Continuous, emerging, and dissipating associations between prenatal maternal stress and child cognitive and motor development

The QF2011 Queensland Flood Study

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Abstract

Background: Exposure to prenatal maternal stress (PNMS) predicts child development across a range of areas. However, we require better information about when different effects may manifest and how they develop over time. **Aims:** This study aims to investigate continuity and change in the association between disaster-related PNMS and child cognitive and motor development from 16 to 30 months of age. **Study design:** Mothers exposed to a major flood during pregnancy completed questionnaires assessing objective hardship, peritraumatic distress (Peritraumatic Distress Inventory) and dissociation (Peritraumatic Dissociative Experiences Questionnaire), posttraumatic stress disorder (PTSD) symptoms (Impact of Event Scale - Revised), and a cognitive appraisal of the overall flood consequences. At 16 and 30 months post-partum, children's (N = 150) cognitive and motor development was assessed using the Bayley-III. **Results:** Continuity was evident in the associations between flood-related stress and children's fine motor development, with the negative effects of PTSD symptoms persisting between 16 and 30 months. Changes were evident in the associations between flood-related stress and both cognitive and gross motor development, with some effects disappearing between time points and new effects emerging. **Conclusions:** These findings suggest that different types of disaster-related maternal stress work together to predict different domains of child development, and signal the potential need for screen-and-treat programs prenatally to prevent potentially harmful effects, or postnatally to improve children's developmental trajectories.

Keywords: prenatal maternal stress; child cognitive development; child motor development; mechanisms of transmission.

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1. Introduction

Questions of continuity and change in the effects of prenatal maternal stress (PNMS) on child development are critically important. With accumulating evidence of the link between PNMS and subsequent child development, including cognitive function and motor skills (1-5), "…addressing maternal psychological distress may represent one of the most modifiable and feasible strategies for reducing risk factors for developmental delay" (6). This highlights the need for prenatal screening as well as investigation of prenatal maternal interventions for efficacy in improving children's developmental trajectories (6-8). However, if the effects of prenatal stress on the child disappear of their own accord, interventions may not be necessary, which is why it is essential to better understand when associations between PNMS and child development emerge and how they progress over time.

The findings from longitudinal studies that incorporate repeated measures of child development show that where associations are found between PNMS and child development, they can be continuous (i.e., evident at all time points at the same or similar magnitude), late-emerging (i.e., evident at later but not earlier time points), or dissipating (i.e., evident at earlier but not later time points). Continuity in findings across time points suggests that the disruption to fetal development continues to exert its influence at older ages (8, 9). For example, O'Donnell, Glover and colleagues (9) found that maternal prenatal anxiety and depression predicted child behavioural and emotional symptoms from 4 to 13 years of age. Late-emerging effects that are only evident at later time points may reflect situations where the affected area of development had not yet manifested, as in some animal studies (10). For example, Huizink, Robles de Medina (11) found that maternal prenatal anxiety predicted child cognitive and motor development at 8 months but not at 3 months of age. Dissipating effects, where earlier associations between PNMS and child development become non-significant at later time points, suggest that the effects of PNMS are temporary rather than enduring (9) or, alternatively, that the effects of PNMS on development may have been ameliorated by postnatal experiences. For example, Thompson, Morgan and colleagues (12) found that prenatal maternal cortisol was related to child learning and memory at 3 months but not at 5 months of age.

1.1 The QF2011 Study and child development

The QF2011 Queensland Flood Study is investigating the biopsychosocial mechanisms that underlie the associations between disaster-related PNMS and subsequent child development (for more details, see 13). In mid-January 2011, 78% of the state of Queensland, Australia was declared a disaster zone when it experienced a major flood that affected 2.5 million people and resulted in 33 deaths (14). QF2011 used the flood as an independent stressor on women who were pregnant at the time of the disaster, and measured the severity of objective hardship and three types of maternal subjective stress reaction (peritraumatic distress, peritraumatic dissociation and posttraumatic stress disorder (PTSD) symptoms) as well as a cognitive appraisal of the overall consequences of the flood.

Developmental assessments of the QF2011 children at 16 months (N = 145) revealed several significant associations between maternal flood-related stress variables and child development (for full details see 15). To summarize, more severe objective hardship during early gestation predicted better cognitive development while more severe objective hardship in later gestation predicted poorer cognitive development.

Additionally, more severe maternal posttraumatic stress disorder (PTSD) symptoms predicted poorer child fine motor development. Finally, children whose mothers appraised the overall consequences of the flood as negative had lower gross motor development compared to children whose mothers appraised the consequences as neutral or positive. The fine and gross motor development results were moderated by the timing of exposure, significant only for children exposed later during gestation.

The results also showed that different types of maternal stress worked together to predict child motor development. Based on previous research showing that peritraumatic distress predicts PTSD symptoms following potentially traumatic events (16, 17), we tested a cascade of maternal stress reactions, hypothesizing that women with higher objective hardship would experience higher peritraumatic distress, and would in turn report more severe PTSD symptoms, and that this would negatively predict child motor development. This model was significant for child fine motor development for those exposed to the flood during the second and third trimesters of pregnancy, and was proposed as a potential psychological mechanism of transmission for the effects of PNMS on child development.

The present study

The present study aimed to determine whether disaster-related PNMS predicted: 1) child development at 30 months, and 2) the change in development between 16 and 30 months. It also aimed to discover whether the pattern of results found at 16 months had persisted or diminished over time.

2. Method

2.1 Participants

The participants for the present study were the QF2011 mother-infant dyads (*N* = 150) with gestation of at least 36 weeks who completed a face-to-face developmental assessment at 30 months (*M* = 30.26 months, *SD* = 0.72 months, *Range* = 28.29 – 32.16 months). At recruitment, the majority of mothers were living with a partner or spouse, with only 10.7% single or never married. Mothers were highly educated, with 58.8% having completed a tertiary degree and only 1.5% reporting they did not complete secondary school. Mothers reported high household incomes, with only 6.7% earning less than $AU34,000 per year. The sample was predominantly Caucasian (96.2%). At the birth of the study child, mothers were, on average, 31.4 years old (*SD* = 5.11 years, *range* = 19 - 47 years). Exposure to the flood occurred during Trimester 1 for 42.0%, Trimester 2 for 36.7%, and Trimester 3 for 21.3%. There were slightly more boys (54%) than girls (46%), average birthweight was 3,552.41 grams (*SD* = 449.52 grams, *range* = 2712 – 5050 grams), and average gestation was 39.35 weeks (*SD* = 1.09 weeks, *range* = 37 – 42 weeks).

2.2 Procedures

Recruitment and data collection procedures for the overall QF2011 Study have been described in detail in AUTHORS (13). Women were recruited into QF2011 between April and November 2011. Measurement for the current study occurred at recruitment and/or 12 months post-flood, and at 16 and 30 months postpartum. Questionnaires at recruitment and 12 months post-flood assessed maternal objective hardship (flood exposure), flood-related stress reactions, mental health, coping strategies, and demographics. Questionnaires at 16 and 30 months postpartum assessed maternal stress (mental health, parenting stress, and stressful life events), coping, social support, and child development. Face-to-face assessments at 16 and 30 months assessed a broad range of child developmental areas and parent-child interaction. The cognitive and motor development data are reported here. Mothers received a $30 gift voucher at each stage of the study, and children received a small toy at the 16 and 30 month assessments. All phases of this study have received ethical approval from the Mater Hospital HREC (1709M, 1844M) and The University of Queensland (2013001236).

