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Infant Behavior and Competence Following Prenatal Exposure to a Natural Disaster: The QF2011 Queensland Flood Study

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This study utilized a natural disaster to investigate the effects of prenatal maternal stress (PNMS) arising from exposure to a severe flood on maternally reported infant social–emotional and behavioral outcomes at 16 months, along with potential moderation by infant sex and gestational timing of flood exposure. Women pregnant during the Queensland floods in January 2011 completed measures of flood-related objective hardship and post-traumatic stress (PTS). At 16 months postpartum, mothers completed measures describing depressive symptoms and infant social–emotional and behavioral problems (n = 123) and competence (n = 125). Greater maternal PTS symptoms were associated with reduced infant competence. A sex difference in infant behavioral problems emerged at higher levels of maternal objective hardship and PTS; boys had significantly more behavioral problems than girls. Additionally, greater PTS was associated with more behavioral problems in boys; however, this effect was attenuated by adjustment for maternal depressive symptoms. No main effects or interactions with gestational timing were found. Findings highlight specificity in the relationships between PNMS components and infant outcomes and demonstrate that the effects of PNMS exposure on behavior may be evident as early as

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infancy. Implications for the support of families exposed to a natural disaster during pregnancy are discussed.

The conditions of the intrauterine environment may shape fetal development, conferring risk for physical and mental health problems across the lifespan (O'Donnell & Meaney, 2017). One factor that may alter the prenatal environment is maternal stress during pregnancy. Elevated maternal stress hormones and other stress-related physiological changes may affect fetal neurodevelopment directly or through epigenetic processes, impacting the structure and function of brain areas important to the developing stress response and future behavior (Bale, 2015; Charil, Laplante, Vaillancourt, & King, 2010; Glover, O'Connor, & O'Donnell, 2010; Monk, Spicer, & Champagne, 2012). In humans, prenatal maternal stress (PNMS) has been operationalized variably as psychological distress (e.g., pregnancy-specific anxiety or depressive symptoms) or stressful life events (e.g., bereavement, daily hassles), with evidence of associations with increased emotional, behavioral, and social problems in childhood (Lahti et al., 2017; Lin, Crnic, Luecken, & Gonzales, 2017; O'Connor, Heron, Golding, Beveridge, & Glover, 2002; Robinson et al., 2008). Nevertheless, despite these associations, conjecture remains concerning the mechanisms and moderators of the influence of PNMS on infant and child outcomes.

Epidemiological research has established sex differences in the prevalence of certain forms of socio-emotional and behavioral problems (Rutter, Caspi, & Moffitt, 2003), and it has been suggested that sex-based differences in the human brain and hypothalamic–pituitary–adrenal (HPA) axis stress response may originate during fetal development (Bale, 2009; Cosgrove, Mazure, & Staley, 2007). The placenta may function differently under adverse conditions in male compared with female pregnancies (Clifton, 2010). However, animal evidence is mixed concerning whether the effects of PNMS on behavior may be greater for males (Bale, 2015) or females (Weinstock, 2007), and there may be sex-based differences in the nature of alterations to the offspring stress response following exposure to PNMS (Glover & Hill, 2012). For example, animal studies suggest that males may demonstrate a blunted or hypoactive stress response following prenatal exposures, whereas females may exhibit a hyperactive response (García-Cáceres et al., 2010; Richardson, Zorrilla, Mandyam, & Rivier, 2006). However, human studies have failed to consistently replicate these sex-based differences in the extent and type of PNMS-related consequences for child psychosocial development. Furthermore, some studies report greater risk of PNMS-related adverse behavioral outcomes for boys (Gerardin et al., 2010; Li, 2010; Rodriguez & Bohlin, 2005; Zhu et al., 2015) and others for girls (Buss et al., 2012; Van den Bergh, Van Calster, Smits, Van Huffel, & Lagae, 2008), with others still finding no moderation by sex at all (O'Connor, Heron, & Glover, 2002; O'Donnell, Glover, Barker, & O'Connor, 2014; Van den Bergh & Marcoen, 2004).

Another potential moderator of prenatal risk is the timing of exposure to PNMS during gestation. Our understanding of the unfolding of fetal neurodevelopment (Selemon & Zecevic, 2015), and the physiology of pregnancy, the placenta and the PNMS response (Duthie & Reynolds, 2013; O'Donnell et al., 2012), suggests that the gestational timing of exposure to PNMS should impact on the nature and severity of alterations to offspring development. Nevertheless, few studies have examined the role of gestational timing and those that have are unable to reach a consensus concerning the most sensitive period for infant and child emotional and behavioral outcomes. For example, pregnancy-specific anxiety may predict greater infant negative affectivity at 2 years postpartum when exposed during early gestation only (Blair, Glynn, Sandman, & Davis, 2011). Conversely, maternal anxiety during late pregnancy had a more potent influence than mid-gestation exposure for predicting behavioral problems in preschoolers (O'Connor, Heron, Golding, et al., 2002). Furthermore, the period during gestation most salient for the effects of PNMS on offspring behavioral problems may depend on infant sex (de Bruijn, van Bakel, & van Baar, 2009; Zhu et al., 2015). Additionally, the way that PNMS is operationalized may or may not allow the precise timing of exposure to be isolated. For example, Lahti et al. (2017) assessed maternal depression symptoms up to 14 times during pregnancy, yet found no gestational-week-specific effects, likely due to the highly stable nature of depressive symptoms in mothers in the study.

