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Prenatal maternal stress is associated with toddler cognitive functioning: The Iowa Flood Study

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1. Introduction

According to the fetal programming hypothesis, in utero exposure to a number of maternal factors, such as depression, anxiety, major life events, and/or stressors, can have potentially permanent and long-lasting effects on postnatal development [1–7]. While the majority of findings suggest that these in utero influences have mainly negative effects on postnatal development, some research suggests that certain levels of adverse early experiences may foster development [8]. Although this line of research has demonstrated that maternal life events or distress during pregnancy predict cognitive and behavioral outcomes in offspring, there remains the concern that some of the children's diminished postnatal functioning might be the result of genetic transmission of traits from mother to child. This is particularly true when examining behavioral outcomes, such as anxiety and depression, for which heritability levels are high [9,10].

Studying the effects of prenatal maternal stress (PNMS) resulting from wide-spread natural disasters overcomes the inherent limitation of relying on maternal report of their own levels of stress/anxiety since disasters are outside of the pregnant women's control, and impact a wide range of individuals in quasi-random fashion in terms of socioeconomic status, genotype, and pre-disaster levels of psychopathology. Moreover, since the start date of sudden-onset disasters can be readily documented, a relatively accurate determination as to when in development the fetuses were exposed to maternal stress can be made. Finally, the PNMS resulting from natural disasters can be decomposed into a pregnant woman's objective hardship (i.e., events she experienced) and subjective distress (i.e., her reactions to the disaster).

Results from Project Ice Storm, the first prospective longitudinal study of the effects of in utero exposure to disaster-related PNMS on offspring postnatal functioning, revealed that both the women's objective hardship and their subjective distress had negative influences on the postnatal functioning of exposed offspring [11,12]. In terms of child cognitive and language functioning, the women's objective hardship, but not their subjective distress, was related to poorer functioning at 2 and 5½ years of age [13,14]. At age 2 years, there was a significant moderating effect of in utero timing, with the greatest negative effects of objective exposure on cognitive functioning seen in toddlers exposed to the ice storm in the first and second trimesters. At age 5½, however, this timing effect disappeared, and a curvilinear effect of objective stress on cognitive outcomes was seen, with a slight advantage of moderate compared to low objective stress, and a drop in functioning at high levels. Although the effects of PNMS on the Project Ice Storm cohort are diverse and long lasting [12], replication is required.

The Iowa Flood Study seeks to replicate the findings obtained in Project Ice Storm. The study was launched in 2008 soon after the worst flooding in 50 years occurred in Iowa and surrounding states. In Iowa alone, the flooding displaced 38,000 individuals and resulted in 24 deaths. The flood was ranked among the top 10 worst disasters in US history with an economic cost reaching several billions of dollars.

The goal of the present study was to determine the extent to which in utero exposure to disaster-related PNMS resulting from the 2008 Iowa flood is related to cognitive and language functioning in 30-month-old toddlers. Based on findings from Project Ice Storm, it was hypothesized that toddlers exposed to higher levels of maternal objective hardship, particularly when the exposure occurred early in pregnancy, would exhibit lower cognitive and language functioning relative to toddlers exposed to lower levels of maternal objective hardship and toddlers exposed to higher levels of maternal objective hardship later in pregnancy. The potential moderating effects of child sex will also be explored.

2. Materials and methods

2.1. Participants

Shortly after the floods, we contacted women who were already involved in a study of maternal characteristics and pregnancy outcomes at the University of Iowa [15]. These women had been recruited at < 20 weeks gestation from the University of Iowa Hospitals and Clinics. We also recruited additional women from three flood-affected counties in Iowa. All participants were recruited between 1 and 9 months (M = 2.1 months; SD = 1.3 months) following June 15, 2008, the peak of the flooding. All women were 18 years of age or older, English

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speaking, and pregnant during the flood. This report includes 132 toddlers (boys = 69, girls = 63) who were exposed in utero to varying levels of PNMS during the 1st (n = 38), 2nd (n = 50), or 3rd (n = 44) trimester of pregnancy. The toddlers were, on average, 30.7 months of age (SD = 1.0, range 29.1–36.4 months) at the time of testing.

2.2. Outcome measures

2.2.1. Cognitive functioning

Cognitive functioning was assessed using the Cognitive scale of the Bayley Scales of Infant and Toddler Development – 3rd Edition [16]. The Cognitive scale has good reliability (0.91) and validity with later Wechsler Preschool and Primary Scale of Intelligence scores (0.79). Composite scores were available for 103 toddlers (55 boys). The assessment occurred at our laboratory in the Department of Psychology at the University of Iowa during which the infants' visual-motor integration, handedness, and play abilities were also assessed.

2.2.2. Language functioning

Language abilities were assessed using the short form of the MacArthur-Bates Communicative Development Inventory [17]. Using the lists of words provided, mothers checked those words that their infant understood (receptive), or understood and spoke (productive). Receptive and productive scores were available for 122 toddlers (62 boys). The mothers were asked to complete the questionnaire packet while their infants were playing with a set of toys. Mothers unable to complete the questionnaire packet while at the laboratory, or who did not participate in the face-to-face assessments, were asked to complete it at home and return it to us using the self-addressed stamped envelope provided.