2.3 Measures

Objective hardship. Flood-related objective hardship was assessed at recruitment using the Queensland Flood Objective Stress Scale (QFOSS; 13). This survey was based on those used in other disaster studies (18, 19) but was tailored to the events of the Queensland Flood. It included questions on the condition of property, vehicles and possessions, changes to diet, impact on pregnancy-related care and access to services. The survey comprises 49 items covering experiences of threat, loss, scope, and change due to the flood, with possible scores ranging from 0 to 200. Higher scores indicate more severe exposure.

Subjective stress reactions. Maternal flood-related stress reactions were assessed at recruitment using three instruments. The 10-item Peritraumatic Dissociative Experiences Questionnaire (PDEQ; 20) retrospectively assessed dissociative reactions that occurred during the disaster using a 5-point scale that ranged from 0 ("Not at all true") to 4 ("Extremely true"). It is internally consistent, with Cronbach's alpha of 0.85 (16), and has a high correlation with PTSD symptoms (21).

The 13-item Peritraumatic Distress Inventory (PDI-Q; 16) retrospectively assessed emotional and physical reactions that occurred during the disaster using a 5-point scale that ranged from 0 ("Not at all true") to 4 ("Extremely true"). The PDI is internally consistent, with a coefficient alpha of 0.76, is stable over time (16), and predicts subsequent development of PTSD symptoms (22).

The Impact of Events Scale – Revised (IES-R; 23) is commonly used in disaster studies to assess three domains of trauma-related distress: intrusive thoughts and images, hyperarousal, and avoidance (18, 24). Participants were directed to reference their experience of the flood and report their symptoms over the past 7 days on 22 items, each using a 5-point Likert scale that ranged 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) (23, 25).

Maternal cognitive appraisal. Participants were also asked to provide a cognitive appraisal of the overall consequences of the flood. A single item in the recruitment questionnaire asked, *"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…"*, and responses were dichotomised into, "Very Negative/ Negative" and, "There were no consequences/ Positive/ Very Positive".

Postnatal covariates. Maternal stress at 16 and 30 months was assessed using three different measures. The modified Life Experiences Survey (LES; 26) was used primarily to capture sources of potential prenatal and postnatal stress. It listed 26 categories of events (e.g., changes to relationships, finances, employment and living conditions within the home or neighbourhood). Participants were asked to indicate whether they had experienced the event since the previous assessment, to list the month and year in which it occurred, and to rate its impact on a 7-point Likert scale that ranged from -3 ("Extremely negative") to 3 ("Extremely positive"). Total (summed) scores were calculated for the number (LES N) and impact (LES IMP) of reported events.

The short form of the Parenting Stress Index (PSI-SF; 27) measured stress within the parent-child relationship. Three subscales were used in this study: Parental Distress (PSIPD), Dysfunctional Interaction (PSIDI) and Difficult Child (PSIDC). Participants rated most items on a 5-point Likert scale that ranged from 1 ("Strongly disagree") to 5 ("Strongly agree"). The PSI-SF is widely used and has good construct validity (28).

The short form of the Depression, Anxiety and Stress Scale (DASS-21; 29) measured maternal mental health. The three 7-item subscales were rated by respondents on a 4-point Likert scale that ranged from 0 ("Did not apply to me at all") to 3 ("Applied to me very much, or most of the time"). The subscales have been found to be reliable, but are moderately correlated (29).

Child development. Children's cognitive and motor development were assessed at 16 and 30 months using the Bayley Scales of Infant Development, 3rd Edition (BSID-III; 30) by researchers who were blind to the severity of the family's flood exposure. The Bayley-III has been extensively validated and has high internal consistency, 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 (31). Scaled scores (*M* = 10, *SD* = 3) can be used to evaluate a child's development relative to same-age peers and are calculated by referencing raw scores against norms for developmental ages. Scaled scores are not suited to studying change in an individual child's scores over time, however raw scores can be converted to growth scores, which have a mean of 500 and a standard deviation of 100 across the entire age range of the Bayley scales. Growth scores provide an ability estimate that is independent of peers and can be used to track a child's progress between time points (30). In this study, growth scores were used to calculate difference scores by subtracting the child's growth score at 30 months from their growth score at 16 months. Higher scores indicate a greater increase in development between time points.

2.4 Statistical analyses

Analyses were performed using SPSS version 24 and AMOS version 24. Participation varied at different time points (*n* = 14 16-month-olds who did not attend the 30-month assessment, and *n* = 19 30-month-olds who did not attend the 16-month assessment) but there were no significant differences between the overall samples at 16 and 30 months on any flood-related variable. Attrition analyses using separate-variance t-tests (adjusted for multiple comparisons) showed that eligible recruited participants (N = 224) who did (N = 150) and did not (N = 74) complete the 30-month assessment did not differ significantly on flood-related variables. Little's MCAR test was non-significant (χ^2 (626) = 545.44, p = .991), indicating that the data can be considered missing completely at random, therefore multiple imputation was judged the most appropriate strategy to address missing data (32). Twenty imputed datasets were created using predictive mean matching due to skewed data. Flood-related variables and cognitive and motor development at 30 months were entered as predictors only (i.e., not imputed). Covariates at 16 and 30 months and cognitive and motor development at 16 months were entered as both predictors and imputed variables (missing data: mental health: 13.3 - 14.7%; parenting stress: 14 - 14.7%; life events: 10 - 16.7%; 16-month motor: 13.3%; 16-month cognitive: 12.7%). Demographic data were not imputed.

Following multiple imputation, predictors and covariates were transformed as necessary to improve normality and reduce the influence of outliers. The single outliers on the cognitive and fine motor development scales at 16 months were recoded to a value that was 3 standard deviations from the mean, which maintained the rank of the score but reduced its influence on normality (33). No multivariate outliers were detected. Multiply-imputed parameters not provided by SPSS were calculated using rules established by Rubin (34).

Once the data were cleaned, bivariate correlations were conducted. Hierarchical regression analyses were used to explore multivariate predictive associations between flood-related variables and child development, with the final step reported (full tables available on request). The PROCESS macro was used to conduct moderation and mediation analyses (35). Moderation analyses were used to investigate whether associations between all flood-related variables and 1) scaled scores at 30 months and 2) difference scores were moderated by the timing of flood exposure during gestation or the child's sex. Serial mediations tested the link between flood exposure and child development via peritraumatic stress and PTSD symptoms. Models used 10,000 bootstraps to generate 95% bias-corrected confidence intervals for indirect effects. All regression coefficients presented are unstandardized. Regression analyses were run for 30-month scaled scores and then difference scores (30m – 16m growth scores). Postnatal stressors that were significantly correlated with the outcome variable were included in initial models as covariates but were trimmed from final models if they were non-significant ($p > .10$). Models were run for cognitive, fine motor and gross motor development.

3. Results

3.1 Associations between maternal stress and child cognitive development

The majority of children were in the average range on the cognitive scale, with 22 children scoring above the average range and none scoring below this range. The mean for cognitive scaled scores at 30 months was comparable to the normed mean (Table 1). Bivariate correlations showed that flood-related variables were not correlated with cognitive scaled scores at 30 months (see Table 1). The sex of the child was positively correlated with cognitive scaled scores, with scores higher for girls than for boys. Maternal depression and parent-child dysfunctional interaction at 30 months were significantly negatively correlated with cognitive scaled scores and were considered as covariates in all further analyses.