Importantly, a number of prominent theories of emotion and psychopathology highlight that it is not the experience of an event itself, but the interpretation of its significance, that determines the psychological distress experienced (Ehlers & Clark, 2000; Ellis, 1962; Gellatly & Beck, 2016; Lazarus, 1993) and the physiological stress response (Gaab, Rohleder, Nater, & Ehlert, 2005; Gartland, O'Connor, Lawton, & Bristow, 2014; Maier, Waldstein, & Synowski, 2003). Accordingly, it may be an individual's subjective experience of an event that may be most important when considering the impact of PNMS on fetal development. Indeed, most studies examining the effects of PNMS on behavior during early childhood have done so using subjective measures of psychological stress and distress, such as symptoms of anxiety and depression or perceived impact of a life event (O'Connor, Heron, Golding, et al., 2002; Pickles, Sharp, Hellier, & Hill, 2017; Soe et al., 2016; Zhu et al., 2015). Studies finding an effect of more objective measures of PNMS (e.g., frequency of certain stressful life events) on child outcomes did not control for the appraisal or emotional distress associated with these experiences (Lin et al., 2017; Robinson et al., 2008; Ronald, Pennell, & Whitehouse, 2011). Furthermore, few studies have examined both aspects of the stress experience in the one cohort, and those that have sought to disentangle the objective from the subjective components of stress during pregnancy (Bergman, Sarkar, O'Connor, Modi, & Glover, 2007; Gutteling et al., 2005) have not yet identified a consistent pattern concerning the differential effects of these aspects of the stress experience, possibly due to their different measurement approaches.

Natural disasters as "natural experiments"

Understanding the mechanisms and moderators of the effects of prenatal stress exposure on child behavior is complicated by wide variation in the operationalization of PNMS, as well as methodological challenges inherent to human PNMS research, including difficulty controlling for gestational timing and the influence of co-occurring risk factors and residual confounds, such as genetic heritability, maternal personality, or lifestyle factors (King & Laplante, 2015; Kingston, Sword, Krueger, & Hanna, 2012). While ethical considerations limit use of experimental designs with pregnant women, there are ways to approximate this. A natural disaster represents a discrete stressor exposing large numbers of pregnant women at varying gestational stages to a severe, sudden-onset stressor, mostly independent of socioeconomic, personality, and genetic factors. The timing of stress onset may be identified, and the effects of different elements of the maternal stress experience on child outcomes may be isolated.

Consequently, a growing number of studies have capitalized on the event of a natural disaster for investigating the impact of PNMS on child development, including those affected by the 1998 ice storms in Quebec, Canada (King, Dancause, Turcotte-Tremblay, Veru, & Laplante, 2012; Laplante, Zelazo, Brunet, & King, 2007; St-Hilaire et al., 2015), Hurricane Katrina (Tees et al., 2010), and the floods in Iowa, USA (Yong Ping et al., 2015). In January 2011, over 70 towns and 200,000 people in the state of Queensland, Australia, were directly affected by the most severe flooding event in 30 years, causing over $1 billion of property and infrastructure damage and 35 deaths. The QF2011 Queensland Flood Study was established to prospectively track the well-being of mothers pregnant during the floods and the development of their prenatally exposed children (Figure 1).

Results to date suggest that children exposed to the Queensland floods prenatally demonstrate alterations in development across a range of domains (Austin et al., 2017; Moss et al., 2017; Simcock, Laplante, et al., 2016). Regarding behavioral development, mothers reporting greater flood-related objective hardship (e.g., extent of property damage), and subjective stress (peritraumatic, posttraumatic, and cognitive reactions) were more likely to describe their 6-month-old infants as exhibiting more difficult aspects of temperament, with the specific impacts dependent on infant sex and timing of exposure (Simcock, Elgbeili, et al., 2017). At 4 years old, greater flood-related objective hardship significantly predicted higher anxiety symptoms and was marginally associated with greater internalizing symptoms (McLean et al., 2018). Regarding social development, there was a trend for objective hardship to be associated with delayed

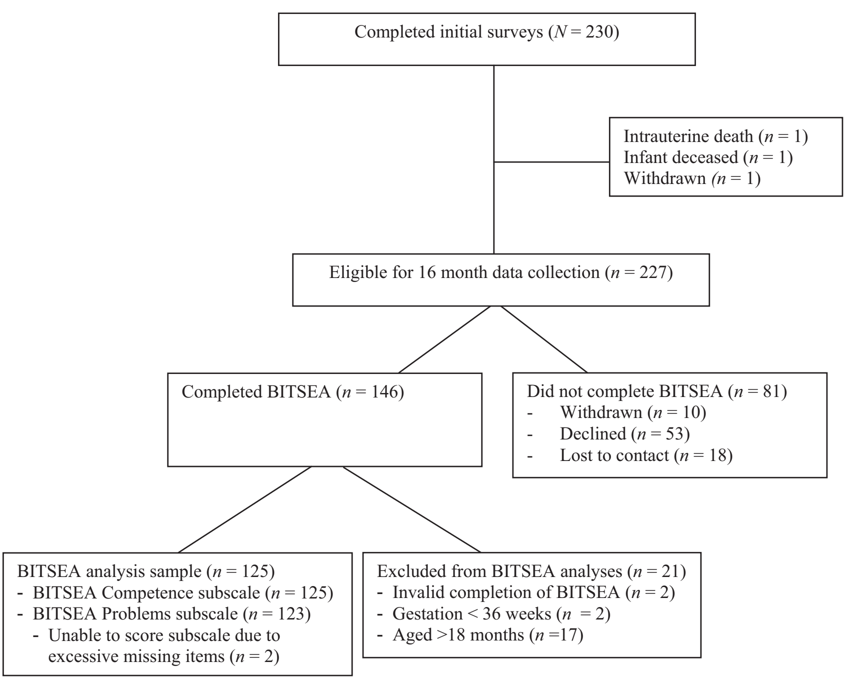

Figure 1 Cohort diagram showing enrollment into the QF2011 study, attrition and participation in the 16 month Brief Infant-Toddler Social and Emotional Assessment (BITSEA) follow-up questionnaire.

acquisition of personal–social skills at 6 months (Simcock, Laplante, et al., 2016), while greater subjective stress predicted less-developed theory of mind at 30 months (Simcock, Kildea, et al., 2017). It is unclear how increased risk due to exposure to PNMS may have manifested for this cohort's behavioral development during late infancy. Indeed, no published studies of children exposed to a natural disaster prenatally have examined the effects on emerging behavioral problems in the second-year postpartum, nor have they examined the influence of PNMS on maternal reports of infant social competence. Understanding the unfolding of increased risk over early development is critically important for implementing appropriate prevention and early intervention approaches for children exposed to stress prenatally.

