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RESEARCH ARTICLE

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A trajectory analysis of childhood motor development following stress in pregnancy: The QF2011 flood study

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Abstract

This prospective, longitudinal cohort study examined the effects of flood-related stress in pregnancy on the trajectory of children's motor development; and the moderating effects of gestational timing of the flood or sex of the child. Women who were pregnant during a severe flood reported on their objective flood-related experiences, emotional reactions, and cognitive appraisal of the disaster. At 2-, 6-, 16-months, 2½- and 4-years postpartum, mothers' assessed their children's fine and gross motor development using the Ages and Stages-3 Questionnaire. High objective flood-exposure, or a negative appraisal, especially in later pregnancy, predicted poorer gross motor skills which rapidly improved across early childhood. Children's fine motor skill was influenced by the sex of the child with improvements in girls' fine motor skills over time, but not boys'. This demonstrates that stress in pregnancy has enduring influences on gross, but not fine, motor skills. Results are discussed in relation to fetal programming and stress appraisal theory.

KEYWORDS

Ages and Stages questionnaire, developmental trajectory, fetal programming, motor development, natural disaster, prenatal maternal stress

1 | INTRODUCTION

Research has demonstrated the importance of motor functioning during early childhood in relation to a number of key developmental outcomes (Bornstein, Hahn, & Suwalsky, 2013), with delays in motor development related to poorer language skill (Walle & Campos, 2014), cognitive functioning (Brandone, 2015; Herbert, Gross, & Hayne, 2007; Piek, Dawson, Smith, & Gasson, 2008), delayed social functioning, and ongoing delays in motor skills (Rose-Jacobs, Cabral, Beeghly, Brown, & Frank, 2004; Siegel, 1983). Furthermore, delayed and/or atypical motor functioning is characteristic of childhood developmental disorders such as autism-spectrum disorders and attention-deficit disorders (Johnson, Gilga, Jones, & Charman, 2015). It is therefore important to further our understanding of factors that adversely affect motor functioning during early childhood.

Prenatal maternal stress (PNMS) is one factor that has recently received attention as contributing to childhood motor functioning. Generally, stress in pregnancy, such as stressful life events or anxiety in pregnancy, predicts poorer motor functioning during childhood (Chuang, Liao, Hsieh, Jeng, & Su, 2011; Grace, Bulsara, Robinson, & Hands, 2016); although this is not always the case (Davis & Sandman, 2010). Furthermore, different types of stress have differential effects on motor skill: one study found that whereas high pregnancy-specific stress was associated with slower motor development at 2 years, mildly elevated levels of prenatal distress had a positive association with motor development (DiPietro, Novak, Costigan, Atella, & Reusing, 2006). Additionally, it appears that PNMS does not consistently affect early motor development across age: two longitudinal studies found a negative association between pregnancy-specific anxiety and daily life hassles and motor development at 8 months, but not at 3 months of age (Buitelaar, Huizink, Mulder, de

Medina, & Visser, 2003; Huizink, Robles de Medina, Mulder, Visser, & Buitelaar, 2003).

The above findings are supported by research using natural disasters as the pregnancy stressor. Sudden-onset disasters as a pregnancy stressor (King & Laplante, 2015; Kinney, Miller, Crowley, & Gerber, 2008; Yehuda et al., 2005) overcome the potential limitation of maternal psychological problems or negative life events in pregnancy being potentially confounded with genetic transmission of psychological traits that can negatively affect child development (King & Laplante, 2015). Furthermore, the same disaster can randomly affect women at varying stages of pregnancy, allowing investigation into whether the gestational timing of PNMS exposure influences child development. Additionally, disaster-related PNMS enables exploration of the various components of the women's stress experiences: objective hardship during the disaster, subjective emotional responses to the stressor, and overall cognitive appraisal of the effects of the event.

One study found that pregnancy exposure to a severe ice storm that occurred in Quebec, Canada in 1998, predicted poorer motor development at 5½ years of age (Cao, Laplante, Brunet, Ciampi, & King, 2014). The children's bilateral coordination and visual motor integration were negatively affected by high levels of maternal subjective stress (e.g., emotional reactions), whereas maternal objective hardship (e.g., days without electricity) adversely affected motor skills only when subjective stress was low. Children's balance was not affected by PNMS. This demonstrates that various domains of motor development are differentially affected by the components of PNMS. Additionally, when the storm occurred later in pregnancy, girls (but not boys) had poorer coordination and motor integration, demonstrating how timing of the stressor in pregnancy and sex of the child can moderate the effects of PNMS on motor function.

Similar differential effects of PNMS were found on aspects of early motor development when utilizing a sudden on-set flood that occurred in Queensland, Australia in 2011, as the pregnancy stressor. Simcock et al. (2016) used the Ages and Stages Questionnaire (ASQ-3; Squires, Twombly, Bricker, & Potter, 2009) to assess mother-rated gross and fine motor development in a cross sectional study at 2, 6, and 16 months of age. Results showed an unexpected positive association of objective hardship on fine motor skill at 2 months of age. However, at 6 months there was a negative association between objective hardship and fine motor skill, and a negative appraisal of the event in late pregnancy predicted poorer fine motor skill. There were no effects of PNMS on fine motor skill at 16 months. For gross motor, there were no significant effects of PNMS at 2 months. However, at 6 months poorer gross motor skill was associated with higher levels of maternal objective hardship and subjective distress. Furthermore, at both 6 and 16 months a negative maternal cognitive appraisal of the event was related to poorer gross motor skills when the flood occurred in late pregnancy.

Using the same QF2011 Queensland flood cohort, Moss and colleagues assessed motor development at 16 (Moss et al., 2017) and 30 months (Moss et al., 2018) using the Bayley-III. At 16 months, fine motor skills were adversely affected by higher levels of maternal subjective distress (post-traumatic stress; PTS); particularly when the flood occurred in late pregnancy. The negative association between flood-related PTS and poor gross motor skill was still evident at 30 months, as well as a new positive association between high peritraumatic stress and better gross motor functioning (Moss et al., 2018). Furthermore, 16-month-olds exhibited poorer gross motor skills if their mothers had had a negative appraisal of the overall impact of the flood and were also exposed to the disaster in late pregnancy. A negative maternal appraisal of the flood adversely affected girls' gross motor skills, but not boys at 16 months. However, by 30 months, the significant associations between flood-related PNMS and gross motor skill had dissipated. These disparate findings across age emphasise the necessity of assessing the relation between PNMS and child development longitudinally.