Regression analyses for cognitive scaled scores at 30 months (Table 2) showed a significant main effect for sex, with girls having higher cognitive scaled scores on average than boys, and a marginal main effect for timing, with cognitive scaled scores higher on average for children exposed to the flood later during gestation. A significant negative main effect for PTSD symptoms became marginally significant once maternal depression at 30 months was added; the significant negative effect of maternal depression indicates that children's cognitive scores were lower the more severe their mothers' depression. The model explained 12.5% of the variance in cognitive scaled scores at 30 months. All moderation analyses were non-significant.

Cognitive difference scores were positively correlated with the timing of the flood, with a greater increase in scores between 16 and 30 months for children exposed to the flood later during gestation (Table 2). The final model explained 12.7% of the variance in cognitive difference scores. All moderation analyses were non-significant.

3.2 Associations between maternal stress and child fine motor development

The majority of children were in the average range on the Motor Composite Scale (fine and gross motor development combined), with 1 child below and 34 children above the average range (Table 1). Average fine motor scaled scores were 1 normed standard deviation above the normed mean. Bivariate correlations showed that flood-related variables were not correlated with fine motor scaled scores at 30 months (Table 1). The sex of the child was significantly correlated with fine motor scaled scores at 30 months, with scores higher for girls than for boys. Maternal depression and parental distress at 16 months were positively correlated with fine motor scaled scores at 30 months and were considered as covariates in all further analyses.

Regression analyses for fine motor scaled scores at 30 months showed a significant main effect for maternal PTSD symptoms, with more severe symptoms predicting lower child fine motor scaled scores (Table 2). There was also a main effect for maternal peritraumatic distress, with higher distress predicting better child fine motor scores. Finally, there was a main effect for sex, with girls having higher fine motor scores on average than boys. These main effects remained significant when controlling for maternal depression at 16 months which had a significant, positive association with fine motor scores. The final model explained 14.8% of the variance in child fine motor scaled scores at 30 months. All moderation analyses were non-significant.

Flood-related variables were not correlated with fine motor difference scores. Difficult child scores at 16 months and parent distress at 30 months were positively correlated with fine motor difference scores and were considered as covariates in further analyses.

Regression analyses showed that no flood-related variables predicted fine motor difference scores (Table 2). All moderation analyses were non-significant.

Table 1

Descriptives of Key Variables and Correlations with Child Cognitive (cog), Fine Motor (FM) and Gross Motor (GM) Development.

	Descriptives			Correlations with Child Development					
Measure	N	*M* (*SD*)	Range	30m Cog. Scaled	Cog. Difference	30m FM Scaled	FM Difference	30m GM Scaled	GM Difference
Stressor/stress reactions									
Objective Hardship	150	21.43 (17.12)	2 - 81	.033	.012	-.012	.068	-.093	-.086
Peri. distress	150	11.99 (8.61)	0 - 35	-.035	-.075	.047	.091	-.016	-.069
Peri. dissociation	150	6.25 (7.70)	0 - 32	.018	-.031	-.001	.046	-.111	**-.201***
PTSD symptoms	150	6.69 (11.01)	0 - 55	-.117	-.072	-.127	.016	-.095	.002
Cognitive appraisal	149	35% neg (0) 65% neut/pos(1)	-	-.033	-.044	.083	-.002	.064	-.070
Child development									

	Descriptives			Correlations with Child Development					
Measure	N	*M* (*SD*)	Range	30m Cog. Scaled	Cog. Difference	30m FM Scaled	FM Difference	30m GM Scaled	GM Difference
16m Cog Scaled	150	11.29 (2.27)	5-18	**.341****	**-.473****	**.212****	-.088	.081	**-.228****
16m FM Scaled	150	12.98 (1.89)	7 - 18	**.251****	.013	**.266****	**-.493****	.163^	**-.180***
16m GM Scaled	150	9.46 (2.24)	4 - 16	.120	**-.190****	**.220****	-.063	**.180***	**-.821****
30m Cog Scaled	149	11.26 (2.0)	7 - 17	-	**.551****	**.328****	.054	**.361****	.076
30m FM Scaled	148	12.34 (2.60)	7 – 19	**.328****	.165^	-	**.668****	**.405****	-.002
30m GM Scaled	142	11.20 (2.59)	6 – 17	**.361****	**.249****	**.405****	**.223***	-	**.337****
Cog Difference	149	78.91 (15.08)	15-119	**.551****	-	.165^	.181^	**.249****	**.279****
FM Difference	148	54.93 (15.96)	0-109	.054	.181^	**.668****	-	**.223***	.134
GM Difference	142	63.17 (20.89)	0-126	.076	**.279****	-.002	.134	**.337****	-
Moderators									
Timing of flood	150	17.16 (11.02)	1 - 268	.122	**.326****	.008	.103	**.169***	.165^
Sex of child	150	54% boys (0)	-	**.209****	.080	**.208****	.110	.111	-.055

	Descriptives			Correlations with Child Development					
Measure	N	*M* (*SD*)	Range	30m Cog. Scaled	Cog. Difference	30m FM Scaled	FM Difference	30m GM Scaled	GM Difference
		46% girls (1)							
Covariates									
Stand. Birthweight [a]	150	0.25 (0.17)	-1.49 - 3.0	.083	.012	.131	.020	-.034	-.027
Depression 30m	150	4.76 (7.00)	0 - 40	**-.187***	-.128	-.052	-.008	-.069	-.152
Anxiety 30m	150	3.60 (5.49)	0 - 26	-.126	-.105	-.093	-.043	-.090	-.179^
Stress 30m	150	10.70 (8.76)	0 - 42	-.083	-.086	.023	.062	-.003	-.098
Depression 16m	150	4.88 (6.87)	0 - 34	-.102	-.107	**.210***	.146	-.105	**-.238***
Anxiety 16m	150	3.14 (4.46)	0 - 18	-.043	.026	.006	.011	-.064	-.088
Stress 16m	150	10.58 (7.94)	0 - 34	-.036	-.035	.133	.136	-.116	-.067
Parent distress 30m	150	26.17 (9.03)	12 - 55	-.158^	-.079	.144^	**.181***	-.066	**-.263****
Dys.. interact. 30m	150	16.62 (5.59)	12 - 49	**-.176***	-.019	.040	.153^	-.055	-.027

Measure	N	*M* (*SD*)	Range	30m Cog. Scaled	Cog. Difference	30m FM Scaled	FM Difference	30m GM Scaled	GM Difference
	Descriptives			Correlations with Child Development					
Difficult child 30m	150	23.87 (8.46)	13 - 55	.004	.048	-.034	.087	.086	-.005
Parent distress 16m	150	26.50 (8.97)	12 - 47	-.088	.020	**.178***	.183^	-.082	**-.190***
Dys. interact. 16m	150	16.20 (5.13)	12 - 37	-.112	.050	.069	.188^	-.015	.070
Difficult child 16m	150	23.57 (8.28)	12 - 50	-.064	.075	.145	**.181***	.049	.030
No. events 17-30m	150	3.20 (2.73)	0 - 21	-.048	.028	-.076	.027	-.085	-.058
Impact 17-30m	150	-1.17 (4.23)	-16 - 12	-.077	-.072	.068	.114	.139	.130
No. events 0-16m	150	3.82 (2.93)	0 - 15	.091	.068	.094	.049	-.024	-.096
Impact 0-16m	150	-1.93 (4.37)	-20 - 12	-.041	-.109	-.038	-.030	.035	.075

[a] Standardized birthweight is birthweight by gestational age.
** $p < 0.01$ * $p < 0.05$ ^ $p = .051 - 0.99$

Table 2

Multivariate Regression Coefficients for Flood Stress Variables and Child Development.