The current study

This study forms part of QF2011, utilizing maternal exposure to the Queensland 2011 floods during pregnancy as an independent stressor to investigate the relationship of PNMS with social–emotional and behavioral problems and competence in infants at 16 months. To explore the influence of different aspects of the maternal stress experience, and in accordance with Lazarus (1991), the influence of a mother's objective hardship from the floods was examined, along with posttraumatic stress (PTS) symptoms in relation to the floods. We also investigated potential moderation of these PNMS effects by infant sex and gestational timing of stress exposure, and models were run before and after adjustment for the influence of concurrent maternal depressive symptoms at 16 months postpartum. It was hypothesized that flood-related objective hardship and PTS symptoms would be associated with increased infant behavioral problems and poorer acquisition of social–emotional competence, with these effects moderated by infant sex and gestational timing. Moderation analyses were exploratory due to conflicting findings in the literature concerning infant sex and gestational timing. Additionally, a specific prenatal influence was predicted, with the effects of PNMS evident independent of concurrent maternal depressive symptoms.

METHOD

Participants and procedure

Mothers (N = 230) were recruited to the QF2011 Queensland Flood Study 4–12 months after the flood through a large tertiary hospital located in a flood-affected area. Eligibility criteria for QF2011 included: (1) pregnant with a singleton during the floods; (2) fluency in English; and (3) age over 18 years. Detailed information is available regarding the broader QF2011 study methodology (King et al., 2015). The present study was conducted according to the Declaration of Helsinki, with informed consent obtained from all mothers included in the study, and ethical approval for all procedures obtained from Mater Human Research Ethics Committee (Ref: 1709M and 1844M) and the University of Queensland (2013001236 and 15-PSYCH-PHD-16-JH).

Three women were ineligible for further follow-up due to intrauterine death (n = 1), infant death (n = 1) or the mother withdrew from the study (n = 1). Eligible mothers (n = 227) who completed questionnaires regarding their exposure and reactions to the flood at recruitment into the study and/or 12 months postflood were invited to provide information at 16 months postpartum concerning their infants' behavior on the Brief

Infant-Toddler Social and Emotional Assessment (BITSEA; Briggs-Gowan & Carter, 2006). Of the mothers who completed this measure (n = 146), 21 participants were excluded for the following reasons: gestational age at birth <36 weeks (n = 2); completion of follow-up questionnaire when infants were older than 18 months (n = 17); and evidence of invalid responding on the BITSEA (n = 2), leaving an analysis sample of 125 participants. As two participants had excessive missing data on the BITSEA Problems scale, which could not be totaled according to author guidelines (Briggs-Gowan & Carter, 2006), complete questionnaire data across time-points were available for 125 mother–infant dyads for the BITSEA Competence subscale and 123 dyads for the BITSEA Problems subscale. Of mothers who completed the BITSEA at 16 months (n = 125), 31 mothers (24.8%) were pregnant at the time of completion of recruitment questionnaires, with 94 (75.2%) postnatal completions. Mothers participating in the 16-month follow-up were mostly Caucasian (97.5%), and married or in a de facto relationship (90.8%), with 62% reporting a weekly pre-tax household income greater than the median Australian income of $1,400 (Australian Bureau of Statistics, 2017). Approximately half of mothers (53.4%) were primiparous with the study infant.

Measures

Obstetric and socio-economic information

Gestational age at birth and birthweight were obtained from hospital records. Socio-economic status was estimated using Australian Bureau of Statistics' Socio-Economic Indexes for Areas (SEIFA) scores based on census data regarding postcode. SEIFA scores have a mean of 1,000 (SD = 100), with higher scores indicating greater socio-economic advantage of the neighborhood of residence. Mothers also reported on income and education.

Prenatal maternal stress

Objective hardship was estimated using the Queensland Flood Objective Stress Scale (QFOSS; King et al., 2015), based on previous disaster research (Brock et al., 2015; Yong Ping et al., 2015) and tailored to the unique circumstances of the Queensland floods to maximize sensitivity. QFOSS assessed four dimensions of flood-related hardship: (1) threat (e.g., "Were you injured?"), (2) loss (e.g., "Did you experience loss of personal income?"), (3) scope (e.g., "How many days were you without electricity?"), and (4) change (e.g., "Did you spend any time in a temporary shelter?"). Each dimension was scored between 0 (*no impact*) and 50 (*extreme impact*), with dimensions summed to find a total QFOSS score (maximum of 200 points), where higher scores indicated greater flood exposure.

As a measure of subjective response to the floods, PTS symptoms were assessed using the 22-item Impact of Events Scale-Revised (IES-R; Weiss & Marmar, 1997), which has been used extensively in natural disaster research (Grimm, Hulse, Preiss, & Schmidt, 2012; Paxson, Fussell, Rhodes, & Waters, 2012), including during pregnancy (King et al., 2012; Qu et al., 2012) and possesses sound psychometric properties (Creamer, Bell, & Failla, 2003). The current study utilized a total PTS score for analyses, reflecting total distress experienced due to intrusion, avoidance, and hyperarousal symptoms in relation to the flood. With a maximum total score of 88, a cutoff score of 33 has been used to indicate clinically significant symptoms (Creamer et al., 2003).

In order to include nonflood sources of PNMS as a potential covariate, mothers completed the Life Experiences Survey (LES; Sarason, Johnson, & Siegel, 1978) at 6 and 16 months postpartum. The LES lists 57 life events and invites the mother to indicate whether they experienced each event, and the impact on them using a 7-point Likert scale from −3 (*extremely negative)* to +3 (*extremely positive*). To reduce participant burden, the list of life events was shortened to 26 items by removing events less relevant to the sample (e.g., "retirement from work"). The total number of life events during pregnancy that mothers rated as negative (NLEs) was used in the current study.

Gestational timing of exposure

Gestational age at exposure was determined by subtracting 280 days (40 weeks) from the mother's due date to estimate the date of conception, then calculating the number of days between estimated conception and the peak of the flood on 11 January 2011.