Taken together, these studies show that various components of the pregnant women's flood-related PNMS experience exert differential effects on gross and fine motor development at each age in early childhood, depending on the scale used; and that the sex of the child and timing of the flood in pregnancy may moderate these effects. However, because most of the research examines infant motor functioning at a single point in time, and because those results can be inconsistent both between studies and within a given study at different ages, little is known about the influence of PNMS on the trajectories of motor development during early childhood using repeated measures.

The aims of the current research were twofold: (a) to explore the developmental trajectory of motor development in the QF2011 prenatally flood-affected cohort at five time-points across early childhood from 2 months to 4 years, and (b) to assess the potential moderating effects of gestational timing of flood exposure and sex of the child on motor skill. Based on past disaster studies (Cao et al., 2014; Moss et al., 2017; Simcock et al., 2016), we expected that the various components of flood-related PNMS would have differential negative effects on gross and fine motor skill, and that late pregnancy flood exposure would be associated with poorer motor skills. Furthermore, given that Simcock et al. (2016) did not find any moderating effects of infant sex on ASQ-3 motor development at ages 2, 6, or 16 months, we did not expect sex to buffer the association between PNMS and motor skill. Given the novel and exploratory nature of the longitudinal analysis, no hypotheses for the developmental trajectory of gross and fine motor skill were developed.

2 | METHOD

2.1 | Participants and procedure

Women fluent in English were recruited into the QF2011 study if they were 18 years of age or older and were pregnant with a singleton pregnancy during the flood on January 10, 2011. Women were primarily recruited at a major urban tertiary hospital in the flood-affected region. Participants in an ongoing randomized controlled trial of midwifery care and women attending the antenatal clinic at the hospital who met inclusion criteria were invited by midwives to participate in the QF2011 study. Additional women in the area responded to ads in the media and at local doctors' offices. Recruitment commenced once ethical approval was received (April 2011) and continued until 1 year post-flood (January 2012). A detailed description of recruitment methods and eligibility criteria can be found in King et al. (2015). At the recruitment into the study, and again at 1-year post-flood, a total of 230 women provided responses to a questionnaire about their flood-related experiences and reactions, their demographics, and mental health. From this initial sample, 206 women (89.6% response rate) also responded to questionnaires about their mental health and their children's development at 2 (n = 122), 6 (n = 124), and 16 (n = 148) months (Simcock et al., 2016), and at 2½ (n = 137) and 4 (n = 119) years of age.

Data from three children born <36 weeks gestation, and data from one child with a medical condition affecting motor development, were removed from the analyses (two with 2-month data, one with 6-month data, two with 16-month data, four with 2½-year data, and four with 4-year data). Additionally, 50 data points were also removed as the questionnaires were completed outside of the specified ASQ-3 age-range for each target age (age ± 1 month at age 2 (n = 14), 6 (n = 8), and 16 months (n = 17) (Simcock et al., 2016); and ± 6 weeks at age 2½ years (n = 9) and ± 3 months at age 4 years (n = 2). Finally, the data from one additional child at 2½-year-old was removed as the survey was completed incorrectly.

At each of the five assessment ages, all mothers enrolled in the QF2011 study were invited to compete the ASQ-3. Data were included if mothers completed the ASQ-3 at one or more of the target ages; n = 30 mothers completed the questionnaire at all five assessment time-points; n = 45 at four time points, n = 39 at three time points, n = 54 at two time points, n = 32 at one time point. The final samples at each age for all analyses included data from 106 2-month-olds (M = 1.99 months, SD = 0.42), 115 6-month-olds (M = 6.25 months, SD = 0.33), 129 16-month-olds (M = 16.11 months, SD = 0.77), 124 2½-year-olds (M = 29.98 months, SD = 0.71), and 113 4-year-olds (M = 48.65 months, SD = 0.91). Across the five samples, approximately half the children at each age were boys: 52% (range = 47% to 58%).

Across the five samples, the mother's mean socioeconomic index on the Socio-Economic Index For Area (SEIFA) (Australian Bureau of Statistics, 2016) was 1,054.50 (SD = 55.21, range = 1,051.70–1,058.07); which is slightly higher than the national mean of 1,000 (SD = 50). The mothers were also well educated with a mean of 14.67 years schooling (SD = 1.75, range = 14.43–14.89) across the five samples. Across the five samples, most women were in married or de facto relationships (M = 88%; sample range = 83%–94%) with approximately half giving birth to their first child (primiparous = 54%; sample range = 52%–57%). Analyses revealed that participants who did not participate in any time point were more anxious at recruitment than those who did (State scale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). However, there were no other differences in other psychological characteristics or demographics between the mothers who participated in each assessment period and those for whom no infant data were available. Moreover, the participating and nonparticipating dyads did not differ in terms infant sex, PNMS measures, or timing of the flood exposure in pregnancy.

This research has ethical approval from the study site Human Research Ethics Committee (M1188) and affiliated university (2013001236). All participants provided informed consent.

2.2 | Child outcome variables

2.2.1 | Motor development

Motor development was assessed at 2, 6, and 16 months (Simcock et al., 2016), 2½ and 4 years using the age-appropriate ASQ-3. This tool relies on parental-report of children's attainment of six listed activities on five domains of development at each age. The gross and fine motor scales of the ASQ-3 are reported here. The six gross motor items assess children's full-body, arm, and leg movements, and the six fine motor items assess hand and finger movements (see Table 1 for examples of ASQ-3 items). Mothers rated their children's development as "yes," "sometimes," or "not yet" for each item depending on whether the child had achieved the described behaviour. Pediatric review for further assessment is recommended if the children's scores fall −2 standard deviations (SD) below the pre-established ASQ-3 cut-off mean for each scale (Squires et al., 2009).