2.3. Predictor variables

2.3.1. Objective hardship

At the time of recruitment, the severity of flood-related events experienced by participants was assessed using a questionnaire that tapped into four categories of exposure: Threat, Loss, Scope, and Change [11,18]. Because each natural disaster presents unique experiences, questions pertaining to each category must be tailor-made (Table 1). This questionnaire was initially completed by the majority of the women (94.8%), on average, 2.1 months (range: 0–9 months) following the peak of the flooding. The questionnaire was re-administered, on average, 22.2 months (range: 21–33 months) following the flood in order to update information specific to Scope (e.g., days away from home) and Loss (e.g., total financial loss). The total score for each dimension could range from 0 (no exposure) to 25 (high exposure). A total objective hardship score, the Iowa Flood 100 (IF100) was calculated by summing scores from all four dimensions using McFarlane's approach of equal weighting [19]. In the present study, scores ranged from 0–50. For 5.2% of the women, the 22-month post-flood assessment was the only time they completed the items; for these women, their scores were based solely on their responses to this 22-month post-flood assessment.

2.3.2. Subjective distress

Also at recruitment, we assessed the women's psychological reaction to the flood using the 22-item Impact of Event Scale–Revised [20], which measures three dimensions relevant to trauma- and stressor-related disorders such as post-traumatic stress disorder (PTSD): Intrusive Thoughts, Hyperarousal, and Avoidance. Participants responded on a 5-point Likert scale, from "*Not at all*" to "*Extremely*," the extent to which each flood-related symptom described how they felt over the preceding seven days. As with the IF100 (described above), the 22-month post-flood responses were used for those women who were missing the IES-R at recruitment. For the women who completed the IES-R at recruitment and 22 months post-flood, IES-R scores were highly correlated (r = 0.74). In the present study, scores ranged from 0 to 64; scores of 22 or above are indicative of possible PTSD.

2.3.3. Timing of Exposure

The timing of the flood exposure during pregnancy was defined as the number of days between June 15, 2008 (the peak of the flooding) and the infant's due date. Third trimester exposure corresponds to due dates falling between 0 and 93 days following June 15th; 2nd trimester, 94–186 days; and 1st trimester, 187–280 days.

2.3.4. Control variables

Positive mental health status of the women was assessed at recruitment and post-flood using the brief version of the Mental Health Continuum [21]. Household socioeconomic status (SES) at recruitment was determined based on maternal and paternal education and occupation using the Hollingshead Social Position criteria; higher values reflect higher SES [22]. Maternal exposure to life events (other than the flood) was assessed at recruitment and at 30 months using the Life Experiences Survey [23], a self-report measure listing life changes, such as death of a spouse or work promotion. Maternal depression was assessed using the Inventory of Depression and Anxiety Symptoms [24] at recruitment and at 30 months: the General Depression score was used. At 30 months, maternal social support (Social Support Questionnaire [25]), parenting stress (Parenting Stress Index [26]), and current maternal stress (Perceived Stress Scale [27]) were also assessed. The infants' gestational age at birth and birth weight were obtained from hospital records. Medical and obstetric history (e.g., cigarette/alcohol usage, hypertension, diabetes, infections), obtained from self-report and hospital records, were combined into a single Obstetric/Fetal risk factor variable. Finally, the age of the child when the mother completed the MacArthur-Bates Communicative Development Inventory was calculated.

2.4. Statistical analyses

Non-transformed means and standard deviations were calculated for the outcome and predictor variables. Since both the objective hardship and subjective distress variables exhibited substantial positive skew, log-transformations were performed on these predictor variables. Since both the receptive and productive language scores exhibited substantial negative skew, reflect and square root transformations [28] were performed on these outcome variables. The transformed results were then multiplied by −1 to retain their original rank order. Pearson Product Moment correlation coefficients were obtained between all variables. Hierarchical multiple regression analyses were used to assess the associations between the predictor and outcome variables. The order of entry reflects the goals of determining, first, the extent to which PNMS explains variance in the outcome and then, second, the extent to which these associations hold when potential confounds are controlled for. As such, Objective hardship was entered into each model in the 1st block. Subjective distress was entered into the 2nd block of the model. Child's sex (0 = male), timing of the in utero exposure, and SES were entered into the model during blocks 3, 4, and 5, respectively. All potential interactions between objective hardship and subjective distress, and child's sex, timing of the in utero exposure, and SES were allowed to enter into the model in a stepwise manner during block 6. Finally, additional predictor variables that were significantly related to the outcome variables were allowed to enter into the model in a stepwise manner during the final block. In order to obtain the most parsimonious model, all predictor variables that were not significantly related to the outcome variable were trimmed from the model.

Table 1
Questions used to assess the four dimensions (Scope, Loss, Change, and Threat) of the Iowa Flood 100 (IF100) questionnaire of objective hardship. Numbers in parentheses following response options indicate weighted scoring. All dimensions have a maximum score of 25 for an overall potential maximum score of 100.