Maternal concurrent depressive symptoms

Mothers completed the short-form Depression Anxiety and Stress Scales (DASS-21; Lovibond & Lovibond, 1995) at 16 months, endorsing the degree to which they experienced a range of symptoms using a 4-point scale, yielding depression, anxiety, and stress subscales. Only the depression subscale was used in the present study, based on previous evidence of an increased risk of depression following exposure to a natural disaster (Brock et al., 2015; Fergusson, Horwood, Boden, & Mulder, 2014; Qu et al., 2012), an association between maternal depression and child behavior (Barker, Jaffee, Uher, & Maughan, 2011; Feldman et al., 2009), and to control for the influence of maternal mood on reports of child behavior (Najman et al., 2001). Cutoff scores for normal (0–9), mild (10–13), moderate (14–20), severe (21–27), and extremely severe (28+) levels of depressive symptoms are provided in the manual (Lovibond & Lovibond, 1995).

Infant social–emotional and behavioral problems and competence

The BITSEA (Briggs-Gowan & Carter, 2006) is a 42-item parent-report screen designed for children between 1 and 3 years, with 31 items assessing child social–emotional and behavioral problems, including aggression, defiance, overactivity, anxiety, withdrawal, and negative emotionality (BITSEA Problems or "BITSEA/P"), and 11 items assessing social–emotional competence, including empathy, compliance, and prosocial behavior (BITSEA Competence or "BITSEA/C"). At 16 months, mothers were invited to rate items between 0 (*not true/rarely*) and 2 (*very true/often*) according to their infant's behavior over the preceding month, with higher BITSEA/P scores indicating greater problems and higher BITSEA/C scores reflecting greater competence. The BITSEA has strong psychometric properties and predictive validity (Briggs-Gowan & Carter, 2008; Briggs-Gowan, Carter, Irwin, Wachtel, & Cicchetti, 2004), along with general screening accuracy for detecting children requiring referral to a mental health service (Kruizinga, Jansen, Mieloo, Carter, & Raat, 2013), and for assessing autistic spectrum disorder (ASD) risk (Kruizinga et al., 2014).

Statistical analysis

Missing data at recruitment on flood variables were imputed using data obtained at 12 months postflood (refer King et al., 2015). As QFOSS, IES-R, BITSEA/P, and a number of potential covariates displayed skewed distributions, Spearman's Rho was used for bivariate analyses, and medians are included in descriptive statistics. For main analyses, variables were transformed where required to correct for positive skewness (Field, 2013). Diagnostic analyses were conducted to ensure that regression assumptions were met. Given small sample size, only potential covariates demonstrating significant or near-significant ($p < .1$) correlations were included in multivariate analyses (refer Table 1).

Four hierarchical multiple regression analyses were conducted using SPSS 22.0 (IBM SPSS Statistics for Windows, Version 22.0. IBM Corp., Armonk, New York, USA) to test the effects of flood-related objective hardship and PTS symptoms on BITSEA/P and BITSEA/C at 16 months, moderated by infant sex and gestational timing of exposure. The same basic model was tested in each analysis, to which one of four interaction terms (objective hardship × infant sex, objective hardship × timing, PTS symptoms × infant sex, and PTS symptoms × timing) was added at the final step. The steps of the models proceeded as follows: (1) potential covariates showing bivariate correlations ($p < .1$) with the relevant infant outcome, along with infant sex and timing; (2) objective hardship (QFOSS), to control for degree of exposure to the floods; (3) PTS symptoms (IES-R), and (4) one of four interaction terms. We did not control for multiple testing due to the small number of analyses and limited sample size.

The PROCESS macro was used to probe conditional effects for any significant interactions ($p < .1$) using the simple slopes or "pick-a-point" approach and the Johnson–Neyman technique. The pick-a-point approach was deemed appropriate for analyses involving a dichotomous moderator; however, may be less suitable for analyses involving continuous moderators (Hayes, 2013). Hayes (2013) proposed the Johnson–Neyman (J-N) technique as an alternative, which probes the interaction in reverse by calculating the exact point along the continuum of moderator values at which the relationship between predictor and outcome becomes significant ("region of significance"). To test the specificity of flood effects to prenatal rather than postnatal factors, all models showing evidence of a PNMS main or interaction effect ($p < .1$) were re-run, adjusting for concurrent maternal depressive symptoms ("adjusted model"). Due to small sample size, models were trimmed of nonsignificant covariates ($p > .1$) and interaction terms, in order to maximize power. The alpha level for the significance of main and interaction effects was set to $p < .05$.

RESULTS

Participant characteristics

Descriptive data (Table 1) indicate that mothers were exposed to the floods across a range of gestational ages. The timing variable is derived from estimated due date, the accuracy of which may range from ±5 to 14 days depending on the method used and

TABLE 1
Descriptive Statistics and Spearman's Rho Correlations with Infant Outcomes

					BITSEA	
	M	*SD*	*Median*	*Range*	*Problems*	*Competence*
PNMS variables						
Objective hardship	20.58	17.38	14.00	2–81	.06	−.11
PTS symptoms	6.56	11.30	1.60	0–66	.08	−.22*
Moderators						
Infant sex[a]	52.8% boys 47.2% girls				−.19*	.27**
Gestational timing of flood						
Days	130.68	79.79		−2.02–264	.06	−.02
Trimester	36% 1st trimester 36% 2nd trimester 28% 3rd trimester					
Covariates						
Maternal age at birth	32.14	4.92	32.31	19.55–47.33	−.05	−.14
SEIFA	1,056.57	54.37	1,070.00	902–1,175	−.09	−.01
Maternal years schooling	15.64	2.72	16.00	10–19	−.01	−.00
Prenatal NLEs	1.20	1.80	0.00	0–8	.03	−.22*
Gestation at birth (weeks)	39.46	1.23	40.00	36–42	−.01	.06
Birthweight (grams)	3,583.14	455.25	3,576	2,712–5,050	−.03	−.05
Maternal MH						
16 m depressive symptoms (DASS)	4.84	5.89	2.00	0–26	.30**	−.14
Infant variables						
Infant age (months)	16.10	.78	16.07	14–17.81	−.00	−.07
BITSEA problems	9.80	5.63	9.00	0–27	–	−.28**
BITSEA competence	16.49	2.64	17.00	9–22	−.28**	–