The ASQ-3 has high test–retest reliability (correlation coefficients range = 0.75–0.82) and good internal consistency (Cronbach alphas

TABLE 1 Examples of items from the gross motor and fine motor scales of the ages and stages-3 questionnaire at each age

Assessment age	Gross motor	Fine motor
2 months	"When your baby is on her tummy, does she turn her head to the side?"	"Does your baby grasp your finger if you touch the palm of her hand?"
6 months	"Does your baby get into a crawling position by getting up on her hands and knees?"	"Does your baby reach for or grasp a toy using both hands at once?"
16 months	"Does your child walk well, and seldom fall?"	"Does your child stack three small blocks or toys on top of each other by herself?"
2½ years	"Without holding onto anything for support, does your child kick a ball by swinging his leg forward?"	"Does your child turn pages in a book, one page at a time?"
4 years	"Does your child hop up and down on either the right or left foot at least one time without losing her balance or falling?"	Does your child unbutton one or more buttons? (Your child may use his own clothing or a doll's clothing.)

range: 0.51–0.87) (Squires et al., 2009). Comparisons of parent report on the ASQ-3 scales to infant classifications on scales administered by a trained assessor, such as the Bayley Scales of Development (Bayley, 1969), the Stanford-Binet Intelligence Scale (Thorndike, Hagen, & Sattler, 1985), and the McCarthy Scales of Children's Abilities (McCarthy, 1972) show the validity of the ASQ-3 with overall agreement of 83% (range = 76%–91%; (Bricker, Squires, & Mounts, 1995).

2.3 | Maternal stress variables

2.3.1 | Objective hardship

Mothers' objective exposure to the flood was assessed using the Queensland Flood Objective Stress Scale (QFOSS), a questionnaire designed especially for the Queensland flood study and based on questionnaires used in prior flood PNMS research (Yong-Ping, 2016). Items were based on the events that occurred during the disaster and they assessed four key dimensions of stress: Threat (e.g., "Where you physically hurt because of the flood?"), Loss (e.g., "Did you experience a loss of property because of the flooding?"), Scope (e.g., "how many days did you lose water because of the flooding?"), and Change (e.g., "How many times were you required to change home because of the flood?"). Each dimension had possible scores ranging from 0 (no impact) to 50 (extreme impact), and were summed to provide a total individual objective hardship score (range = 0–200). Higher scores indicated higher levels of objective hardship.

2.3.2 | Composite subjective stress

Three scales assessed mothers' subjective reactions to the flood. Mothers' post-traumatic subjective stress was assessed using the 22-item Impact of Event Scale-Revised (IES-R, Weiss & Marmar, 1997) which assesses post-traumatic stress symptoms during the past 7 days (e.g., "Any reminder brought back feelings about the flood"). Mothers rated each item using a 5-point Likert scale: 0 (not at all true) to 4 (extremely true). The IES-R has high internal consistency (alpha coefficients range: 0.79–0.94) and good test–retest reliability (correlation coefficients range: 0.51–0.94) (Creamer, Bell, & Failla, 2003; Weiss & Marmar, 1997).

Mothers' peritraumatic distress was assessed with the 13-item peritraumatic distress inventory (PDI-Q; Brunet et al., 2001) and the 10-item peritraumatic dissociative experiences questionnaire (PDEQ; Marmar, Weiss, & Metzler, 1997). The PDI retrospectively assesses the severity of emotional distress and panic-like physical reactions the pregnant women recalled experiencing when the flood occurred (e.g., "I thought I might die"). The PDEQ retrospectively assesses the severity of dissociative-like experiences the women recalled from when the flood occurred (e.g., "My sense of time changed." "Things seemed to be happening in slow motion"). Mothers completed these self-report questionnaires using a 5-point rating scale from "not at all true" to "extremely true" regarding their peritraumatic reactions to the flood.

To reduce the number of regression analyses conducted, a composite score for mothers' subjective stress (COSMOSS) was computed using principal component analysis (PCA) on IES-R, PDI and PDEQ total scores from the 230 women who provided complete PNMS data. The PCA-derived algorithm was: COSMOSS = 0.358*IESR + 0.397*PDI + 0.387*PDEQ; resulting in one standardized factor explaining 76.27% of the overall subjective stress variance.

2.3.3 | Cognitive appraisal

Mothers' cognitive reactions to the flood were assessed using a single item: "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...?" They were asked to rate their appraisal of the flood experience on a 5-point Likert scale, from Very Negative (−2) to Neutral (0) to Very Positive (+2). Scores were dichotomized into negative versus neutral/positive to discriminate women who harbored negative appraisals of the flood from those who did not.

2.3.4 | Timing of flood exposure

When the Queensland flood occurred on January 10, 2011, participants were at various stages of pregnancy. Estimates of conception dates was calculated by subtracting 280 days (40 weeks) from each woman's due date (based on infant gestational age and date of birth). The difference between the peak date of the flood and estimates of conception dates was calculated to determine the age of gestation at which the fetus was exposed to the flood.

2.4 | Covariates

2.4.1 | Maternal factors

To control for potentially confounding variables other than flood-related stress responses, we assessed maternal mental health at each age. At 2 and 6 months, maternal depression was assessed with the 10-item Edinburgh Postnatal Depression Scale (EPDS; Cox, Holden, & Sagovsky, 1987) and maternal anxiety was assessed with the 20-item state scale of the state-trait anxiety inventory (STAI; Lovibond & Lovibond, 1995). At 16 months, 2½ and 4 years, maternal depression and anxiety were assessed with the 21-item depression, anxiety and stress scale (DASS-21; Lovibond & Lovibond, 1995). We also controlled for maternal socioeconomic status using the SEIFA (M = 1,000, SD = 50) based on Australian census data regarding ranking of residential areas according to relative advantage and disadvantage. Maternal education level using number of years schooling, her relationship status (married or de facto vs. single/separated/divorced), and parity of the study child were also controlled for.

2.4.2 | Child factors

To control for factors other than flood-related stress known to influence child motor development, we gathered birth outcome data (gestational age, birth weight, and head circumference) from the birthing-hospital database.