	Cognitive development			
	Scaled scores (30m)		Difference scores (30m–16m)	
	Coefficient (*SE*)	95% *CI*	Coefficient (*SE)*	95% *CI*
Intercept	**10.80*****(1.08)	[8.68, 12.91]	**76.54***** (5.62)	[65.52, 87.55]
Obj. hardship	0.22 (0.29)	[-0.34, 0.78]	0.02 (0.10)	[-0.17, 0.20]
Peri. distress	-0.06 (0.30)	[-0.64, 0.53]	-1.85 (2.35)	[-6.46, 2.76]
Peri. dissociation	0.21 (0.21)	[-0.19, 0.61]	1.25 (1.53)	[-1.76, 4.25]
PTSD symptoms	-0.32^ (0.18)	[-0.68, 0.05]	-1.38 (1.43)	[-4.18, 1.42]
Cog. appraisal	-0.42 (0.41)	[-1.21, 0.38]	-3.00 (3.09)	[-9.07, 3.06]
Timing of flood	0.03^ (0.02)	[-0.00,0.05]	**0.45***** (0.11)	[.022, 0.67]
Sex [b]	**0.78*** (0.32)	[0.16, 1.41]	1.54 (2.43)	[-3.22, 6.30]
30m Depression	**-0.85*** (0.38)	[-1.59,-0.11]	-	-
R^2	12.5%		12.7%	
	Fine motor development			
	Scaled scores (30m)		Difference scores (30m-16m)	
	Coefficient (*SE*)	95% *CI*	Coefficient (*SE*)	95% *CI*
Intercept	**9.09***** (1.34)	[6.47, 11.71]	**26.48*** (11.83)	[3.28. 49.67]
Obj. hardship	0.29 (0.36)	[-0.43, 1.00]	1.87 (2.36)	[-2.76, 6.50]
Peri. distress	**0.79*** (0.39)	[0.04, 1.55]	2.36 (2.64)	[-2.82, 7.55]
Peri. dissociation	-0.25 (.026)	[-0.77, 0.27]	-0.41 (1.74)	[-3.81, 3.00]
PTSD symptoms	**-0.54*** (0.24)	[-1.00,-0.08]	-1.55 (1.54)	[-4.56, 1.46]
Cog. appraisal	0.51 (0.51)	[-0.49, 1.52]	1.04 (3.34)	[-5.50, 7.58]

Timing of flood	0.00 (0.02)	[-0.03, 0.04]	0.13 (0.12)	[-0.12, 0.37]
Sex [b]	**1.17*** (0.41)	[0.36, 1.98]	4.04 (2.70)	[-1.25, 9.33]
16m Depression	**1.34*** (0.49)	[0.38, 2.30]	-	-
16m Difficult child	-	-	1.86 (2.02)	[-2.10, 5.82]
30m Parent distr.	-	-	0.24 (0.17)	[-0.10, 0.58]
R^2	14.8%		8.0%	

	Gross motor development			
	Scaled scores (30m)		Difference scores (30m-16m)	
	Coefficient (*SE*)	95% *CI*	Coefficient (*SE*)	95% *CI*
Intercept	**10.24*****(1.41)	[7.48, 13.01]	**94.01***** (12.94)	[68.58,119.44]
Obj. hardship	-0.15 (0.40)	[-0.92, 0.63]	-4.72 (3.28)	[-11.16, 1.71]
Peri. distress	0.55 (0.41)	[-0.25, 1.34]	2.80 (3.45)	[-3.97, 9.58]
Peri. dissociation	-0.40 (0.28)	[-0.95, 0.15]	**-5.28*** (2.20)	[-9.59, -0.96]
PTSD symptoms	-0.23 (0.25)	[-0.73, 0.26]	1.81 (2.20)	[-2.51, 6.14]
Cog. appraisal	-0.02 (0.56)	[-1.12, 1.09]	-7.55 (4.69)	[-16.76, 1.67]
Timing of flood	0.04^ (0.02)	[.00, .08]	**0.36*** (0.16)	[0.05, 0.68]
Sex [b]	0.63 (0.44)	[-0.22, 1.49]	-1.76 (3.44)	[-8.49, 4.98]
30m Parent distr.	-	-	**-0.73*** (0.21)	[-1.15, -0.32]
R^2	7.1%		19.5%	

[a] Coding for cognitive appraisal: 0 = negative/ very negative; 1 = neutral/ positive, very positive.
[b] Coding for sex: 0 = male, 1 = female.

**$p < .01$, * $p < 0.05$, ^ $p = .051 - 0.99$

3.3 Associations between maternal stress and child gross motor development

Average gross motor scaled scores at 30 months were comparable to the normed mean (Table 1). Bivariate correlations showed that flood-related variables were not correlated with child gross motor scaled scores at 30 months (Table 1). Timing was significantly correlated, with exposure later during pregnancy associated with higher (better) scores.

Regression analyses showed that none of the flood-related or other variables predicted child gross motor scaled scores at 30 months (Table 2), despite a marginal positive association with timing, and all moderations were non-significant.

Gross motor difference scores were negatively correlated with peritraumatic dissociation, with higher dissociation associated with a smaller increase between the two ages. Difference scores were also correlated with timing, with a greater increase in gross motor skills associated with flood exposure later during gestation. Maternal depression at 16 months and maternal distress at 16 and 30 months were significantly negatively correlated with gross motor difference scores and were considered as covariates in future analyses.

Regression analyses (Table 2) showed a significant main effect for maternal peritraumatic dissociation, with higher dissociation predicting a smaller increase in gross motor skills between time points. There was also a significant main effect for timing, with a larger increase in skills between time points for children exposed to the flood later in gestation. These effects remained significant when controlling for the significant, negative effect of maternal distress at 30 months, with greater distress predicting smaller improvements in gross motor skills. The model explained 19.5% of the variance in gross motor difference scores.

Moderation analyses (Table 3) showed that the association between cognitive appraisal and gross motor difference scores was moderated by timing (Figure 1). When cognitive appraisal was neutral or positive, the association between timing of exposure and gross motor difference scores was not significant. However, when cognitive appraisal was negative, the improvement in gross motor scores between 16 and 30 months of age was greater for children exposed to the flood later during gestation (significant from approximately 19 weeks gestation). In other words, only when mothers had a negative cognitive appraisal of the flood did timing make a significant difference such that those exposed later in gestation had greater improvements in motor scores. The total model explained 13.9% of the variance in gross motor difference scores.

Table 3

Regression Coefficients for the Moderation by Timing of Flood Exposure During Pregnancy of the Association Between Cognitive Appraisal and Gross Motor Difference Scores.