Note. BITSEA = Brief Infant-Toddler Social and Emotional Assessment; DASS = Depression Anxiety Stress Scales; infant age = infant age at 16 m follow-up; Prenatal NLEs = prenatal negative life events; PTS symptoms = posttraumatic stress symptoms; SEIFA = Socio-Economic Indexes for Area.
[a]Coded 0 = boy, 1 = girl.
$^{*}p < .05$, $^{**}p < .01$.

trimester when estimated (American College of Obstetricians and Gynecologists' Committee on Obstetric Practice, 2017). In light of this, and given that the acute effects of the flood persisted for up to a week (Queensland Floods Commission of Inquiry, 2011), one participant with a gestational timing age of −2.02 was retained in the current study. Table 1 also shows a wide range of flood-related PNMS scores in the current sample. Mean and median maternal PTS symptoms scores were considerably lower than the accepted IES-R cutoff of 33 for probable PTS disorder, with 4% of mothers reporting clinically significant PTS symptoms. Most mothers (82.4%, $n = 103$) reported depression scores in the normal range, with 8% ($n = 10$) reporting depression scores in the "mild" range, 7.2% ($n = 9$) in the "moderate" range, and 2.4% ($n = 3$) in the "severe" range. PNMS variables showed significant intercorrelations (see Table 2).

TABLE 2
Spearman's Rho Correlations among Prenatal Maternal Stress and Maternal Concurrent Depressive Symptoms

	1	2	3	4
Objective hardship	–			
Posttraumatic stress symptoms	.58**	–		
Prenatal negative life events	.26**	.23*	–	
Maternal depressive symptoms	.19*	.15†	.18†	–

Note. *p < .05, **p < .01, $^{\dagger}p$ < .1.

BITSEA scores were consistent with norms reported for a community cohort, with 32 infants (26%) in the "possible problem" range based on a BITSEA/P cutoff score of 13 reflecting the top 25th percentile based on the normative sample, and nine infants (7.2%) in the "possible delay/deficit" range on the BITSEA/C based on scores below 12, representing the bottom 15th percentile of the normative sample (Briggs-Gowan & Carter, 2006; Briggs-Gowan et al., 2004).

Attrition analyses

Comparing all mothers who completed the 16-month BITSEA questionnaire (n = 146) with those who did not respond at this time-point (n = 84) found no differences on flood-related objective hardship or PTS symptoms, or depressive symptoms. Participating mothers were older (M = 31.83, SD = 4.84, versus M = 29.73, SD = 5.80, t (149.09) = 2.80, p = .006), had more years of schooling (M = 15.51, SD = 2.69, versus M = 13.60, SD = 2.14, t (202.91) = 5.88, p < .001), and were later in gestation during the floods (M = 130.05, SD = 77.26 versus M = 92.78 days, SD = 61.36, t (205.57) = 4.03, p < .001) compared with mothers with data unavailable.

BITSEA problems

There were no significant bivariate correlations between PNMS variables and BITSEA/P scores (see Table 1). Maternal concurrent depressive symptoms showed significant correlations with BITSEA/P, with greater depressive symptoms associated with more infant problems. Of the other covariates, only infant sex was negatively correlated (p = .04) with BITSEA/P, indicating that mothers of boys reported greater infant problems. The total number of nonflood negative stressful life events during pregnancy (NLEs) was not significantly correlated with this infant outcome and hence was not controlled in subsequent analyses.

The results of the final trimmed model predicting BITSEA/P from objective hardship are presented in Table 3a. In the initial hierarchical regression model predicting BITSEA/P scores, the influence of infant sex at the first step fell short of significance and gestational timing was not a significant predictor and hence was trimmed from the model. Objective hardship and PTS symptoms were not significantly associated with BITSEA/P scores when entered at steps 2 and 3. At step 4, the interaction between objective hardship and sex was significantly associated with BITSEA/P scores

TABLE 3
Hierarchical Multiple Regression Analyses for Predicting Infant Behavioral Problems, Before and After Adjustment for Maternal Depressive Symptoms

	Unadjusted					*Adjusted*[a]				
Model	*B*	*SE*	*β*	*p*	ΔR^2	*B*	*SE*	*β*	*p*	ΔR^2
a) Objective hardship × infant sex										
1 Infant sex[b]	−1.98	1.00	−.18	.051	.03†	−1.71	0.96	−.15	.078	.02†
2 Infant sex[b]	−1.93	1.01	−.17	.059	.01	−1.71	0.97	−.15	.081	.00
Objective hardship	0.56	0.66	.08	.391		0.08	0.65	.01	.897	
3 Infant sex[b]	−1.89	1.01	−.17	.064	.01	−1.67	0.97	−.15	.088	.01
Objective hardship	0.07	0.81	.01	.931		−0.40	0.79	−.06	.611	
Posttraumatic stress symptoms	0.55	0.54	.11	.309		0.54	0.51	.11	.294	
4 Infant sex[b]	5.31	3.74	.47	.159	.03*	5.22	3.59	.47	.149	.03*
Objective hardship	1.37	1.04	.19	.189		0.85	1.01	.12	.401	
Posttraumatic stress symptoms	0.49	0.53	.10	.356		0.49	0.51	.10	.339	
Objective hardship × infant sex	−2.58	1.30	−.68	.049		−2.48	1.24	−.65	.049	
b) Posttraumatic stress symptoms × infant sex										
1 Infant sex[b]	−1.98	1.00	−.18	.051	.03†	−1.71	0.96	−.15	.078	.02†
2 Infant sex[b]	−1.93	1.01	−.17	.059	.01	−1.71	0.97	−.15	.081	.00
Objective hardship	0.56	0.66	.08	.391		0.08	0.65	.01	.897	
3 Infant sex[b]	−1.89	1.01	−.17	.064	.01	−1.67	0.97	−.15	.088	.01
Objective hardship	0.07	0.81	.01	.931		−0.40	0.79	−.06	.611	
Posttraumatic stress symptoms	0.55	0.54	.11	.309		0.54	0.51	.11	.294	
4 Infant sex[b]	0.38	1.48	.03	.796	.03*	0.18	1.42	.02	.901	.02†
Objective hardship	0.16	0.80	.02	.844		−0.30	0.79	−.04	.703	
Posttraumatic stress symptoms	1.25	0.63	.26	.048		1.12	0.61	.23	.067	
Posttraumatic stress symptoms × infant sex	−1.80	0.87	−.31	.040		−1.47	0.84	−.25	.082	

