motor development are controlled by different regions of the brain (Gabbard, 2012). These findings suggest that different types of prenatal maternal stress may influence the development of specific brain regions. Peritraumatic reactions did not have direct relationships with motor development but peritraumatic distress was part of the cascade of reactions linking objective hardship with child motor development.

Timing. As hypothesized, relationships between prenatal maternal stress and child development were moderated by the timing of the flood during gestation. Relationships between objective hardship and cognitive development were significant when flood exposure occurred prior to 5 weeks and from 30 weeks gestation. Relationships between cognitive appraisal and gross motor development were significant when flood exposure occurred from approximately 17 weeks of gestation onward, and between PTSD symptoms and fine motor development when flood exposure occurred from approximately 26 weeks onward, with development worsening as stress exposure occurred later in pregnancy. These results are similar to some of those from Project Ice Storm (see King et al., 2012 for a summary). In particular, Cao et al. (2014) reported that motor development is more sensitive to stress exposure closer to birth. First trimester exposure has been implicated in areas of child development such as cognition and language (DiPietro et al., 2006; Laplante et al., 2004), and the second and third trimesters seem to be particularly sensitive for motor development (Cao et al., 2014; Grace et al., 2015). Similarly, mothers in the Queensland Flood Study who had a negative appraisal of the flood and who experienced the flood late in their pregnancy rated their toddler's gross motor functioning as less developed (Simcock et al., 2016). The finding in the present study that the relationship for gross motor development was significant from 17 weeks and fine motor was significant from 26 weeks suggests different yet overlapping periods of susceptibility for the development of the different regions of the brain responsible for these distinct motor functions. For example, this may indicate an interruption to the development of the cerebellum, which begins critical development from 16 weeks gestation and is vulnerable to prenatal exposures (Garel, Fallet-Bianco, & Guibaud, 2011; Sandman et al., 2012; Strominger & Laemle, 2012). Timing effects for cognitive development may indicate changes in the hippocampus or cerebral cortex (Charil, Laplante, Vaillancourt, & King, 2010).

Sex. Contrary to our hypothesis, relationships between objective hardship, subjective stress reactions and child development were not moderated by sex. However, there was a strong trend. The interaction between cognitive appraisal and sex was not significant, but the conditional effect was significant for girls, suggesting that gross motor scores were lower for girls when cognitive appraisal was negative compared to positive. This is similar to the findings of Cao et al. (2014), who reported that motor development decreased for girls, but not boys, as stress exposure occurred closer to birth. Sandman et al. (2012), reported that delayed neuromotor development associated with prenatal stress was only significant for boys, but sex differences may be more salient in other areas of development, such as anxiety (Sandman et al., 2013). Research findings on sex differences in the effects of prenatal maternal stress are mixed, with some studies reporting no significant differences (e.g., DiPietro et al., 2006), others reporting that effects can apply to only one sex (e.g., Sandman et al., 2012), and still others reporting that relationships may be different for each sex (e.g., Ellman et al., 2008). This area requires further research.

Limitations and Summary

There are some limitations to the study. The sample is relatively small for the moderated mediation analysis. Thus, despite the fact that the magnitude of the flood effect was sufficient to detect significant results, these results should be considered exploratory in nature. The sample is also largely homogenous in terms of socioeconomic status and cultural background, which limits the generalizability of the findings to different populations. It is possible that the relationships seen here may be different in communities with fewer financial and educational resources. In addition, children's cognitive and motor development scores were, on average, well within the normal range. Finally, we excluded three infants who had been born before 36 weeks gestation and, thus, cannot generalize our findings to the special case of preterm birth which presents additional developmental challenges. In any case, their inclusion in the analyses makes no appreciable difference in the results, and three cases would not be sufficient for a subgroup analysis.

Despite these limitations, the novel indirect model advances our understanding of the psychological mechanisms by which prenatal stress may influence child development. Objective hardship was directly related to child cognitive development and indirectly related to child motor development via peritraumatic reactions and PTSD symptoms, and these relationships were dependent on the timing of flood exposure. This has implications for optimizing child development in the wake of natural disasters by identifying clear risk factors that may be used for intervention and screening.

Future research should further explore the novel cascade of maternal stress reactions identified here, particularly in relation to other areas of child development, and investigate correspondence between the stress reactions identified here and the physiological cascades identified as potential mechanisms of transmission. It would be useful to replicate these findings in children of different ages and in communities with lower financial and educational resources than the current sample. Future studies should take into account the effects of the timing of stress exposure, investigate potential sex differences in findings, and explore the ways in which different types of prenatal stress can work together to predict development.

Overall, these findings from an exploratory path analysis illustrate the complexity of the relationship between prenatal stress and subsequent child development. It is not as simple as asking whether prenatal stress can adversely influence aspects of child development: relationships depend on the type of stress, when it is experienced, how the mother responds, and whether different types of stress interact.

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