	B	*SE*	*t*	*p*
Intercept	**58.13*****	6.44	9.02	<.001
Cognitive appraisal	8.62	7.30	1.18	.238
Timing	**0.87****	0.28	3.06	.002
Cog.apprais. X timing	**-0.82***	0.35	-2.34	.019
Peri. dissociation	**-4.31***	1.72	-2.50	.013

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

3.4 Testing a cascade of maternal stress reactions

In our previous report (15) we found that objective hardship was indirectly related to child fine motor development (but not to cognitive or gross motor development) via maternal peritraumatic distress and PTSD symptoms acting in serial. We tested this model again at 30 months and found that this indirect association was still significant. Serial mediations using fine motor scaled scores showed that higher objective hardship predicted higher maternal peritraumatic distress (a_1), which predicted more severe maternal posttraumatic stress (d_{21}), which in turn predicted poorer child fine motor scaled scores at 30 months (b_1) (Figure 2). The negative indirect effect of objective hardship was significant ($a_1d_{21}b_2$ = -0.13, 95% *CI* [*Lower*: -0.32 to -0.29; *Upper*: -0.05 to -0.03]), suggesting that higher objective hardship predicts lower child fine motor development via maternal peritraumatic distress and posttraumatic stress symptoms. The model predicted 13.9% of the variance in fine motor scaled scores.

4. Discussion

Prenatal exposure to a natural disaster predicted child fine motor development at 30 months, and the difference between 16 and 30 months for child cognitive and gross motor development. Both continuity and change were evident when comparing results with those obtained at 16 months. Additionally, the findings further validate a potential psychological mechanism of transmission for the effects of prenatal maternal stress, and reinforce the notion that different types of stress can work together to predict development, especially in the context of a potentially traumatic event like a natural disaster.

4.1 The association between PNMS and child cognitive development

There were no significant associations between maternal flood-related variables and child cognitive development at 30 months. These findings contrast with those from several other prenatal stress studies. Laplante, Barr and colleagues (36) studied mothers exposed to an ice storm during pregnancy. They found that children whose mothers reported more severe objective hardship during the first and second trimesters had lower cognitive and language development at 24 months of age, with no effects for maternal PTSD symptoms; they had not included measures of peritraumatic reactions in their study. DiPietro, Novak and colleagues (4) found that at 24 months of age, children of mothers who reported higher daily hassles had lower cognitive development, although there was no association with perceived stress. It is possible that the perceived stress measure used by DiPietro, Novak and colleagues may align more closely with the PNMS measures used in our study, whereas daily hassles may be more closely related to factors such as maternal personality. Bergman, Sarkar (37) also found that at 14 to 19 months of age, children of mothers who reported more stressful life events had lower cognitive development. It is possible that the differences in the findings between the studies may relate to the ages of the children, as discussed below.

Difference scores were used to investigate whether flood-related variables predicted the amount of change in children's development between 16 and 30 months of age. The timing of flood exposure during gestation predicted the difference in cognitive scores between 16 and 30 months, with a greater improvement (i.e., accelerated development) for children exposed to the flood later during gestation. This may suggest a facilitative effect for late but not early flood exposure. However, considered with the null findings reported above, it likely suggests that children whose cognitive development was flood-affected at 16 months had caught up to their peers by 30 months.

At 16 months, we found that more severe maternal flood-related hardship was associated with better child cognitive development when it occurred up to 5 weeks gestation, and with poorer cognitive development when it occurred from 34 weeks gestation (15), however these relationships were not evident at 30 months. These findings are similar to other studies where effects have been evident at early time points but dissipated by later time points (11, 38). It is possible that factors in the postnatal environment ameliorated these early developmental delays, as previous research has suggested the buffering impact of maternal factors such as early caregiving (39). Further evidence for the importance of postnatal factors in the current study is suggested by the disappearance of a significant association between maternal PTSD symptoms and child cognitive development at 30 months after accounting for significant postnatal covariates.

4.2 The association between PNMS and child fine motor development

Several associations were evident between maternal flood-related variables and child fine motor development at 30 months. More severe maternal PTSD symptoms predicted poorer development, and higher maternal peritraumatic distress predicted better development. Chuang, Liao (40) found negative effects, with work stress during pregnancy related to lower fine motor development at 2 years of age. However, DiPietro, Novak (4) did not find any association between maternal stress during pregnancy and child motor development at 3, 6 or 12 months of age. This may be due to the difference in the children’s ages, as it can be more difficult to measure fine motor development in very young infants compared to 30-month old toddlers; alternatively, it may be that associations between PNMS and child motor development may not manifest until later developmental stages.

In contrast, the difference in scores for fine motor development between 16 and 30 months was not predicted by any flood-related variable. Additionally, difference scores were lowest for fine motor (compared to cognitive and gross motor). Taken together, these findings suggest that the flood-related variables are related to fine motor development at each time point, but not the rate of change between time points.

The negative association between PTSD symptoms and fine motor development was also evident at 16 months (15), suggesting continuity in effects, although at that time the association was only significant for children exposed in the second and third trimesters. At 16 months the regression model explained 10% of the variance and at 30 months it explained 15%, indicating that maternal PTSD symptoms have a persistent negative association with child fine motor development. Additionally, the indirect association between objective hardship and child fine motor development identified at 16 months (15) was also significant at 30 months: higher objective hardship predicted higher maternal peritraumatic distress, which in turn predicted more severe PTSD symptoms, which was linked with poorer child fine motor development. This cascade, proposed as a potential psychological mechanism of transmission between prenatal stress and child development, seems to be robust, explaining 13% of the variance in fine motor scores at 16 months and 14% of the variance at 30 months.

The continuity in the association between child fine motor development and both maternal PTSD symptoms and (indirectly) objective hardship indicates a persistent negative association between the events of the flood and later motor development. The cerebral cortex and motor cortex drive the precise movements of the arms, hands, fingers and feet and control fine motor muscles (41). These findings suggest that prenatal stress may have influenced the development of the cerebral and motor cortices or perhaps the cerebellum, suggesting that the brain circuitry for these functions had not been developed to its full potential at the time of assessment (41). These results are similar to King, Dancause (42) who found that the associations between ice storm-related PTSD symptoms and child development persist until early adolescence, and to other prenatal stress studies with consistent findings across time points (e.g., 8, 9, 38, 44).

The emergence of the association between maternal peritraumatic distress and child fine motor development highlights the importance of longitudinal studies in this area. This pattern of results, in which effects are not evident at the first time point but emerge later, is seen in other prenatal stress studies (e.g., 45, 46-49). It is possible that the affected area of development had not manifested at the earlier time point, or was not readily measurable (10).

4.3 The association between PNMS and child gross motor development

There were no significant associations between maternal flood-related variables and child gross motor development at 30 months. This contrasts with the findings of Chuang, Liao (40), who found lower gross motor development at 2 years of age for children whose mothers reported work stress during pregnancy. This may reflect differences in the measures of PNMS used in the two studies, or may be related to the ages of the children, as significant relationships were found in our study at 16 months but not 30 months (discussed below). It also contrasts with DiPietro, Novak (4), who found a significant association between prenatal maternal daily hassles and child motor development at 2 years, although the measure of child development used in that study (Bayley-II) did not separate fine and gross motor development. Our null findings for gross motor development but significant findings for fine motor development affirm the importance of being able to examine these two areas of development separately.