Note. [a]Models adjusted for concurrent maternal depressive symptoms.
[b]Coded boy = 0, girl = 1.
$^*p < .05$, $^{**}p < .01$, $^{\dagger}p < .1$.

(p = .049); however, the positive conditional effect for boys (1.37, SE = 1.03, p = .189) and the negative effect for girls (−1.22, SE = 1.03, p = .241) were both nonsignificant. The overall model explained 7.6% of variance in BITSEA/P scores (F (4, 118) = 2.44, p = .05). To test whether this significant interaction may reflect a specific prenatal effect, the model was then adjusted for maternal depressive symptoms at 16 months, which increased the variance explained by the model to 15.8% (F (5, 117) = 4.38, p = .001), and explained unique variance in the prediction of BITSEA/P scores (β = .29, p = .001). The objective hardship by sex interaction remained significant (p = .049), and the conditional sex effects nonsignificant, although the directions of effects were the same. Probing the interaction in the adjusted model found a significant sex difference in BITSEA/P at log-transformed QFOSS scores greater than 2.88, reflecting a back-transformed QFOSS score of 17.81, a value slightly below the mean, but higher than the median for the sample (see Figure 2, panel A). Moderation analysis, including steps 1–3, but with the addition of the objective hardship × timing interaction term at the final step, found that the association between objective hardship and BITSEA/P scores was not moderated by gestational timing of exposure.

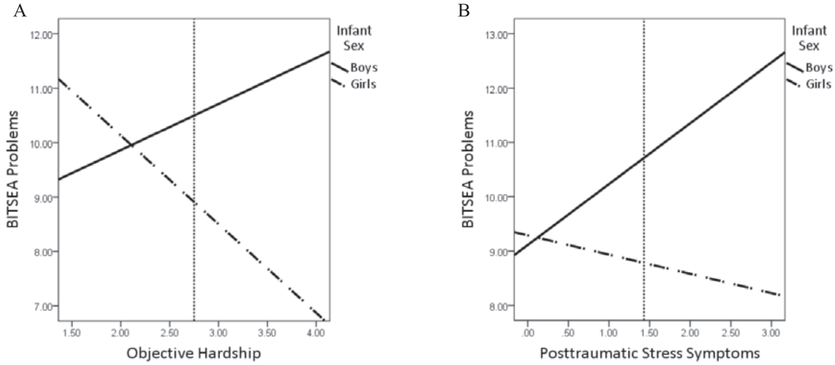

Figure 2 The moderating effect of infant sex on the relationship between objective hardship (log-transformed; panel A) and posttraumatic stress symptoms (log-transformed; panel B) and infant behavioral problems on the Brief Infant-Toddler Social and Emotional Assessment (BITSEA), adjusted for maternal depressive symptoms, with the region of significance (p = .05) indicated to the right of the vertical dashed line.

The same initial hierarchical regression model predicting BITSEA/P scores was re-run, testing the interaction of PTS symptoms × infant sex at step 4, with the results for the final trimmed model presented in Table 3b. The effect of PTS on BITSEA/P was significantly moderated by infant sex, with the interaction explaining an additional 3.4% of variance (p = .04) in scores in the unadjusted model. Probing the interaction revealed that greater PTS symptoms were associated with increased problems in boys only (coefficient = 1.25, SE = .63, p = .048; for girls, coefficient = −.55, SE = .74, p = .465). The final unadjusted model explained 7.9% of variance in BITSEA/P scores (F (4, 118) = 2.54, p = .044). To test whether this significant interaction may reflect a specific prenatal effect, the model was adjusted for maternal concurrent depressive symptoms (β = .28, p = .002), which improved model fit, explaining 15.1% of variance in BITSEA/P scores (F (5, 117) = 4.18, p = .002), but reduced the PTS by sex interaction effect to a trend (p = .082). In the adjusted model, the conditional effect for boys was also reduced to a trend (p = .067; girls p = .624). The J-N technique performed on the adjusted model found a significant sex difference in BITSEA/P at log-transformed IES-R scores greater than 1.43, equating to back-transformed IES-R score of 3.18, which is below the mean and median for this sample (Figure 2, panel B). Moderation analysis, including steps 1–3, with the addition of the PTS symptoms × timing interaction term at the final step, found that the association between PTS symptoms and BITSEA/P scores was not moderated by gestational timing of exposure.

BITSEA competence

Maternal PTS symptoms were negatively associated with BITSEA/C scores based on bivariate correlations (p = .014; Table 1), indicating that the greater the maternal PTS scores, the lower the infant competence. Infant sex and total number of NLEs during pregnancy demonstrated significant correlations with BITSEA/C, with greater infant competence in girls (p = .003) and in infants of mothers with fewer nonflood prenatal negative life events (p = .009). Consequently, total number of prenatal NLEs was included as a covariate in the models predicting this outcome. Despite not demonstrating a significant association with maternal concurrent depressive symptoms, all significant models were adjusted for this variable to determine the independence of prenatal effects from postnatal maternal mood influences.