TABLE 2 Descriptive statistics for the prenatal maternal stress (PNMS) predictor variables and Ages and Stages Questionnaire (ASQ-3) outcomes at each age; and comparisons with the standardized norms and established cut-off scores

	Sample age at assessment				
Variables	**2 Months**	**6 Months**	**16 Months**	**2½ Years**	**4 Years**
PNMS Variables					
Objective hardship, *M* (*SD*)	18.29 (13.92)	21.33 (16.77)	20.68 (17.09)	20.98 (16.62)	21.13 (17.57)
Composite subjective stress, *M* (*SD*)	−0.09 (0.91)	0.09 (1.12)	0.04 (1.09)	−0.02 (0.910)	−0.02 (0.87)
Cognitive appraisal: Negative, *N* (%)	37 (35)	42 (37)	46 (35)	47 (38)	40 (35)
Cognitive appraisal: Neut/Pos, *N* (%)	68 (65)	72 (63)	84 (45)	77 (62)	73 (65)
Timing of exposure (days) , *M* (*SD*)	84.63 (52.85)	112.56 (74.59)	131.98 (78.61)	118.52 (76.41)	129.41 (78.59)
ASQ–3 Variables					
Gross motor					
ASQ standardized scores, *M* (*SD*)	55.32 (6.74)	45.64 (11.69)	56.31 (9.20)	53.54 (8.70)	52.71 (9.97)
QF2011 sample scores, *M* (*SD*)	49.514 (12.81)***	45.28 (11.27)	54.23 (12.54)*	53.04 (8.92)	54.14 (7.94)
ASQ cut-off scores, *M* < −2SD	41.84	22.25	37.91	36.14	32.78
QF2011 below cut-off, *N* (%)	21 (20)	4 (3.5)	12 (9)	5 (4)	4 (4)
Fine motor					
ASQ Standardized scores, *M* (*SD*)	49.80 (9.82)	48.93 (11.90)	51.96 (9.99)	46.78 (13.76)	45.35 (14.77)
QF2011 sample scores, *M* (*SD*)	42.50 (11.37)***	47.17 (11.57)*	47.65 (12.94)***	42.63 (14.34)***	48.00 (12.26)**
ASQ cut-off scores, *M* < −2SD	30.16	25.14	31.98	19.25	15.81
QF2011 below cut-off, *N* (%)	25 (24)	7 (6)	18 (14)	9 (7)	16 (12)

Note:. Untransformed scores are used for the maternal stress measures; data from the 2-, 6-, and 16-month sample ages from Simcock et al. (2016).
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

2.5 | Statistical analyses

Descriptive statistics for the sample are shown in Table 2. Pearson product-moment correlations conducted to examine the relation between the children's gross and fine motor scores, the PNMS predictor variables, and the covariates are shown in Table 3 for each age. All tests used an alpha level of 0.05 (two-sided tests).

Mixed model analyses were used to investigate any effects of PNMS on the pattern of change in fine and gross motor skills from 2 months to 4 years. The models were tested allowing the intercept and the effect of age to vary across assessment ages and participants, setting them as both fixed and random effects. The random effects were removed if found to be nonsignificant. All other variables were entered only as fixed effects, one at the time: objective hardship was entered first, followed by the composite subjective stress, cognitive appraisal, child sex, timing of exposure, age at assessment, and in the final step, any covariates significantly correlated with the outcome. We added an additional step to the models, testing interactions including infant age, to determine if PNMS variables changed the trajectory of motor development across assessment ages. We also explored three-way interactions, all including child age, to determine the extent to which PNMS interacted with sex or timing of exposure to influence the evolution of motor skills from 2 months to 4 years. If both random effects (intercept and age) were nonsignificant, there was no need to use mixed models, and as such, the analyses were run as regular hierarchical multiple regressions, pooling all the time points together, and the outcome becoming the overall motor skills. Any variable that was no longer significant in the final model was removed from the model, except for objective hardship and any variable included in a significant interaction for a given outcome. Analyses were conducted using SPSS v22.

TABLE 3 Correlations between gross and fine motor scores, predictor variables, and covariates by age

	2 Months	6 Months	16 Months	2½ Years	4 Years
Gross motor					
Objective Hardship[a]	0.182*	−0.315***	−0.095	−0.062	−0.105
Composite subjective stress	0.136	−0.298***	−0.122	−0.167*	−0.016
Cognitive appraisal	−0.047	0.100	0.115	−0.032	0.099
Timing of exposure	−0.088	−0.178	−0.191**	−0.128	0.231**
School level (years)	−0.049	−0.084	−0.027	−0.039	−0.141
Socioeconomic status	0.074	−0.028	−0.065	−0.065	0.054
Concurrent anxiety	−0.074	−0.100	−0.272**	−0.089	−0.124
Concurrent depression	−0.040	−0.140	0.016	−0.133	−0.186
Marital status	0.049	−0.099	−0.021	−0.024	−0.022
Parity	0.049	0.082	0.253***	0.023	0.090
Gestational age at birth	0.042	0.208**	0.041	−0.028	0.053
Birth weight	0.185	0.063	0.055	−0.012	−0.006
Head circumference	0.046	−0.067	0.044	0.027	0.081
Child sex (0 = boy)	−0.117	−0.019	0.157	0.013	0.141
Fine Motor					
Objective Hardship[a]	0.063	−0.231**	−0.093	−0.091	−0.209**
Composite subjective stress	0.157	−0.200**	0.071	−0.024	−0.149
Cognitive appraisal	−0.005	0.119	0.050	−0.010	0.096
Timing of exposure	−0.042	0.034	−0.152	0.023	**0.2**15**
School level (years)	0.006	0.090	0.101	0.096	0.021
Socioeconomic status	−0.073	−0.011	−0.126	−0.190**	−0.088
Concurrent anxiety	−0.053	−0.074	−0.185**	−0.181**	0.043
Concurrent depression	0.042	−0.198**	0.051	−0.010	−0.026
Marital status	0.026	−0.102	−0.020	0.014	−0.052
Parity	−0.059	0.071	0.054	0.062	0.104
Gestational age at birth	−0.019	0.169	0.099	0.055	0.099
Birth weight	0.011	0.114	0.058	0.149	0.083
Head circumference	−0.044	−0.100	0.067	−0.014	0.050
Child sex (0 = boy)	0.076	0.049	−0011	0.124	0.393***