Scope	
To what extent was your neighborhood (% of homes) affected by the flooding?	0% (0); 1–10% (1); 11–25% (2); 26–50% (4); 50%+ (6)
How many days were you away from your home?	0 (0); 1–3 (1); 4–5 (2); 6–7 (3); 8–9 (4); 10–13 (5); 14–20 (6); 21–60 (7); 61–98 (8); 99 + (9)
How many days were you deprived of electricity because of the flooding?	0 (0); 0.05–0.5 (1); 1–2 (2); 3–7 (3); 8–30 (4); 31 + (5)
How many days were you deprived of home telephone service because of the flooding?	0 (0); 0.05–0.5 (1); 1–3 (2); 4–9 (3); 10–21 (4); 22 + (5)
Loss	
Was your home damaged?	Untouched (0); Slightly damaged (1); damaged but habitable (2); Damaged and not habitable (3); Totally destroyed (4)
Was there a loss of family heirlooms?	No (0); Yes (2)
Was there a loss of personal property?	No (0); Yes (2)
Was there a loss of personal investments?	No (0); Yes (2)
Was your vehicle damaged?	No (0); Yes (1)
Did you experience loss of personal income?	No (0); Yes (2)
How much is your total loss?	< $100 (0); $101–$1000 (1); $1001–$10,000 (2); $10,001–100,000 (3); $100,001–$200,000 (4); $200,001 + (5)
The total loss of your personal business?	< $100 (0); $101–$1000 (1); $1001–$10,000 (2); $10,001–100,000 (3); $100,001–$200,000 (4); $200,001 + (5)
If your home was damaged, were you protected by flood insurance?	No (2); Yes (0)
Change	
For how many days were members of your family apart from each other?	0 (0); 1–6 (1); 7–14 (2); 15 + (3)
How many times were you required to change residence?	0 (0); 1 (1); 2 + (2)
Did you stay in shelter?	No (0); Yes (1)
Number of days you housed people (multiplied by the number of people)	0 (0); 1–7 (1); 8–14 (2); 15–42 (3); 43 + (4)
Did you experience a decrease/increase in physical work?	No (0); Yes (2)
Did you experience a decrease/increase in work hours?	No (0); Yes (1)
Did you experience longer commuting times?	No (0); Yes (2)
Did you experience difficulty in accessing prenatal care?	No (0); Yes (2)
Did you experience a change in your birth plan?	No (0); Yes (1)
Was your place of work damaged?	No (0); Yes (1)
Was the place of work of your spouse damaged?	No (0); Yes (1)
Did you experience a change in your diet?	No (0); Yes (2)
How many meals did you skip?	0 (0); 1–5 (1); 6–10 (2); > 10 (3)
Threat	
Were you physically hurt?	No (0); Yes (1)
Was someone close to you physically hurt?	No (0); Yes (1)
Were you in any kind of danger?	No (0); Yes (1)
Danger from: drowning?	No (0); Yes (2)
Danger from: increasing water level?	No (0); Yes (4)
Danger from: electrical shocks?	No (0); Yes (1)
Danger from: collapse of bridges?	No (0); Yes (1)
Danger from: lack of safe drinking water?	No (0); Yes (3)
Danger from: exposure to raw sewage?	No (0); Yes (1)
Danger from: lack of food?	No (0); Yes (1)
Danger from: isolation?	No (0); Yes (1)
Danger from: other dangers?	No (0); Yes (1)
How much time were you given to leave home?	< 1 h (7); 1–6 h (4); 7–12 h (2); > 1 day; (1); Was not required to leave my home (0)

3. Results

3.1. Descriptive analyses

Means (or percentages) and standard deviations for all outcome, predictor and control variables can be found in Table 2. The families in this study were relatively highly educated (i.e., > 50% with an undergraduate degree or higher), and had relatively high status occupations and household income levels (i.e., > 49% had household revenues of $70,000 or greater). Based on Hollingshead classifications, 80% of the participating families scored in the Upper Middle to Upper class. As such, the participating families were not representative of the state of Iowa. Approximately 4.5% of the women had a score of 22 or more on the Impact of Events Scale-Revised, indicating potential post-traumatic stress disorder.

Moreover, comparison of demographic information of families participating in the 30-month assessment of the study to those families who did not participate, revealed participating families had, on average, a higher family income level compared to non-participating families ($p = 0.015$). Comparisons of the flood-related stress variables, infants' birth outcomes, and maternal characteristics between the participating and non-participating families revealed that participating mothers experienced fewer obstetric complications ($p = 0.08$) and lower general depression scores at recruitment ($p = 0.03$) compared to the non-participating mothers. The objective hardship and subjective distress measures did not differ.

The participating toddlers had, on average, a Bayley Composite Score of 101.3 (SD = 10.1), understood but did not yet speak 85.9 words (SD = 5.8), and spoke, on average, 76.4 (SD = 15.7) words.

3.2. Correlations

Pearson's correlation coefficients between all outcome and predictor variables, in their inverse square root or log-transformed states as indicated, are presented in Table 3. Bayley Composite scores had low, trend-level correlations with Receptive and Productive language levels which were highly correlated with each other: higher Bayley scores were associated with higher child vocabularies. Objective hardship and subjective distress were positively correlated with each other, while only subjective distress was correlated with the three outcome measures: higher subjective distress levels predicted significantly lower Bayley, and trended towards lower receptive and productive language

Table 2
Means and standard deviations for outcome, predictor, and control variables.

Variable	n	Mean or percent	Standard deviation
Outcomes			
Bayley cognitive scale	103	101.4	10.0
Receptive language	122	86.1	5.7
Productive language	122	76.8	15.1
Prenatal stress measures			
Objective hardship	132	8.0	9.5
Subjective distress	132	5.4	8.2
Trimester of exposure	132		
1st	38	28.8%	
2nd	50	37.9%	
3rd	44	33.3%	
Child covariates			
Child sex	132		
Males	69	52.3%	
Females	63	47.7%	
Gestational age (wks)	130	39.2	1.5
Birth weight (g)	130	3500.5	517.6
Obstetric complications (#)	130	0.7	1.0
Age at MCDI assessment (wks)	122	30.7	1.4
Maternal covariates			
Recruitment			
General depression	99	32.5	7.9
Life events	100	3.4	2.2
Positive mental health	100	51.3	10.1
Socio-economic status	132		
Lower middle class	7	5.3%	
Middle class	21	15.9%	
Upper middle class	82	62.1%	
Upper class	22	16.7%	
30 Months			
General depression	132	33.1	8.6
Life events	132	4.7	2.9
Parenting stress	132	66.9	14.8
Perceived stress	132	13.2	4.9
Social support	132	4.2	1.7

scores. SES was positively correlated with the Bayley Composite Score, and higher maternal depression at 30 months was correlated with lower productive language. Age at the completion of the MacArthur-Bates Communicative Development Inventory tended to be associated with the children's productive levels: older children tended to speak more words. There were no other significant correlations between cognitive scores and either PNMS or potential confound variables.