In the initial hierarchical regression model predicting BITSEA/C scores, infant sex was significantly associated with this outcome, with prenatal NLEs showing a negative effect falling short of significance (p = .068) at step 1. Gestational timing was not a significant predictor of BITSEA/C scores and was trimmed from the model. At step 2, objective hardship was not significantly associated with BITSEA/C; however, PTS symptoms showed a significant main effect for predicting BITSEA/C scores when added at the third step. At step 4, neither infant sex nor timing moderated the association between objective hardship or PTS symptoms and BITSEA/C scores; hence, the interaction terms were trimmed from the final model. The results for the final trimmed model predicting BITSEA/C scores are presented in Table 4, showing that greater PTS significantly predicted lower BITSEA/C scores when controlling for infant sex, prenatal NLEs, and objective hardship, with this main effect remaining significant (p = .035) upon adjustment for maternal concurrent depressive symptoms ($\beta = -.09$, *ns*; Table 4). Girls demonstrated greater BITSEA/C scores in the multivariate model, before (p = .003) and after (p = .004) adjustment for maternal concurrent depressive symptoms; however, a nonsignificant association of greater maternal nonflood negative life events with lower BITSEA/C scores (p = .068) attenuated after adjustment (p = .100). The final adjusted model explained 15.3% of variance in BITSEA/C (F (5, 119) = 4.307, p = .001).

DISCUSSION

The present study is the first to our knowledge to use a natural disaster design to find evidence of an association between two components of the maternal stress experience

TABLE 4
Hierarchical Multiple Regression Analyses for Predicting Infant Social-Emotional Competence, Before and After Adjustment for Maternal Depressive Symptoms

Model	*Unadjusted*					*Adjusted*[a]				
	B	SE	β	p	ΔR^2	B	SE	β	p	ΔR^2
1 Infant sex[b]	1.39	0.45	.27	.002	.11**	1.37	0.45	.26	.003	.10**
Prenatal negative life events	−1.70	0.78	−.19	.031		−1.52	0.79	−.17	.057	
2 Infant sex[b]	1.39	0.45	.26	.003	.00	1.37	0.45	.26	.003	.00
Prenatal negative life events	−1.62	0.81	−.18	.048		−1.49	0.82	−.16	.072	
Objective hardship	−0.09	0.30	−.03	.757		−0.05	0.31	−.02	.872	
3 Infant sex[b]	1.35	0.45	.26	.003	.03*	1.33	0.45	.25	.004	.03*
Prenatal negative life events	−1.48	0.80	−.16	.068		−1.35	0.81	−.15	.100	
Objective hardship	0.34	0.36	.10	.346		0.39	0.37	.11	.291	
Posttraumatic stress symptoms	−0.51	0.24	−.23	.035		−0.50	0.24	−.23	.035	

Note. [a]Models adjusted for concurrent maternal depressive symptoms.
[b]Coded boy = 0, girl = 1.
*p < .05, **p < .01, †p < .1.

during pregnancy and maternally reported infant behavioral and social functioning in the second postnatal year. Furthermore, findings suggest that exposure to the floods affected infant development in domain-specific ways. Greater PTS from the floods was associated with more problems in boys; however, the reduced effect after adjusting for maternal depressive symptoms suggests a role of the postnatal environment. The effect of objective hardship on problems was also moderated by infant sex, indicating a significant difference in the slopes for girls (negative) and boys (positive). When maternal objective hardship was slightly above the median, boys had significantly more problems than girls; however, the conditional effect of objective hardship on problems was not significant for either boys or girls.

For infant socio-emotional competence, greater PTS symptoms were associated with lower competence, with no moderation of effects by infant sex or timing for this outcome. When considering nonflood stressful life events during pregnancy, there was a significant negative zero-order correlation with infant competence, but the association fell short of significance when infant sex and PNMS entered the unadjusted model. As its effect reduced further after controlling for maternal depressive symptoms in the adjusted model, this may indicate a specific association of flood-related PNMS with this outcome, beyond the influence of nonflood stressful life events during pregnancy. Although association of stress during pregnancy with aspects of child social functioning conflicts with some existing studies (Karam et al., 2016; Kvalevaag et al., 2015), the current results are consistent with delayed acquisition of social competencies in infants of mothers higher in prenatal trait anxiety (Koutra, 2013) and maternal subjective distress in the QF2011 cohort (Simcock, Kildea, et al., 2017; Simcock, Laplante, et al., 2016). Together, these findings lend support to an enduring effect of PNMS on offspring social–emotional development from early infancy to toddlerhood. Delayed acquisition of social competencies is among the vulnerabilities associated with ASD (American Psychiatric Association, 2013). Accordingly, our findings are also consistent with evidence of increased autistic traits among children exposed to PNMS (Class et al., 2014; Kinney, Miller, Crowley, Huang, & Gerber, 2008; Walder et al., 2014), possibly reflecting a programming effect of PNMS exposure on fetal neurodevelopment, particularly the hippocampus and HPA axis (Charil et al., 2010).

Alternatively, rather than mothers' greater PTS symptoms conferring risk of delayed competence, the results may indicate that mothers with lower levels of flood-related symptoms may have conferred enhanced competence in their infants, particularly considering that mothers' objective exposure to the floods was controlled. In a recent exploratory study, Phua et al. (2017) found that infant socio-emotional competence at 12 months was better predicted by factors reflecting positive maternal mental health during pregnancy than those assessing psychopathology. Accordingly, the association between PTS and infant competence in this study may reflect an influence of maternal resilience under conditions of adversity, which may also be influenced by genetic heritability (Eid, Riemann, Angleitner, & Borkenau, 2003). Including a measure of prenatal maternal well-being in future PNMS studies would enable this potential mechanism to be further explored.

There are established sex-based differences in the prevalence of certain types of behavioral problems, which may be influenced by sexually dimorphic responses to PNMS exposure (Glover & Hill, 2012). The current study found evidence for this, with the effects of both flood-related stress measures showing evidence of moderation by infant sex. Although greater objective hardship was not associated with significantly more problems for either sex, it contributed to a sex difference in scores between boys and girls, with boys showing significantly higher problems than girls only after being exposed to the flood at greater levels. Accordingly, although objective hardship did not predict significantly increased behavioral problems, these findings may reflect sexually dimorphic responses under conditions of prenatal adversity, with this specific pattern of results consistent with theories that predict greater PNMS-related behavioral alterations in boys that may be contributed to by the interaction of maternal stress physiology with fetal testosterone (Davis & Pfaff, 2014; Rutter et al., 2003).