[a]Log transformed scores; data from the 2-, 6-, and 16-month sample ages from Simcock et al. (2016).
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

3 | RESULTS

3.1 | Descriptive statistics

The Kolmogorov–Smirnov test of normality showed the objective hardship PNMS measure was highly positively skewed, so the scores were log-transformed. Descriptive statistics for the PNMS predictor variables, maternal and child factors, and infants fine and gross motor scores, with comparisons with the ASQ-3 standardized norms (one-sample t tests) and cut-off ($-2\ SD < M$) scores at each assessment age are shown in Table 2. In terms of the women's mental health, their EPDS scores were low compared to the score of >12 for clinical referral at the 2 and 6 month samples ($M = 5.75$, $SD = 4.32$), and their DASS depression scores from 16 months to 4 years ($M = 4.87$, $SD = 6.53$) were comparable to normative community sample scores

(M = 6.43; SD = 6.97). The 2- and 6-month samples also had state anxiety scores on the STAI (M = 33.45, SD = 9.10) and anxiety scores from 16 months to 4 years on the DASS (M = 3.51, SD = 5.27) that were comparable to normative community sample scores (M = 35.20, SD = 10.61; and M = 4.70, SD = 6.79), respectively.

Across the five samples, the infants were an average of 39.40 weeks gestational age at birth (SD = 1.22; range = 36–42 wks), weighing 3,566.77 g (SD = 452.89; range = 2,712–5,050 g), with an average head circumferences of 34.94 cm (SD = 1.40; sample range = 32–39 cm).

3.2 | Correlation coefficients

3.2.1 | Gross motor

As shown in Table 3, at 2 months of age, there were no significant associations between gross motor skill and the PNMS measures, although the correlation with objective hardship approached significance. At 6 months of age, however, gross motor skill was significantly negatively correlated with maternal objective hardship and composite subjective stress levels, suggesting that higher in utero objective hardship and subjective stress levels predicted poorer gross motor development. At 16 months of age, there was no relation between gross motor development and any PNMS measure, although there was a negative correlation with timing of exposure to the flood, indicating that flood-exposure in late pregnancy predicted worse gross motor skills at 16 months. At 2½ years, there was a marginally significant negative correlation with composite subjective stress, suggesting a trend for higher maternal subjective stress to predict worse gross motor skill; but no other PNMS variables were significant. At 4 years of age, the children's gross motor skills were not significantly correlated with any of the maternal PNMS measures. However, there was a significant correlation between gross motor scores and timing of exposure to the flood: unlike at earlier ages, later exposure to the flood in pregnancy was associated with better gross motor skills at age 4.

Three control variables were significantly correlated with gross motor development: at 6 months, longer gestation was associated with better gross motor skills, while at 16 months, a negative correlation between gross motor development and maternal anxiety (on the DASS) was evident; as well as a significant correlation between gross motor and parity. None of the covariates were significantly related to gross motor skill at 2½ or 4 years of age.

3.2.2 | Fine motor

As shown in Table 3, at 2 months of age, there were no significant correlations between fine motor skill and the PNMS measures. In contrast, at 6 months of age, fine motor skill was negatively correlated with both maternal objective hardship and composite subjective stress, suggesting that higher levels of objective and subjective PNMS predicted poorer fine motor development. At 16 months and 2½ years, there was no correlation between any of the PNMS variables and fine motor skill. At 4 years of age, children's fine motor skills were significantly negatively correlated with objective hardship: higher maternal hardship predicted poorer fine motor development at age 4. There was also a significant correlation between fine motor and timing of exposure to the flood, suggesting that later exposure to the flood in pregnancy was associated with better fine motor skills at age 4.

At 2 months of age, there were no significant correlations between fine motor skill and the control variables. However, at 6 months, fine motor skill was negatively correlated with maternal depression (EPDS), while at 16 months, fine motor skill was negatively correlated with maternal anxiety (DASS). At 2½ years, fine motor skill was negatively correlated with socioeconomic status, suggesting higher SES was associated with poorer fine motor skill; and a positive correlation with (high) concurrent anxiety was associated with poorer fine motor skills (DASS). Furthermore, the correlation, and t test, indicated that 4-year-old girls (M = 52.84, SD = 9.28) had better fine motor skills than the boys (M = 43.25, SD = 13.03), $t(111) = -4.515$, $p < 0.001$.

3.3 | Mixed models

3.3.1 | Gross motor main effects

The random effects of the intercept and age of the child, as well as their covariance, were not significant in the model for gross motor skills, so mixed modeling was not necessary for this outcome: hence, the analyses were run using fixed effect model, shown in Table 4a. In step 1, objective hardship explained a marginally significant amount of variance in gross motor skill. In steps 2, 3, and 4, adding composite subjective stress, cognitive appraisal, and then timing of exposure into the model did not explain additional significant variance in children's gross motor skills. When age of the child at the assessment was added at step 5, this explained an additional 4.6% of the outcome's variance, such that gross motor scores increased as a function of increasing age. Timing of exposure in pregnancy also became significant, such that later exposure was associated with poorer gross motor skills.

3.3.2 | Gross motor interactions

A significant three-way interaction was detected between objective hardship, timing of exposure and child's age (see Table 4b). Probing the interaction (Figure 1) revealed that, for participants whose mothers had low levels of objective hardship (black lines), being exposed early in pregnancy (before 12.7 weeks gestation) was associated with a significant increase in gross motor over time, while there was no significant change over time for participants exposed later in pregnancy. Inversely, for participants whose mothers had high levels of objective hardship (red lines), being exposed early in pregnancy was not associated with a significant change in gross motor over time, while there was a significant increase over time for participants exposed later in pregnancy (after 25.7 weeks gestation). Also,

TABLE 4 Summary of hierarchical regression analyses for the gross motor scale from 2 months to 4 years, trimmed of all non-significant variables