In contrast, flood-related variables did predict differences in gross motor development between 16 and 30 months of age. Higher peritraumatic dissociation predicted a smaller improvement (i.e., slower development), suggesting that although peritraumatic dissociation did not predict gross motor scores at 30 months, gross motor development for these children progressed at a slower rate than for children whose mothers reported lower peritraumatic dissociation. No studies outside QF2011 have investigated the influence of maternal peritraumatic reactions on child development, but these findings suggest that peritraumatic symptoms may be a useful indicator to identify children at risk of slower gross motor development.

Additionally, flood exposure later during gestation predicted a greater improvement in gross motor development from 16 to 30 months of age (i.e., accelerated development). This may be related to the findings of the moderation analyses, which showed that maternal cognitive appraisal predicted the difference in gross motor scores between 16 and 30 months, but only for children who were exposed to the flood from mid gestation. These children showed a greater increase in their gross motor development between time points, indicating the importance of timing. As with cognitive development, these findings suggest that children whose development was negatively influenced by flood-related variables at 16 months of age had caught up to their peers at 30 months.

The disappearance of the effect of cognitive appraisal between 16 and 30 months suggests that the influence on child development was temporary. This same cognitive appraisal item predicted DNA methylation in adolescents in Project Ice Storm (50), suggesting that maternal cognitive appraisal of a stressor could have different patterns, and longevity, of effects on different aspects of child development. All of this could be related to the neuroplasticity of the developing brain. Brain development continues into early adulthood, and during this time the quality and quantity of postnatal sensory experiences can increase nerve connections and reorganise neural pathways; in short, experience can improve outcomes (41, 51). In our sample, even though most of the children were within the normal range of development at 16 months, the differences between children at the lower and higher ranges of gross motor development were obvious to researchers during face-to-face assessments (e.g., walkers and non-walkers). Parents received a developmental report indicating the level of development compared to standardised norms, and several mothers commented during testing that their children were not doing some of the things that their siblings or peers were doing. It is possible that mothers acted on what they perceived as a deficit, for example, by providing more assistance and encouragement to slow walkers, and this increased caregiving behaviour may explain the disappearance of the effect. This potential interaction between prenatal and postnatal environments should be investigated in future research.

Overall, the findings from this study suggest that different objective and subjective aspects of maternal experiences with, and reactions to, a natural disaster during pregnancy predicts cognitive, fine and gross motor development, but that the pathways of influence differ for each outcome. For cognitive and gross motor development, flood-related variables (particularly timing), predicted the rate of change between 16 and 30 months but not development at 30 months. It was the opposite for fine motor development, with flood-related variables predicting development at 30 months but not the rate of change from 16 months.

4.4 Limitations

This study has some limitations. The sample size was relatively small and the mothers were generally highly educated and well resourced, which may affect the generalizability of the findings. The homogeneity of the sample in terms of cultural and socioeconomic background can be an advantage, as it reduces the influence of potential confounders on child development and the ability to recover effectively from natural disasters (52). However, it does mean that the findings presented here may not generalize to more diverse communities. In addition, natural disasters represent a particular type of potentially traumatic event (PTE), and it is possible that these findings may not generalize to other types of PTEs (e.g., acts of terrorism), or to daily stress (e.g., pregnancy-specific anxiety). While the use of a natural disaster reduced the influence of some potential confounders, such as heritability, other confounding factors may still be present, such as individual variation in maternal stress reactivity. Additionally, factors such as maternal mental health during pregnancy, father mental health postnatally, parenting and social support may function as confounders, or could represent alternative or additional causal pathways. These variables should be considered in future research. It should also be noted that although the flood-related measures used different frames of reference for the occurrence of symptoms (objective hardship and peritraumatic distress were retrospective while PTSD symptoms were current), these measures were all collected for most of the mothers at one time point. This introduces potential recall bias and limits the longitudinal nature of the path models. Future research should measure maternal stress at multiple time points during pregnancy. Future research should also assess child development at more than two time points in order to better understand the continuity, or lack thereof, in longitudinal effects and enable the use of growth curve modelling. Multiple measures carry the risk that mothers will act on results from earlier assessment points, potentially influencing the areas of infant development under investigation, although this risk may be ameliorated by incorporating measures of postnatal caregiving into the research design.

4.5 The next step

Echoing the results of other studies, different types of PNMS predicted different areas of child cognitive and motor development. While much is still unknown within the field of prenatal maternal stress research, the accumulating evidence across diverse studies signals a potent and enduring effect. The next step in this field is to investigate variables or interventions that can reduce harmful effects and improve the developmental trajectories of children (53). For example, interventions (such as mindfulness-based cognitive therapy, massage therapy, and acupuncture) for mothers experiencing anxiety or depression during pregnancy can reduce psychological and physiological symptoms (7). Studies need to investigate whether such prenatal interventions have an effect on postnatal child development (7, 54). Prenatal maternal stress studies can be extended to include potentially protective or ameliorating influences, such as maternal caregiving, coping strategies and social support. The models tested here identify psychological reactions connecting prenatal exposures with subsequent development, and these may offer intervention points. It is clear that prenatal maternal stress can have long-term effects on child development. We know these effects exist; the next step is to do something about them.

References

1. Laplante DP, Brunet A, Schmitz N, Ciampi A, King S. Project Ice Storm: prenatal maternal stress affects cognitive and linguistic functioning in 5 1/2-year-old children. Journal of the American Academy of Child and Adolescent Psychiatry. 2008 Sep;47(9):1063-72. PubMed PMID: 18665002.

2. Simcock G, Kildea S, Elgbeili G, Laplante DP, Stapleton H, Cobham V, et al. Age-related changes in the effects of stress in pregnancy on infant motor development by maternal report: The Queensland Flood Study: Pregnancy Stress and Infant Motor Development. Developmental psychobiology. 2016;58(5):640-59.

3. Cao X, Laplante DP, Brunet A, Ciampi A, King S. Prenatal maternal stress affects motor function in 5½ - year - old children: Project Ice Storm. Developmental psychobiology. 2014;56(1):117-25.

4. DiPietro JA, Novak MFSX, Costigan KA, Atella LD, Reusing SP. Maternal Psychological Distress during Pregnancy in Relation to Child Development at Age Two. Child Development. 2006;77(3):573-87.

5. Huizink AC, de Medina PGR, Mulder EJ, Visser GH, Buitelaar JK. Coping in normal pregnancy. Annals of Behavioral Medicine. 2002;24(2):132-40.

6. Kingston D, Tough S, Whitfield H. Prenatal and postpartum maternal psychological distress and infant development: a systematic review. Child psychiatry and human development. 2012 Oct;43(5):683-714. PubMed PMID: 22407278.

7. Glover V. Maternal depression, anxiety and stress during pregnancy and child outcome; what needs to be done. Best practice & researchClinical obstetrics & gynaecology. 2014;28(1):25-35.

8. O'Connor TG, Heron J, Golding J, Glover V, Team AS, the ALSST. Maternal antenatal anxiety and behavioural/emotional problems in children: a test of a programming hypothesis. Journal of Child Psychology and Psychiatry. 2003;44(7):1025-36.

9. O'Donnell KJ, Glover V, Barker ED, O'Connor TG. The persisting effect of maternal mood in pregnancy on childhood psychopathology. Development and psychopathology. 2014;26(2):393-403.

10. Glover V. Prenatal stress and its effects on the fetus and the child: Possible underlying biological mechanisms. In: Antonelli MC, editor. Perinatal programming of neurodevelopment. 10. New York: Springer; 2014. p. 269-83.