3.3. Regression analyses (Table 4)

3.3.1. Bayley composite

Objective hardship was unrelated to the toddlers' composite scores, explaining only 1.1% of the variance. The main effect of subjective distress accounted for 3.6% of additional variance in the toddlers' composite scores at entry into the equation: higher levels of subjective distress predicted lower composite scores. Sex of the child and timing of the in utero exposure were not related to the toddlers' composite scores when first entering the equation. Parental SES increased variance explained from 5.9% to 14.1%, explaining 8.2% of unique variance in the toddlers' composite scores: higher SES levels predicted higher composite scores. Finally, the significant subjective distress × timing of exposure interaction term accounted for an additional 4.3% of the variance. As seen in Fig. 1, the effect of maternal subjective distress was significant when flood exposure occurred before day 123 of pregnancy (17 weeks, or 4 months): in early pregnancy, the greater the subjective maternal stress the lower the child's Bayley score. The lowest composite scores were observed for toddlers exposed to high levels of subjective distress during the first 4 months of pregnancy. The effect of timing on Bayley scores was significant when maternal subjective distress scores were > 2.1 (untransformed IES-R = 7). The final model accounted for 18.3% of the variance of the toddlers' composite scores.

3.3.2. Receptive language

At entry into the model, the main effects of objective hardship, subjective distress, sex of the child, and timing of the in utero exposure were unrelated to the toddlers' receptive language abilities and, collectively, explained 4.5% of the variance in receptive language. The significant objective hardship × sex interaction term accounted for an additional 7.2% of the variance in the number of words the toddlers understood. As seen in Fig. 2, for boys, the higher the degree of maternal objective hardship the more words they understood ($p < 0.001$), while for girls the level of objective stress had no significant effect on the number of words understood. If objective hardship levels were low (below a log score of 1.73, which is equivalent to an untransformed score below 5), there were no sex differences in receptive vocabulary; when objective hardship levels were above that level, however, boys understood significantly more words than girls. The final model included a trend for greater subjective distress to predict lower receptive vocabulary ($p = 0.078$). Together, the variables in the final model accounted for 11.6% of the variance in the toddlers' receptive language abilities.

3.3.3. Productive language

At entry, Objective hardship was unrelated to the toddlers' productive language abilities, accounting for only 0.4% of the variance. Subjective distress accounted for an additional 3.7% of the variance in the toddlers' productive language abilities: higher subjective distress levels tended to be associated with lower number of words spoken ($p < 0.10$). Child sex and timing of exposure were unrelated to the toddlers' productive language abilities, and together explained an additional 2.2% of the variance in productive language. Current maternal general depression accounted for an additional 4.5% of the variance: higher general depression levels were associated with lower word production in the toddlers. Likewise, age at the assessment accounted for an additional 3.1% of the variance in the toddlers' productive language abilities: older children spoke more words. The significant objective hardship × sex interaction accounted for an additional 4.0% of the variance in the toddlers' productive language abilities. As seen in Fig. 3, the interaction for productive language was similar to that for receptive language: for boys, the higher the level of objective hardship, the more words they spoke ($p < 0.01$); for girls, the number of words spoken was not associated with the level of objective hardship experienced by their mothers. When objective hardship was low (below a log-transformed value of 1.62, or untransformed value of 4), there were no sex differences; above this level, however, boys had significantly higher productive language scores than girls. In the final model, subjective distress had a significant negative effect on productive vocabulary controlling for all other variables in the model and the interaction. Together, the variables in the final model accounted for 18.0% of the variance in the toddlers' productive language abilities.

4. Discussion

Similar to our previous findings with our Project Ice Storm cohort [13,14], the present results suggest that elements of in utero exposure to disaster-related maternal stress predict offspring cognitive and language development. In the present study, high levels of maternal objective hardship and subjective distress, the timing of exposure in utero, infant sex, and their interactions were predictive of both cognitive development and receptive and productive language abilities in prenatally flood-exposed 30-month old toddlers; the final models, including control variables, explained a total of 18.3%, 11.6%, and 16.0% of the variance, respectively. The results suggest that cognitive functioning, as reflected in Bayley scores, was most affected in toddlers who were exposed to higher levels of maternal subjective distress early in pregnancy. Similarly, language development, particularly words spoken,