Predictor variables	β	B	Std. error	R	R^2	ΔR^2	F	ΔF
a) Main effects								
Step 1				0.073	0.005	0.005	3.10*	3.10*
Objective hardship	−0.073*	−1.076*	0.611					
Step 2				0.099	0.01	0.004	2.864*	2.62
Objective hardship	−0.035	−0.52	0.701					
Composite subjective stress	−0.077	−0.903	0.558					
Step 3				0.1	0.01	0	1.939	0.099
Objective hardship	−0.028	−0.418	0.772					
Composite subjective stress	−0.075	−0.885	0.651					
Cognitive appraisal	0.015	0.356	1.135					
Step 4				0.113	0.013	0.003	1.85	1.578
Objective hardship	−0.028	−0.408	0.772					
Composite subjective stress	−0.074	−0.871	0.561					
Cognitive appraisal	0.018	0.423	1.136					
Timing of exposure	−0.052	−0.008	0.006					
Step 5				0.241	0.058	0.046	7.109****	27.801***
Objective hardship	−0.037	−0.547	0.755					
Composite subjective stress	−0.072	−0.845	0.549					
Cognitive appraisal	0.015	0.341	1.11					
Timing of exposure	−0.082**	−0.012**	0.006					
Age at assessment	0.216****	0.147****	0.028					
b) Interactions								
Step 6a				0.282	0.08	0.021	5.490****	3.321**
Objective hardship	0.186	2.744	1.872					
Composite subjective stress	−0.078*	−0.917*	0.545					
Cognitive appraisal	0.012	0.277	1.104					
Timing of exposure	0.361	0.054	0.044					
Age at assessment	0.641**	0.436**	0.205					
Objective hardship × Age	−0.629**	−0.139**	0.069					
Objective hardship × Timing	−0.662**	−0.031**	0.015					
Timing × Age	−0.672	−0.003	0.002					
Age × Timing × Objective hardship	0.992**	0.001**	0.001					
Step 6b				0.3	0.09	0.032	6.293****	5.023****
Objective hardship	−0.039	−0.58	0.747					
Composite subjective stress	−0.063	−0.735	0.546					
Cognitive appraisal	−0.292**	−6.861**	2.774					
Timing of exposure	−0.559****	−0.084****	0.018					
Age at assessment	−0.087	−0.059	0.085					
Cognitive appraisal × Age	0.199	0.135	0.106					
Cognitive appraisal × Timing	0.539***	0.073***	0.022					
Timing × Age	0.538***	0.002***	0.001					
Age × Timing × Cognitive appraisal	−0.369*	−0.002*	0.001					

*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.
****$p < 0.001$.

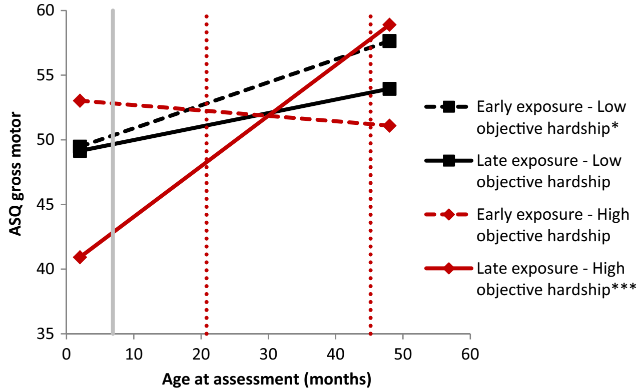

FIGURE 1 Three-way interaction between the level of mother's objective hardship, timing of exposure in pregnancy, and child age at assessment on children's gross motor skill. When mothers' experienced low objective hardship, and the flood was timed early in their pregnancy (black dashed line), their children's gross motor skill significantly improved across age; whereas the increase in scores with age is not significant with low objective hardship and late pregnancy flood (black solid line). In contrast, with high levels of objective hardship, with timing in late pregnancy, there was a significant increase in gross motor skill across age (red solid line); but no change across age with high objective hardship with early gestation flood exposure (red dashed line). The red dashed vertical lines show the regions of significance below 21 months and above 45 months where the effect of timing of exposure on gross motor skills is significant for participants exposed to high objective hardship. Thus, when those participants were 21 months of age or younger, timing had a significant effect on gross motor skills such that the later in pregnancy the exposure the worse the skills; however, by 45 months of age the direction of effect had reversed such that later timing of exposure was associated with significantly better gross motor skills. The gray solid vertical line shows the region of significance below 7 months where the effect of objective hardship on gross motor skills is significant for participants exposed late in pregnancy. When those participants were 7 months old or younger, higher objective hardship was associated with lower gross motor skills

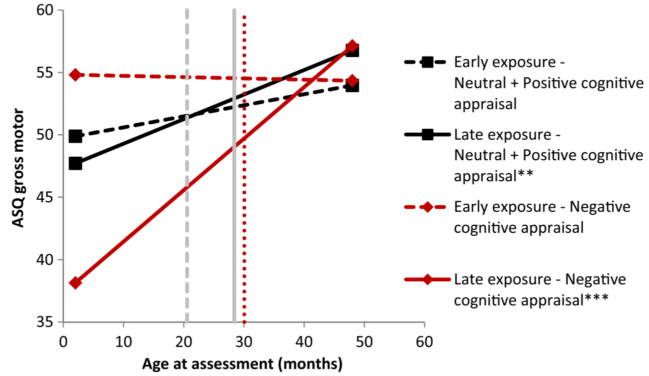

FIGURE 2 Three-way interaction between the level of mother's cognitive appraisal of the flood, timing of exposure in pregnancy, and child age at assessment on children's gross motor skill. With a neutral or positive maternal cognitive appraisal of the flood and late gestation exposure, children's gross motor skill improved across age (black solid line); but they do not change across age with early gestation flood exposure (black dashed line). Similarly, with a negative maternal appraisal of the flood and late gestation exposure, children's gross motor skill improved across age (red solid line); but they do not change across age with early gestation flood exposure (red dashed line). The red dashed vertical line shows the region of significance below which the effect of timing of exposure on gross motor skills is significant (below 30 months) for participants with negative cognitive appraisal, such that later exposure is associated with poorer gross motor skills. The gray dashed vertical lines show the region of significance where there is a significant difference in gross motor skills between participants with negative and neutral + positive cognitive appraisal which had an early exposure to the flood, such that when they were younger than 21 months, negative cognitive appraisal was associated with better gross motor skills. Similarly, the gray solid vertical line shows the same region of significance but for participants exposed late in pregnancy, and in the opposite direction: when they were 28 months or younger, negative cognitive appraisal was associated with poorer gross motor skills

for participants exposed in utero to high levels of objective hardship, when they were aged 21 months or below, the later in pregnancy they were exposed to the flood, the poorer their gross motor skills, while the opposite effect was found when children reached 45 months.