11. Huizink AC, Robles de Medina PG, Mulder EJH, Visser GHA, Buitelaar JK. Stress during pregnancy is associated with developmental outcome in infancy. Journal of Child Psychology and Psychiatry. 2003;44(6):810-8.

12. Thompson LA, Morgan G, Unger CA, Covey LA. Prenatal maternal cortisol measures predict learning and short‐term memory performance in 3‐but not 5‐month‐old infants. Developmental psychobiology. 2017.

13. King, S. et al. QF2011: A protocol to study the effects of the Queensland flood on pregnant women, their pregnancies, and their children's early development. BMC Pregnancy and Childbirth. 2015.

14. Queensland Floods Commission of Inquiry. Final Report. 2012.

15. Moss, K. et al. A potential psychological mechanism linking disaster-related prenatal maternal stress with child cognitive and motor development at 16 months: The QF2011 Queensland Flood Study. Developmental psychology. 2017;53(4):629.

16. Brunet A, Weiss DS, Metzler TJ, Best SR, et al. The peritraumatic distress inventory: A proposed measure of PTSD criterion A2. The American Journal of Psychiatry. 2001;158(9):1480-5. PubMed PMID: 220451304; 11532735. English.

17. Thomas É, Saumier D, Brunet A. Peritraumatic distress and the course of posttraumatic stress disorder symptoms: a meta-analysis. Canadian journal of psychiatryRevue canadienne de psychiatrie. 2012;57(2):122.

18. Laplante DP, Zelazo PR, Brunet A, King S. Functional Play at 2 Years of Age: Effects of Prenatal Maternal Stress. Infancy. 2007;12(1):69-93.

19. Yong Ping E, Laplante DP, Elgbeili G, Hillerer KM, Brunet A, O'Hara MW, et al. Prenatal maternal stress predicts stress reactivity at 2½ years of age: The Iowa Flood Study. Psychoneuroendocrinology. 2015;56:62-78.

20. Marmar CR, Weiss DS, Metzler TJ. The Peritraumatic Dissociative Experiences Questionnaire. In: Wilson JP, Keane TM, editors. Assessing psychological trauma and PTSD. New York: Guilford Press; 1997. p. 412-28.

21. Brooks R, Bryant RA, Silove D, Creamer M, O'Donnell M, McFarlane AC, et al. The latent structure of the Peritraumatic Dissociative Experiences Questionnaire. Journal of Traumatic Stress. 2009;22(2):153-7.

22. Guardia D, Brunet A, Duhamel A, Ducrocq F, Demarty A-L, Vaiva G. Prediction of trauma-related disorders: a proposed cutoff score for the peritraumatic distress inventory. The primary care companion for CNS disorders. 2013;15(1).

23. Weiss DS, Marmar CR. The Impact of Events Scale - Revised. New York: Guilford; 1997.

24. Benight CC, Harper ML. Coping Self-Efficacy Perceptions as a Mediator Between Acute Stress Response and Long-Term Distress Following Natural Disasters. Journal of Traumatic Stress. 2002;15(3):177-86.

25. Creamer M, Bell R, Failla S. Psychometric properties of the Impact of Event Scale—Revised. Behaviour research and therapy. 2003;41(12):1489-96.

26. Sarason IG, Sarason BR, Shearin EN, Pierce GR. A Brief Measure of Social Support: Practical and Theoretical Implications. Journal of Social and Personal Relationships. 1987 November 1, 1987;4(4):497-510.

27. Abidin RR. Parenting Stress Index. 3rd ed. Odessa, FL: Psychological Assessment Resources; 1995.

28. Reitman D, Currier RO, Stickle TR. A Critical Evaluation of the Parenting Stress Index-Short Form (PSI-SF) in a Head Start Population. Journal of Clinical Child & Adolescent Psychology. 2002;31(3):384-92.

29. Lovibond PF, Lovibond SH. The structure of negative emotional states: Comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. Behaviour Research and Therapy. 1995 3//;33(3):335-43.

30. Bayley N. Bayley Scales of Infant and Toddler Development - Third Edition - Administration Manual. San Antonio, TX: Harcourt Assessment; 2006.

31. Bayley N. Bayley Scales of Infant And Toddler Development, 3rd edition - Technical manual. San Antonio, Texas: PsychCorp; 2006.

32. Graham JW. Missing data analysis: making it work in the real world. Annual Review of Psychology. 2009;60(1):549-76.

33. Ghosh D, Vogt A, editors. Outliers: An evaluation of methodologies. Survey Research Methods Section, American Statistical Association; 2012.

34. Rubin DB. Multiple imputation for nonresponse in surveys. New York: Wiley; 1987.

35. Hayes AF. Introduction to mediation, moderation, and conditional process analysis: a regression-based approach. New York: Guilford Press; 2013.

36. Laplante DP, Barr RG, Brunet A, Galbaud du Fort G, Meaney ML, Saucier JF, et al. Stress during pregnancy affects general intellectual and language functioning in human toddlers. Pediatric research. 2004 Sep;56(3):400-10. PubMed PMID: 15240860.

37. Bergman K, Sarkar P, O'Connor TG, Modi N, Glover V. Maternal stress during pregnancy predicts cognitive ability and fearfulness in infancy. Journal of the American Academy of Child and Adolescent Psychiatry. 2007;46(11).

38. Ramchandani PG. Maternal prenatal stress and later child behavioral problems in an urban South African setting. Journal of the American Academy of Child and Adolescent Psychiatry. 2010;49(3):239-47.

39. Kaplan LA, Evans L, Monk C. Effects of mothers' prenatal psychiatric status and postnatal caregiving on infant biobehavioral regulation: can prenatal programming be modified? Early human development. 2008;84(4):249-56.

40. Chuang C-H, Liao H-F, Hsieh W-S, Jeng S-F, Su Y-N, Chen P-C. Maternal psychosocial factors around delivery on development of 2-year-old children: A prospective cohort study. Journal of Paediatrics and Child Health. 2011;47(1-2):34-9.

41. Gabbard CP. Lifelong motor development. San Francisco: Pearson-Benjamin Cummings; 2012.

42. King S, Dancause K, Turcotte-Tremblay A-M, Veru F, Laplante DP. Using Natural Disasters to Study the Effects of Prenatal Maternal Stress on Child Health and Development. Birth Defects Research Part C: Embryo Today: Reviews. 2012;96(4):273-88.

43. Cao-Lei L, Massart R, Suderman MJ, Machnes Z, Elgbeili G, Laplante DP, et al. DNA methylation signatures triggered by prenatal maternal stress exposure to a natural disaster: Project Ice Storm. PloS one U6 2014;9(9):e107653.

44. Grace T, Bulsara M, Robinson M, Hands B. The Impact of Maternal Gestational Stress on Motor Development in Late Childhood and Adolescence: A Longitudinal Study. Child Development. 2015:n/a-n/a.

45. Huizink AC, De Medina PR, Mulder EJH, Visser GHA, Buitelaar JK. Prenatal maternal stress, HPA axis activity, and postnatal infant development. International Congress Series. 2002 9//;1241(0):65-71.

46. Davis EP, Sandman CA. The Timing of Prenatal Exposure to Maternal Cortisol and Psychosocial Stress Is Associated With Human Infant Cognitive Development. Child Development. 2010;81(1):131-48.