Table 3
Correlation coefficients between all outcome and predictors variables.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Outcomes																			
1	Bayley cognitive scale	–																	
2	Receptive language (transformed)[a]	0.22*	–																
3	Productive language (transformed)[a]	0.24*	0.58***	–															
Prenatal stress measures																			
4	Objective hardship (log)	− 0.11	0.03	0.07	–														
5	Subjective distress (log)	− 0.21*	− 0.13†	− 0.17†	0.36****	–													
6	Timing of exposure	0.06	0.06	− 0.02	0.19*	0.01	–												
Child covariates																			
7	Gestational age	0.04	− 0.07	0.06	− 0.06	0.14	− 0.08	–											
8	Birth weight	− 0.03	− 0.08	0.12	− 0.01	0.11	0.08	0.57****	–										
9	Obstetric complications	− 0.14	0.06	− 0.01	− 0.02	0.03	− 0.03	− 0.19*	− 0.11	–									
10	Age at MCDI assessment	− 0.14	0.11	0.16†	0.11	− 0.05	0.17†	− 0.16†	− 0.06	− 0.02									
Maternal covariates																			
Recruitment																			
11	General depression	0.04	0.12	0.12	0.15	0.20*	0.17†	− 0.02	0.13	0.11	− 0.20†	–							
12	Life events	0.05	0.10	0.03	0.08	− 0.06	0.08	− 0.01	0.14	− 0.06	0.06	0.49****	–						
13	Positive mental health	0.14	− 0.11	< − 0.01	− 0.14	− 0.18†	− 0.11	− 0.02	− 0.18†	− 0.05	0.10	− 0.61****	− 0.23**	–					
14	Socio-economic status	0.32***	0.09	0.14	− 0.07	− 0.21*	0.05	− 0.15†	0.08	− 0.22*	− 0.18*	− 0.15	− 0.04	0.07	–				
30 Months																			
15	General depression	− 0.07	0.01	− 0.22*	− 0.10	− 0.03	0.09	− 0.15†	− 0.11	0.12	0.09	− 0.11	− 0.03	0.06	− 0.16†	–			
16	Life events	− 0.05	− 0.07	− 0.06	− 0.04	< − 0.01	0.02	− 0.05	0.11	− 0.08	− 0.01	− 0.08	0.01	− 0.11	− 0.08	0.49****	–		
17	Parenting stress	− 0.08	0.05	− 0.05	− 0.02	− 0.01	− 0.01	− 0.06	− 0.08	0.04	0.10	− 0.04	0.16	0.11	< 0.01	0.49****	0.24**	–	
18	Perceived stress	0.03	0.10	− 0.13	− 0.07	− 0.04	− 0.06	− 0.04	− 0.06	0.09	0.12	− 0.09	0.11	− 0.03	− 0.15	0.68****	0.28***	0.56****	–
19	Social support	0.06	− 0.02	− 0.11	0.08	0.13	< 0.01	0.08	0.20*	0.04	− 0.04	0.04	− 0.02	0.09	− 0.03	− 0.33****	− 0.09	− 0.22*	− 0.36****

[a] Values were transformed using the inverse square root then multiplied by − 1 to retain same rank order as raw scores: higher values equals more words.
† $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.005$.
**** $p < 0.001$.

Table 4
Summary of hierarchical linear regression models for the infants' cognitive and language functioning.

Predictor variables	Values in final model				β	Values after entry of each variable				
	B	SE B	β	B p-value		R^2	ΔR^2	F*	ΔF	ΔF p-value
Cognitive functioning: Bayley composite scores (n = 103)										
(Constant)	88.247	6.450								
Objective hardship	0.119	1.230	0.017	0.872	− 0.107	0.011		1.162		
Subjective distress	− 5.189	1.975	− 0.552	0.009	− 0.208	0.047	0.036	2.474†	3.755	0.055
Child's sex (0 = male)	0.887	1.896	0.044	0.641	0.080	0.053	0.006	1.864	0.661	0.418
Timing of exposure (days)	− 0.026	0.019	− 0.209	0.185	0.076	0.059	0.006	1.536	0.574	0.450
Socioeconomic status	0.334	0.099	0.322	0.001	0.293	0.141	0.082	3.173*	9.207	0.003
Subjective distress × timing of exposure	0.026	0.012	0.535	0.027	0.535	0.183	0.043	3.593***	5.035	0.027
Language functioning: MCDI receptive scores[a] (n = 122)										
(Constant)	2.531	0.353								
Objective hardship	0.444	0.167	0.354	0.009	0.013	0.000		0.021		
Subjective distress	− 0.171	0.096	− 0.167	0.078	− 0.160	0.022	0.022	1.352	2.683	0.104
Child's sex (0 = male)	1.535	0.444	0.723	0.001	0.138	0.041	0.019	1.693	2.345	0.128
Timing of exposure (days)	0.001	0.001	0.045	0.612	0.059	0.045	0.003	1.396	0.420	0.518
Objective hardship × child's sex	− 0.674	0.220	− 0.684	0.003	− 0.684	0.116	0.072	3.051*	9.388	0.003
Language functioning: MCDI productive scores[a] (n = 122)										
(Constant)	− 8.545	3.367								
Objective hardship	0.751	0.297	0.335	0.013		0.066	0.004		0.522	
Subjective distress	− 0.390	0.167	− 0.213	0.022		− 0.206	0.041	0.037	2.560†	4.582	0.034
Child's sex (0 = male)	2.134	0.790	0.563	0.008		0.146	0.062	0.021	2.614†	2.652	0.106
Timing of exposure (days)	− 0.001	0.002	− 0.042	0.634		− 0.035	0.064	0.001	1.984	0.151	0.698
General depression (30 mos)	− 0.050	0.021	− 0.214	0.016		− 0.217	0.109	0.045	2.834*	5.898	0.017
Age at MDCI assessment (30 mos)	0.200	0.121	0.145	0.102		0.180	0.140	0.031	3.116**	4.146	0.044
Objective hardship × child's sex	− 0.914	0.389	− 0.519	0.021		− 0.519	0.180	0.040	3.564***	5.517	0.021

[a] Values were transformed using the inverse square root then multiplied by − 1 to retain same rank order as raw scores: higher values equals more words.
† $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.005$.

was lower overall in toddlers whose mothers experienced high subjective distress. At low levels of maternal hardship, there were no sex differences in vocabulary; when objective hardship was at moderate or high levels, however, boys (who experienced a significant, *positive* effect of maternal hardship) had significantly higher vocabulary scores than girls. As such, it appears that maternal flood-related objective hardship eliminated the usual superiority of girls in early language development by accelerating language acquisition in boys [29].