A marginally significant three-way interaction was found between cognitive appraisal, timing of exposure and child's age (Figure 2). Probing the interaction showed that for participants whose mothers had negative cognitive appraisal (red lines), being exposed very early in pregnancy was not associated with a significant change in gross motor skills over time, but being exposed later than 11.1 weeks gestation was associated with a significant increase over time; those two slopes differed significantly from each other. Also for participants with maternal negative cognitive appraisal, when participants where 30 months or younger, being exposed later in pregnancy was associated with poorer gross motor skills; this effect diminished with age such that beyond 30 months timing of exposure no longer had a significant effect. For participants whose mothers had neutral or positive cognitive appraisal (black lines), no significant change over time in gross motor skills was detected if exposed early in pregnancy (before 5.6 weeks gestation), while a significant increase in those skills was detected for participants exposed later in pregnancy.

3.3.3 | Fine motor main effects

Mixed model analyses were used to explore the effects of PNMS on the children's fine motor skill, as the random effect for the intercept was significant, but not the one for age. As shown in Table 5a, in step 1, there was a significant effect of objective hardship, suggesting that higher levels of flood-exposure were related to poorer fine motor skills. Furthermore, in step 2, there was a significant main effect of sex showing that girls had better fine motor skills than did boys. In step 3, there was no main effect of age at assessment. Finally, in step 4, there was a marginally significant association between socio-economic status and children's fine motor skills: higher socioeconomic status was related to poorer fine motor skills.

TABLE 5 Summary of mixed model regression analyses for the fine motor scale from 2 months to 4 years, trimmed of all non-significant variables

Predictor variables	B	Std. error	df	t	p-value	Lower bound CI	Upper bound CI
a) Main effects							
Step 1							
Objective hardship	−1.835**	0.786	174.322	−2.335	0.021	−3.386	−0.284
Step 2							
Objective hardship	−1.715**	0.774	172.911	−2.217	0.028	−3.242	−0.188
Sex	3.197***	1.188	170.644	2.69	0.008	0.851	5.543
Step 3							
Objective hardship	−1.747**	0.774	173.665	−2.259	0.025	−3.274	−0.221
Sex	3.227***	1.188	171.225	2.716	0.007	0.882	5.572
Age at assessment	0.046	0.03	501.049	1.506	0.133	−0.014	0.105
Step 4							
Objective hardship	−1.356*	0.795	180.143	−1.704	0.09	−2.926	0.214
Sex	3.353***	1.182	173.044	2.835	0.005	1.019	5.686
Age at assessment	0.046	0.03	502.443	1.533	0.126	−0.013	0.106
Socio-economic status	−0.021*	0.011	171.919	−1.917	0.057	−0.043	0.001
b) Interaction							
Step 5							
Objective hardship	−1.412*	0.796	179.677	−1.773	0.078	−2.982	0.159
Sex	−0.569	1.712	474.312	−0.332	0.74	−3.933	2.795
Age at assessment	−0.047	0.042	514.064	−1.125	0.261	−0.13	0.035
Socio-economic status	−0.020*	0.011	171.66	−1.841	0.067	−0.042	0.001
Sex × Age	0.190***	0.06	498.949	3.169	0.002	0.072	0.307

*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

3.3.4 | Fine motor interactions

In the interaction model shown in Table 5b, there was a significant sex by age interaction on children's fine motor skill: boys' fine motor skill did not change significantly across age, but girls' fine motor skills improved significantly as they got older. Also, when children reached 16 months and beyond, girls had significantly better fine motor skills than boys (see Figure 3).

4 | DISCUSSION

This study utilized a sudden onset flood to examine the effects of various aspects of PNMS on the developmental trajectory of children's motor skills from 2 months to 4 years on the ASQ-3. We were in a unique position to examine the effects of PNMS on gross and fine motor development across early childhood by combining cross-sectional ASQ-3 data from infants aged 2, 6, and 16 months (Simcock et al., 2016) with the additional data from the same sample at 2½ and 4 years for a novel longitudinal analysis. Given the interconnectedness of early motor development to other key domains of development (e.g., language and cognition) (Herbert et al., 2007; Rose-Jacobs et al., 2004; Walle & Campos, 2014) and that delayed motor development is characteristic of several developmental disorders (Johnson et al., 2015), it is important to understand how PNMS is associated with these skills at multiple time-points across early childhood.

4.1 | Gross motor and timing effects

Higher levels of objective hardship from the flood were marginally associated with poorer gross motor skills, and there was a significant association between late gestation flood-exposure and poorer gross motor skills. The finding that gross motor skills were poorer in children whose mothers were flood-affected in late pregnancy was consistent with the stated hypothesis and prior disaster-related PNMS research in this (Moss et al., 2017; Simcock et al., 2016) and other cohorts (Cao et al., 2014). Furthermore, the mixed model results show that the developmental trajectory of children's gross motor skills were associated with different aspects of flood-related PNMS.

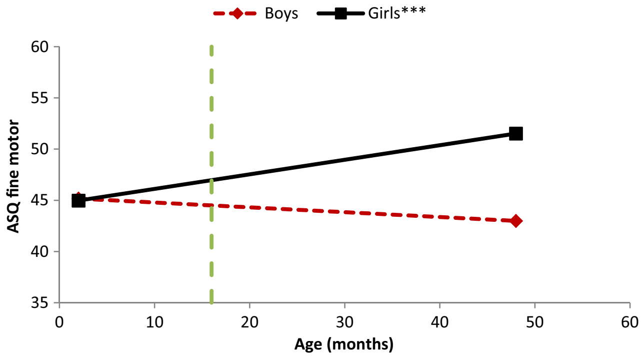

FIGURE 3 Two-way interaction representation of the fixed effect between children's sex and age on children's fine motor skill. Boys' fine motor skill did not change significantly with age, but girls' skill improved significantly. The green dashed vertical line shows the region of significance to the right of which there is a significant difference between boys' and girls' fine motor skills

The children exposed in later gestation whose mothers had either high objective hardship or a negative appraisal of the flood had the lowest gross motor scores in early infancy (i.e., before the age of about 2 or 2½ years) but they eventually "caught up" with the children with other combinations of timing and maternal stress. In the case of high objective hardship with later exposure, the children's gross motor skills eventually exceeded those of the early-gestation exposed children.