47. Brouwers EPM, van Baar AL, Pop VJM. Maternal anxiety during pregnancy and subsequent infant development. Infant Behavior and Development. 2001;24(1):95-106.

48. Tearne JE, Allen KL, Herbison CE, Lawrence D, Whitehouse AJO, Sawyer MG, et al. The association between prenatal environment and children's mental health trajectories from 2 to 14 years. European child & adolescent psychiatry. 2014.

49. Polanska K, Krol A, Merecz-Kot D, Jurewicz J, Makowiec-Dabrowska T, Chiarotti F, et al. Maternal stress during pregnancy and neurodevelopmental outcomes of children during the first 2 years of life. Journal of Paediatrics and Child Health. 2017;53(3):263-70.

50. Cao-Lei L, Elgbeili G, Massart R, Laplante DP, Szyf M, King S. Pregnant women's cognitive appraisal of a natural disaster affects DNA methylation in their children 13 years later: Project Ice Storm. Translational psychiatry. 2015;5(2):e515.

51. Piek JP. Infant motor development. Champaign, IL: Human Kinetics; 2006.

52. DiPietro JA. Maternal stress in pregnancy: considerations for fetal development. The Journal of adolescent health : official publication of the Society for Adolescent

Medicine. 2012 Aug;51(2 Suppl):S3-8. PubMed PMID: 22794531. Pubmed Central PMCID: 3402207.

53. Lewis AJ, Galbally M, Gannon T, Symeonides C. Early life programming as a target for prevention of child and adolescent mental disorders. BMC medicine. 2014;12(1):33.

54. O'Connor TG, Monk C, Fitelson EM. Practitioner Review: Maternal mood in pregnancy and child development – implications for child psychology and psychiatry. Journal of Child Psychology and Psychiatry. 2014;55(2):99-111.

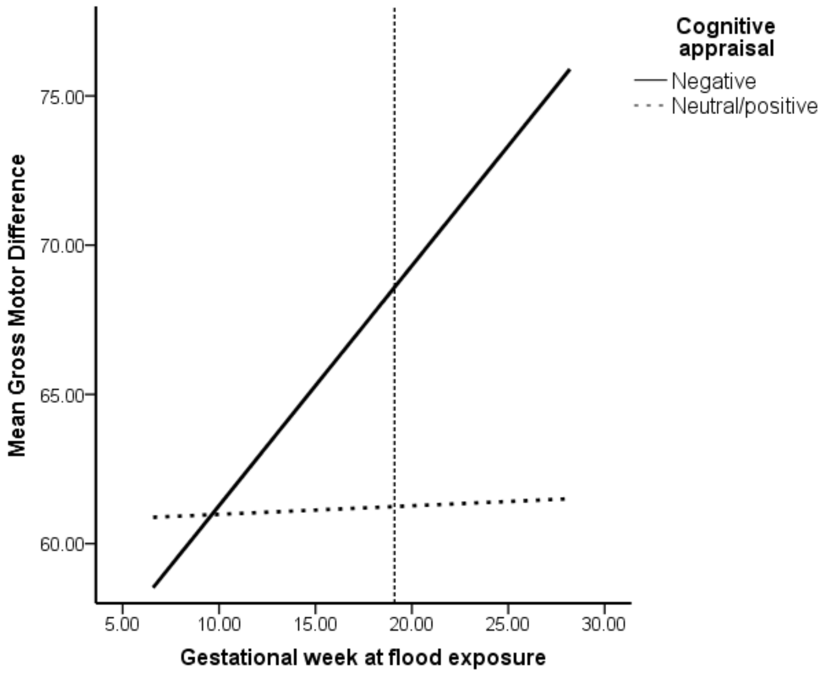

Figure 1. The moderating effect of timing (i.e., the week of flood exposure during gestation) on the relationship between maternal cognitive appraisal and child gross motor difference scores. The approximate region of significance is to the right of the vertical dashed line.

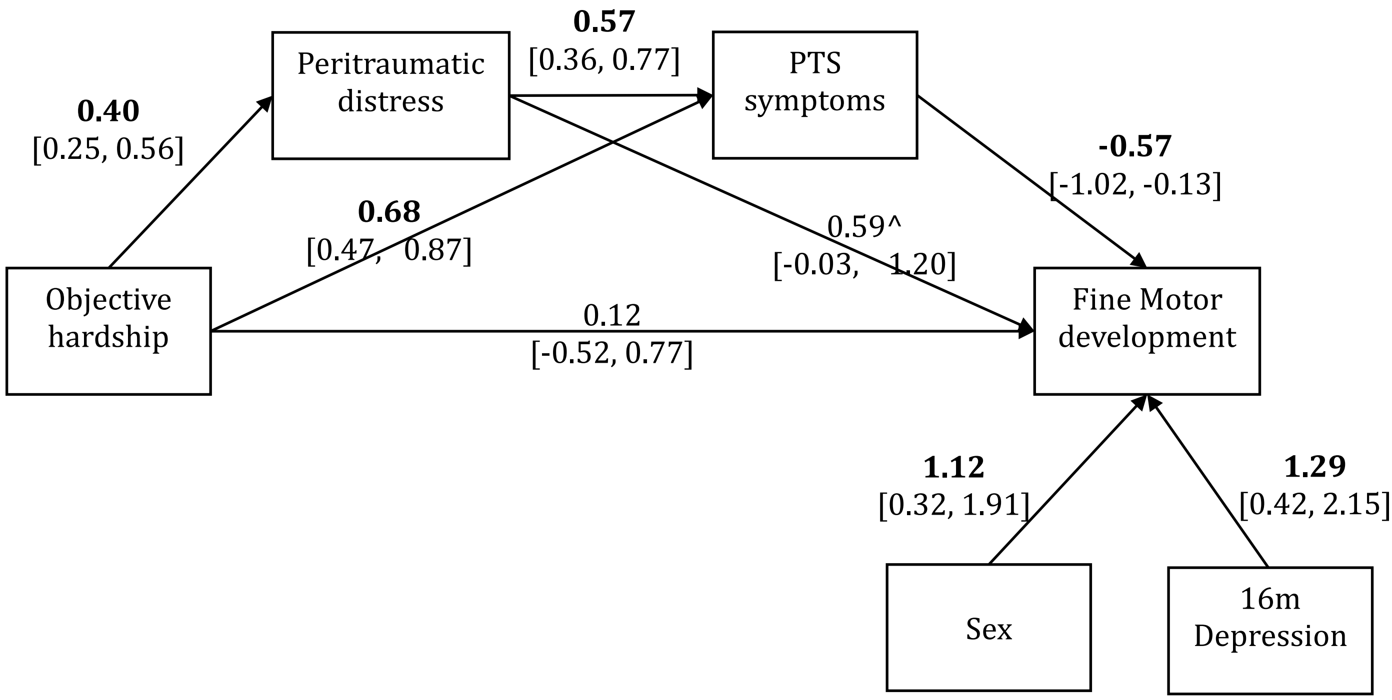

Figure 2. Path model for the serial mediation. The relationship between objective hardship and child fine motor development at 30 months is mediated by maternal peritraumatic distress and PTS symptoms acting in serial (with sex and significant postnatal distress as covariates). Values in bold are significant based on their 95% Confidence Interval (in square brackets beneath each value). All coefficients are unstandardized.