Additionally, boys exposed to more maternal PTS symptoms were described by their mothers as displaying significantly greater behavioral problems; however, this reduced to nonsignificant after adjustment for maternal depression at 16 months. While this may reflect the influence of maternal negative mood on ratings of child behavior, exposure to a natural disaster during pregnancy is associated with increased maternal depressive symptoms up to 2.5 years after the event (Brock et al., 2015), and greater objective hardship from the floods was associated with higher levels of maternal depressive symptoms at 16 months postpartum in the present sample. Substantial evidence suggests that maternal depression is associated with more offspring behavioral problems during infancy and early childhood (Bayer, Hiscock, Ukoumunne, Price, & Wake, 2008; Gjerde et al., 2017; Prenoveau et al., 2017). Accordingly, it is possible that the impact of flood-related PNMS on infant behavior may have operated by altering the postnatal environment, reflected in concurrent maternal mental health (Barker et al., 2011; Rice et al., 2010). Overall, these results highlight the importance of future research considering the multiple pathways through which prenatal natural disaster exposure may increase risk of poorer infant and child outcomes, along with the moderators of these.

The lack of an interaction of PNMS with gestational timing for our infant outcomes is concordant with some previous studies (O'Donnell et al., 2014; Robinson et al., 2011), but contrasts with other PNMS research (O'Connor, Heron, et al., 2002; Van den Bergh & Marcoen, 2004) including our study finding late-pregnancy exposure to PNMS to be most influential for child motor and cognitive development in the QF2011 cohort (Moss et al., 2017; Simcock, Kildea, et al., 2016) and others (Cao, Laplante, Brunet, Ciampi, & King, 2014). It is likely that the importance of timing differs according to child outcome due to the specific neurological structures and developmental processes involved. Conversely, moderation of PNMS by timing may also depend on infant sex (de Bruijn et al., 2009), which we were unable to investigate due to sample size, but warrants future consideration.

The current study has a number of strengths, including its prospective design and the quasi-random allocation of stress condition characteristic of a natural disaster; however, like other studies capitalizing on a "natural experiment" (Rutter, 1998), certain limitations were unable to be avoided. Although our measure of objective hardship assessed level of flood exposure, with a broad range of flood experiences reported (from the complete loss of one's home to no exposure at all), our study did not include a completely unexposed control group. On the other hand, our wide range of exposure levels renders this a "dose–response" study rather than a "case–control", allowing us to indicate the exact level of exposure that results in significant effects. Similarly, the logistical challenges that characterize the initiation of a natural disaster study resulted in a modest sample size, which may have limited available power to detect effects. While there was also sizeable attrition between recruitment and follow-up at

16 months, simulation studies have found that, while selective dropout from cohort studies may bias prevalence rates of behavioral problems, there is no substantial impact on the validity of associations with predictor variables (Gustavson, Von Soest, Karevold, & Røysamb, 2012; Wolke et al., 2009). Although there was a range of maternal PNMS and depression scores reported by mothers in the study, the sample was overall healthy, consistent with a non-treatment-seeking community sample. These low levels of stress may have reduced power to detect significant associations with infant outcomes. As the current study relied on maternal report to assess both PNMS and infant outcomes, shared method variance should be considered when interpreting these findings, particularly with respect to maternal subjective stress. However, while maternal mood may influence ratings of child behavior (Najman et al., 2001), the influence of reporter bias on results was reduced by adjusting for concurrent maternal depressive symptoms.

CONCLUSIONS AND CLINICAL IMPLICATIONS

The present findings suggest that exposure to a natural disaster during pregnancy had domain-specific effects on infant development. Flood-related PNMS contributed to a sex difference in behavioral problems, with boys demonstrating higher scores than girls. Greater maternal PTS symptoms predicted worse infant social–emotional competence, as well as a trend-level effect predicting more behavioral problems for boys only; however, this latter association was largely accounted for by maternal depressive symptoms at 16 months. It is noteworthy that a significant sex difference in problems, where boys displayed higher scores than girls, emerged at low-to-moderate levels of both objective hardship and PTS symptoms. For example, the J-N technique found a region of significance for IES-R scores above 3.18, significantly below the clinical cutoff of 33. Importantly, as these associations were occurring within the normal range of scores for infant behavior, these findings may suggest that infants exposed to greater flood-related stress in utero were developing "less well" than expected, particularly among boys, which may increase risk of psychopathology in the context of other risk factors over development.

Considering that participants of the current study were healthy overall and reported relatively low levels of flood-related stress and distress, this may suggest that more clinically significant adverse effects could be expected under conditions of greater PNMS exposure; however, further research with more affected and diverse samples is needed to generalize these findings. Nevertheless, these results underscore the importance of routine monitoring of stress and distress in pregnant women, and in particular, supporting the well-being of those exposed to a natural disaster. Preliminary evidence indicates that interventions offered to pregnant women may buffer the effects of stress on child outcomes, including approaches designed to enhance maternal self-efficacy (Bolten, Fink, & Stadler, 2012) and mindfulness (van den Heuvel, Johannes, Henrichs, & Van den Bergh, 2015), to reduce maternal avoidant coping and improve social support (Zhu et al., 2015), and to improve the quality of the couple relationship (Feinberg, Jones, Roettger, Solmeyer, & Hostetler, 2014).

This is also the first study to our knowledge to examine the effects of exposure to a natural disaster prenatally on emerging behavioral problems and social competence in the second-year postpartum. Finding evidence of associations of flood-related PNMS with infant social–emotional competence as early as infancy has important clinical implications and highlights the potential benefits of early intervention to support the social and emotional development of infants exposed to stress during pregnancy. Investigating the effectiveness of both prenatal and postnatal opportunities to enhance the outcomes of PNMS-exposed children represents a critical next step in future PNMS research.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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