These findings only partly replicated those found in Project Ice Storm. In Project Ice Storm, it was found that in utero exposure to

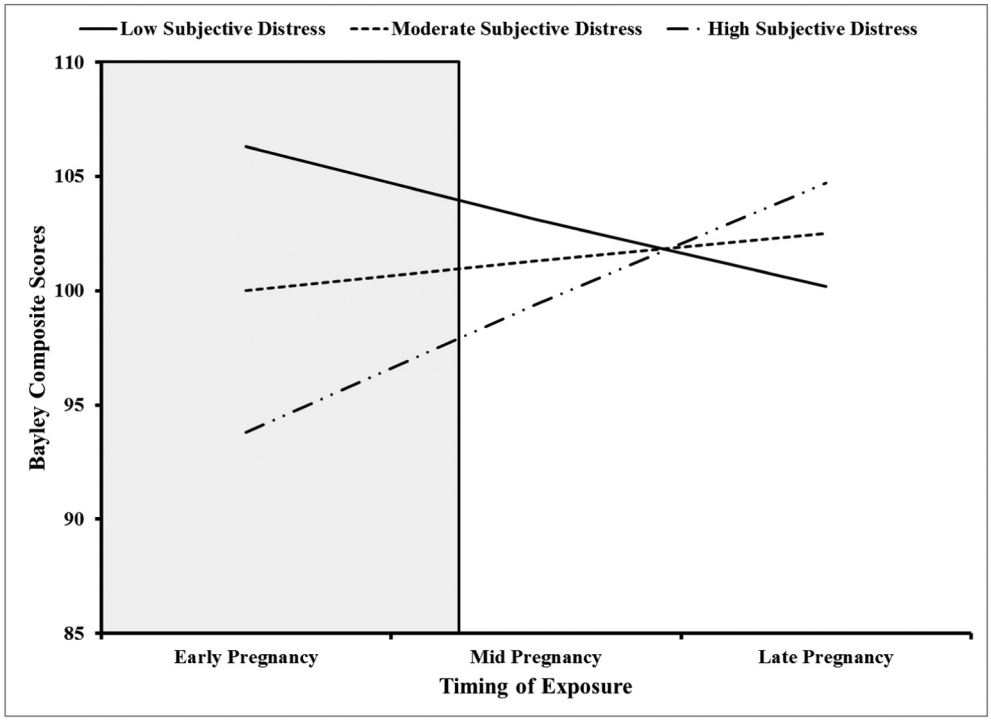

Fig. 1. Cognitive functioning as a function of maternal subjective distress and in utero timing of exposure to the flood (n = 103). The Timing-by-Subjective Distress interaction is represented using lines indicative of low scores (bottom 10th percentile), moderate (50th percentile) and high scores (90th). There was a significant association between subjective distress and Bayley Composite when the toddlers' mothers were exposed to the flood any time during the first 121 days of pregnancy (shaded area). The effect of timing was only significant ($p < 0.05$) when maternal subjective distress (log) scores were 2.1 or higher.

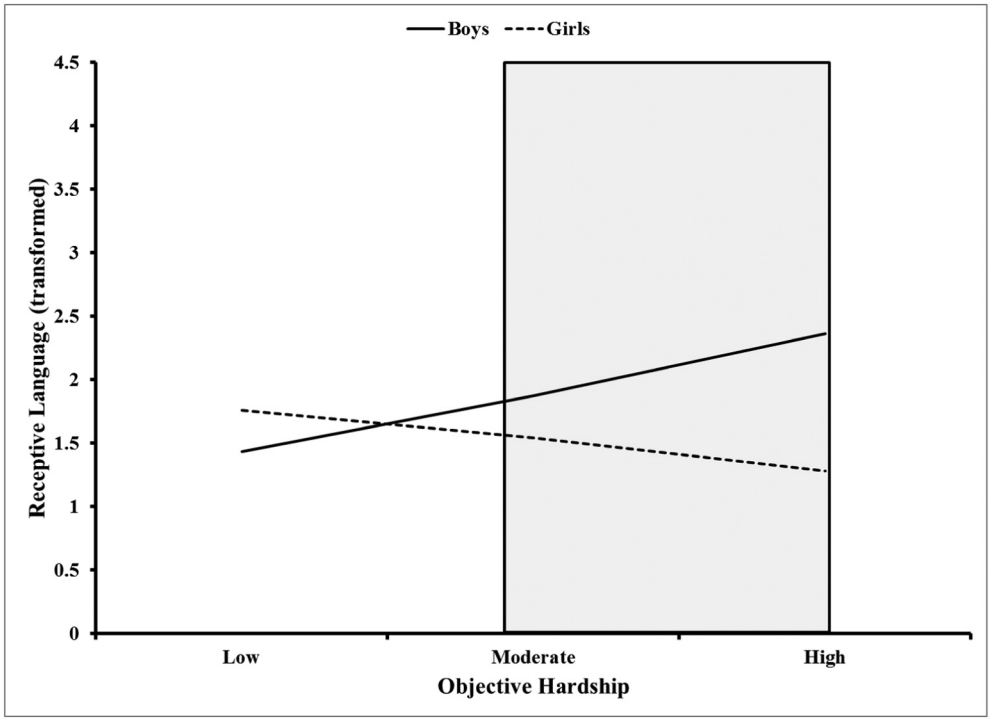

Fig. 2. Receptive language abilities as a function of maternal objective hardship and toddler sex (n = 122). Receptive language abilities differed significantly for boys (n = 62) and girls (n = 60) when the level of maternal objective hardship was at or above the log value of 1.73. Only the slope for boys was significant (p = 0.009).

maternal objective hardship, but not subjective distress, was associated with poorer cognitive and language abilities in 24-month-old toddlers [13,14]. Our results from the Iowa Flood Study, however, demonstrate main effects of subjective maternal stress, but not objective hardship, on Bayley scores and language. As we show here with the Iowa Flood cohort, however, language development appears to have been sensitive to both subjective and objective PNMS in this group.