The implication of these results is that the timing of the motor assessment is an important consideration in PNMS research. As noted in the introduction, results within the same cohort can change according to the age of assessment. The current results suggest that effects of prenatal factors can predict poor motor skills at an early age, but with rapid catch-up development. Without repeated measures over time that demonstrate differential trajectories, it would be difficult to reconcile positive effects of a variable at one age and negative effects at another.

4.2 | Mechanisms of timing effects

What accounts for the negative effects of late gestation flood-exposure on gross motor skill and improving trajectory of gross motor skills across early childhood? One proposed mechanism for the effects of PNMS on child development is the fetal programming hypothesis (Barker, 1998). That is, PNMS increases the levels of maternal stress hormones such as glucocorticoids (Davis & Sandman, 2010), which are transmitted to the fetus via the placenta and have teratogenic effects on fetal neurodevelopment at critical time points that have long-term consequences for child outcomes. Structurally, the cerebellum, which plays an important role in gross motor functioning (Houk, Buckingham, & Barto, 1996), is one of the last cortical regions to develop prenatally. Thus, high levels of objective hardship or a negative cognitive appraisal in late gestation could have exerted teratogenic effects on the developing fetal cerebellum, negatively affecting gross motor skill in infancy. However, it is possible that as the children got older the cerebellar structure also matured, thereby ameliorating the earlier deficit in gross motor functioning.

4.3 | Fine motor and sex effects

For the fine motor scale, higher levels of maternal objective hardship were associated with poorer fine motor skills. However, as hypothesised based on our earlier findings (Simcock et al., 2016), flood-related PNMS was not associated with fine motor skill as a function of child sex. Although sex-differences have been detected in PNMS research investigating children's motor development (Cao et al., 2014; Moss et al., 2017), this is not always the case (DiPietro et al., 2006; Grace et al., 2016). Therefore, the extent to which the increase in maternal stress-related hormones crossing the placental barrier may cause sexual dimorphisms (Clifton, 2010) warrants further investigation in relation to children's motor development.

The mixed model results showed that girls gradually developed better fine motor scores than did boys by the age of about 16 months, and that girls' fine motor skills improved across age, but that of boys did not change. Prior research shows that young girls have more advanced fine motor skills than boys (Mosner & Reikeras, 2014); and this difference may become more apparent as children approach the school years and fine motor skills are required for emerging writing skills. The results also showed that the boys' fine motor skills appeared to "flat-line" across early childhood. Although the boys' ASQ-3 scores were within the typically developing range, this was based on whether or not the child's mother reported observing the behavior rather than information regarding the *quality* of the behavior; which may be less than optimally functional. This may be related to problems in motor behaviors evident in young boys with developmental disorders, such ASD, which are more prevalent in children whose mothers experienced a disaster in pregnancy (Kinney et al., 2008; Walder et al., 2014).

4.4 | Types of PNMS

In the current study, objective hardship and maternal cognitive appraisal of the flood were associated with children's gross motor development whereas composite subjective stress was not; and children's fine motor skills were associated only with objective hardship. However, as the models we tested always controlled for objective hardship, they may have failed to reach significance due to the shared variance between objective hardship and composite subjective stress and cognitive appraisal (both r's = 0.50, $p < 0.01$). Nonetheless, the finding that different aspects of maternal stress in pregnancy have different associations with children's motor skills has also been found in prior research (Cao et al., 2014; DiPietro et al., 2006; Moss et al., 2017; Simcock et al., 2016). This fits with the theoretical framework of appraisal theory, whereby two people who experience the same stressor may have different cognitive reactions to the event (Folkman & Lazarus, 1988; Smith & Lazarus, 1990). This highlights the complexity of the maternal stress experience and shows the importance of assessing various aspects of a stressed pregnant woman's experiences and reactions to fully understand their association with child development.

4.5 | Study limitations

There are some limitations to the study that warrant consideration. First, both the stress measures and the child outcome measures relied on maternal report, which may be confounded and prone to biases. However, to account for reporter biases we controlled for concurrent maternal depression and anxiety and they were not significantly associated with maternal report of children's motor skills. Furthermore, the ASQ-3 has sound psychometric properties and is widely used as a screening tool and research shows that mothers accurately report on their children's development using this tool (Squires et al., 2009). Second, the sample was relatively small and was skewed towards a group of well-educated Caucasian women from upper-middle class backgrounds, which may limit the generalizability of these finding to the broader community. Finally, we did not collect data on the children's motor experiences across development; so we cannot account for whether differences in opportunities for movement in their postnatal environment may have played a role in the trajectory of their motor skill. However, we found that that postnatal factors we measured, such as infant birth variables, family composition, maternal mental health, and SES factors, were not systematically associated with the QF2011 children's motor functioning; which may be due to the relatively homogenous and well-resourced nature of the QF2011 sample.

5 | CONCLUSION

This is the first prospective longitudinal study utilizing a natural disaster to examine the effects of PNMS on the development of gross and fine motor skills across early childhood, and to trace the trajectory of motor skill development across five time points aged 2 months to 4 years in a prenatally stressed cohort. Our primary findings were that high objective hardship or a negative maternal appraisal of the flood in late pregnancy had negatively associated with gross motor skill and gross motor skill trajectory, with a rapid catch up from lower to higher ASQ-3 motor scores across development. The children's fine motor skill trajectory was associated with the sex of the child rather than by flood-related PNMS variables. We will continue to track whether changes in motor skill due to flood-related PNMS continue across middle childhood.

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