One finding that was consistent across the two studies is that the effects of PNMS on cognitive functioning (Bayley scores) during toddlerhood are most prominent when the exposure occurred early in gestation; this is true for objective hardship exposure in Project Ice Storm, and subjective distress in the Iowa Flood Study. With the ice storm cohort, the timing effect at age two years applied to both Bayley and receptive and productive language scores, while the timing effect on language was not seen in the Iowa cohort. It remains to be determined whether early exposure will remain a significant predictor of decreased cognitive functioning in the Iowa cohort at later ages. In Project Ice Storm, this timing effect at age two was lost for cognitive development assessed using the Wechsler scales at subsequent ages (5½ [13,14], and at 8½ and 11½ [11]).

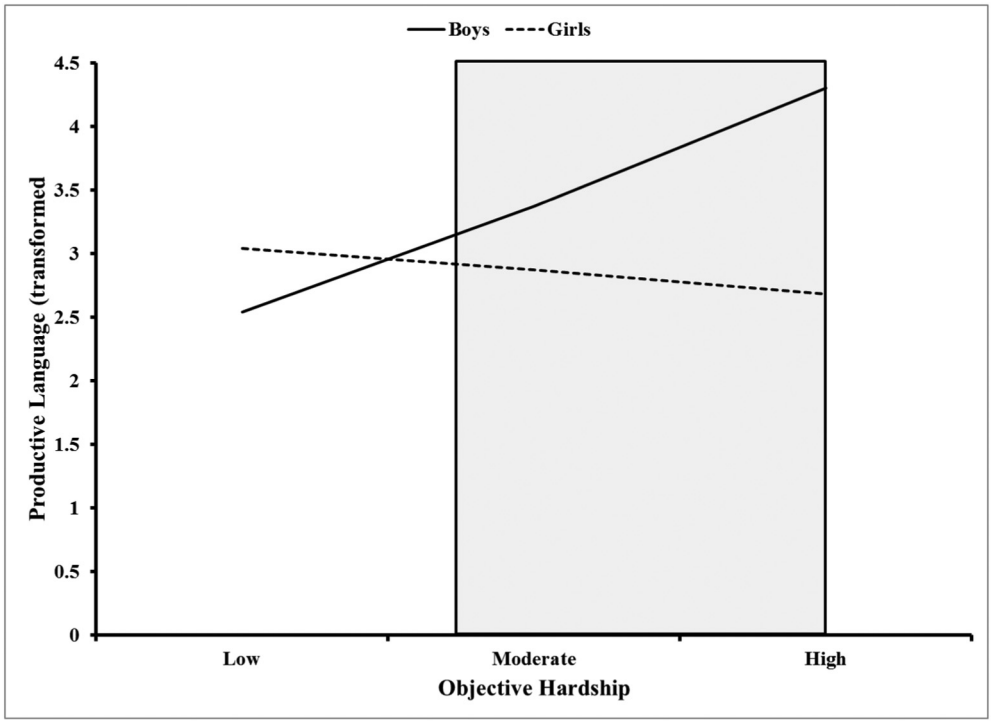

Fig. 3. Productive language abilities as a function of maternal objective hardship and toddler sex (n = 122). Productive language abilities differed significantly for boys (n = 62) and girls (n = 60) when the level of maternal objective hardship was at or above the log value of 1.62. Higher objective hardship scores were related to only the slope for boys was significant (p = 0.005).

An unexpected finding in the present study was that higher levels of maternal objective hardship predicted greater receptive and productive language abilities in male toddlers. According to normative data for productive language (i.e., number of words spoken) using the long form of the MacArthur-Bates Communicative Development Inventory, girls at 30 months speak 23 words more than boys, on average [29]. Results from the present study using the short form of this inventory demonstrate that the number of words spoken (and understood but not yet spoken) by boys whose mothers had experienced high levels of objective hardship surpassed that exhibited by girls, suggesting that exposure to increased levels of maternal objective hardship facilitated early language development in the boys. However, it must be remembered that in utero exposure to higher levels of maternal subjective distress was associated with fewer words spoken, regardless of child sex. Although counter-intuitive, there is evidence in the literature suggesting that mild or moderate levels of in utero stress exposure may be beneficial to the developing fetus [7]. DiPietro cautions against viewing maternal stress and/or anxiety as potentially only having negative consequences on fetal development and subsequent postnatal performance. Based on evidence from human studies, DiPietro suggests that moderate in utero stressors may actually have beneficial effects on fetal development and postnatal functioning in accordance with the Yerkes-Dodson [30] rule. For example, DiPietro and colleagues demonstrated that mild and moderate pregnancy-related stress in a sample of healthy women was related to better fetal development and postnatal performances. In the Queensland Flood Study, which was patterned after Project Ice Storm and the Iowa Flood Study, our group has shown that greater maternal subjective distress from the Australian floods predicted higher vocabulary scores at 30 months, but only in children whose mothers were high in structuring behaviors during a joint play session [31]. Moreover, we demonstrated that our Project Ice Storm children at 5½ years of age exposed in utero to moderate levels of objective hardship had better cognitive functioning than children exposed to high levels of objective hardship but also slightly better performance than children exposed to low levels of objective hardship [14]. The fact that the apparent beneficial effects of objective hardship on language development in Iowa were only seen in boys suggests that PNMS might influence neurodevelopment in a sex-specific manner [32,33]. Alterations in sexually dimorphic behavior and traits resulting from PNMS have been reported previously. For example, Barrett et al. [34] reported that play behavior in childhood was affected by maternal pregnancy stress such that the play of girls was masculinized while that of boys feminized. Likewise, Barrett et al. [35] reported that girl infants of parents who experienced a high number of major life events during the pregnancy had more masculinized ano-genital distances relative to girls whose parents experienced fewer events during the pregnancy. While elevated maternal stress during pregnancy appears capable of altering sexually dimorphic behavior and/or traits, the exact mechanism by which this occurs is still relatively unknown [32], however epigenetic influences on brain developing starting in the fetal period has been suggested as a possible mechanism [3].

Unfortunately, there is no way to compare the objective severity of hardship between the Project Ice Storm and Iowa flood cohorts. It is possible that this finding of a positive effect of objective PNMS in Iowa Flood Study boys reflects the ascending portion of a curvilinear effect in the absence of sufficient numbers of women at high objective stress levels that may have demonstrated the descending portion of the curve. We can compare the two cohorts on average levels of subjective distress, however, and the Iowa cohort has significantly lower levels of post-traumatic distress symptoms than the ice storm sample [12], suggesting the possibility of lower levels of objective hardship in the Iowa than in the Ice Storm cohorts.

As such, we suspect that differences between the nature of the two disasters might, at least partially, explain why different aspects of the women's stress experience were related to the toddlers' cognitive and language functioning. The 1998 Quebec ice storm literally covered southern Quebec with a thick layer of ice and resulted in a continuous fear that one's electricity could go out at any moment as the ice build-up threatened to topple electrical lines that had not already collapsed. As such, all women in Project Ice Storm experienced some level of objective hardship during this disaster. While some women were highly distressed by the crisis even though they themselves experienced little objective hardship, others reported not being distressed by the event even though they experienced many hardships. On the other hand, while the flooding that occurred in Iowa and surrounding states in 2008 was devastating, its destruction was limited to areas adjacent to the swollen rivers. Only women who resided and/or had a business in the flood zone were affected, while those residing outside of the flood zone were largely unaffected. Moreover, once the flooding reached its peak, the threat for further flooding ceased. As such, the scope of the 2008 Iowa flood was more restricted than that of the 1998 Quebec ice storm. As well, women were often subjected to the cold during the ice storm crisis, while the Iowa flood was not associated with unusual exposure to extreme temperatures. These differences between disasters may potentially explain why different aspects of the women's disaster-related stress experience were related to the toddlers' cognitive and language functioning in the two studies.

The findings from these two disaster studies on the effect of PNMS on cognitive and language functioning in early development clearly demonstrate the need to assess various aspects of pregnant women's disaster experience. Assessing only the women's objective hardship or their subjective distress may potentially result in failing to ascertain that the effects of the disaster were great enough to disrupt early development. For example, assessing only the women's subjective distress following the 1998 Quebec Ice Storm would have led us to conclude that the disaster had no effect on cognitive and language functioning in early childhood. Moreover, assessing only the women's objective hardship following the 2008 Iowa Flood would have resulted in us concluding that the disaster had no effect on the children's cognitive functioning, but appeared to stimulate early language functioning in boys. These studies demonstrate the need for disaster research to determine the severity of specific events the pregnant women experienced and their subjective reaction to the disaster itself since both aspects of the stress experience may play a role in the subsequent development of exposed fetuses.

The Iowa Flood Study has limitations. Similar to the Ice Storm cohort, the Iowa Flood cohort is predominately from the higher socioeconomic bracket with approximately 78% of families being Upper Middle class and higher. Likewise, 31% of families reported yearly household incomes exceeding $90,000 US with 58% of mothers and 62% of fathers having completed at least an undergraduate degree. As such, findings from this study are not generalizable to the population at large, and may potentially underestimate the disaster effects in lower SES families with fewer resources. Moreover, the study lacks a completely stress-free control group for case-control (stress versus non-stress) comparisons. However, the dose-response approach to our analyses remains highly informative. Finally, the assessment of the women's PNMS was conducted, on average, 79.6 days (SD = 40.0 days; range 29–283 days) following the peak of the flooding (June 15, 2008); as in all disaster research, such reports are retrospective, with the associated potential for bias. However, correlational analyses indicate no significant association between the PNMS data and the time between the peak of the flood and the recruitment questionnaire ($|r| = 0.019$ to 0.079, $p = 0.216$ to 0.766), suggesting that the responses of the women were not influenced by the time lag since the flooding. Finally, while all efforts were made to assess the women as quickly as possible post-flood, a wide range on when the initial assessment of the women's flood-related objective hardship and subjective distress levels existed. However, unpublished data from Project Ice Storm indicates that women had excellent recall of events they experienced during the crisis more than six years later suggesting that 22-month delay in the present study would not affect their assessment of flood-related experiences to any

great extent. Furthermore, analyses of the women's responses to our subjective distress measures indicated that scores did not differ greatly when assessed within several months of the flooding and again nearly two years post-flood.

Regardless of these limitations, the present study demonstrates both the negative and positive effects of in utero exposure to disaster-related maternal stress. In the present study, both subjective distress alone, and in conjunction with timing of fetal exposure, were shown to diminish the toddlers' cognitive functioning, while both subjective distress (for all children) and objective hardship (for boys) affected the development of language skills. Interestingly, exposure to higher levels of objective hardship actually increased the receptive and productive language abilities in boys, but not girls, disturbing the usual sex differences in language development at this age. As such, we are in agreement with DiPietro [7] that the magnitude and direction (negative or positive) of the effect of in utero exposure to disaster-related stress may rely on the severity of the exposure and its timing during pregnancy. Moreover, the findings from this study by themselves, and in comparison to previous findings from our Project Ice Storm cohort, suggest that both exposure to objective hardship and subjective distress may influence subsequent postnatal functioning; which aspects of the stress experience play a role in shaping postnatal functioning may be crisis-dependent. Finally, with our third disaster study, The Queensland Flood Study (QF2011) [36], we will be able to test the hypothesis that the effects of PNMS from the two flood studies are more similar to each other than to those from the ice storm.

Conflicts of interest

The authors declare no conflicts of interest.

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