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Parenting Style Moderates the Effects of Exposure to Natural Disaster-Related Stress on the Neural Development of Reactivity to Threat and Reward in Children

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Abstract

Little is known about the impact of natural disasters on children's neural development. Additionally, despite evidence that stress and parenting may both influence the development of neural systems underlying reward and threat processing, few studies have brought together these areas of research. The current investigation examined the impact of parenting styles and hurricane-related stress on the development of neural reactivity to reward and threat in children. Approximately 8 months before and 9 months after Hurricane Sandy, 74 children experiencing high and low levels of hurricane-related stress completed tasks that elicited the reward positivity (RewP) and error-related negativity (ERN), event-related potentials indexing sensitivity to reward and threat, respectively. At the post-Hurricane assessment, children completed a self-report questionnaire to measure promotion- and prevention-focused parenting styles. Among children exposed to high levels of hurricane-related stress, lower levels of promotion-focused, but not prevention-focused, parenting were associated with a reduced post-Sandy RewP. In addition, in children with high stress exposure, greater prevention-focused, but not promotion-focused, parenting was associated with a larger ERN after Hurricane Sandy. These findings highlight the need to consider contextual variables like parenting when examining how exposure to stress alters the development of neural reactivity to reward and threat in children.

Keywords

natural disaster; brain development; parenting; event-related potentials

In recent decades, there has been a steady increase in the frequency and severity of natural disasters, and climatologists predict that this trend will likely continue as the climate

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continues to warm (ECIU, 2017). Children may be particularly vulnerable to such events due to their age and reliance on adults. Indeed, children who live through natural disasters experience higher rates of mental health problems even in adulthood, likely due to the stress and trauma associated with such events (Maclean, Popovici & French, 2016).

Stress and neurodevelopment

Mounting evidence suggests that stress can have enduring effects on neural development that may influence subsequent behavioral phenotypes (Masten & Cicchetti, 2010). Most research examining the impact of stress on neural functioning in children and adolescents has focused on very severe forms of early life stress (ELS), including chronic events like neglect or repeated traumatic events like abuse. For example, physically abused and institutionally-reared children exhibit preferential attention (Briggs-Gowan et al., 2015), and increased activation in brain regions involved in threat processing, including the amygdala, anterior cingulate cortex and dorsolateral prefrontal cortex, compared to children who have not been abused (for a review see: McCrory & Viding, 2017). While hyperresponsiveness to threatening stimuli may be adaptive in unsafe environments, it can also place an individual at risk for developing maladaptive behaviors (e.g., extreme avoidance) characteristic of several anxiety disorders.

Neurocognitive systems supporting reward processing have also been shown to be vulnerable to the effects of stress. For example, compared to typically developing youth, children who experienced severe neglect and were reared in institutions fail to alter their behavioral response to stimuli as a function of reward value and exhibit reduced activation in the ventral striatum during reward anticipation and in response to positive cues (Goff et al., 2011). In addition, adolescents with a history of parental neglect have been shown to exhibit reduced reward-related neural activation across a two-year period (Hanson et al., 2015). Reward insensitivity may reduce approach-oriented behaviors and increase the likelihood of survival in an environment fraught with danger. However, reward insensitivity may also lead to the development of particular forms for psychopathology, such as depression and substance use (Baskin-Sommers & Foti, 2015). Taken together, these studies suggest that stress may have an opposing influence on neural systems that support reward and threat processing. However, as most of this research has focused on maltreatment, the precise cause of neural changes is difficult to pinpoint, as they may be influenced by numerous factors working alone or in tandem (e.g., poverty, substance abuse, low educational attainment, family violence, other co-occurring forms of abuse and neglect).

Only a handful of studies have examined neurodevelopment in the context of less severe and repetitive stressful life events (SLEs; e.g. parental divorce, loss of a grandparent, etc.). These studies suggest that SLEs during childhood and adolescence may impact neural reactivity to reward and threat in a similar fashion as ELS (e.g. Casement et al., 2014). For example, in adolescents, exposure to common SLEs in the prior 12-months was associated with increases in amygdala reactivity to fearful faces over a two-year period (Swartz et al., 2015). Other studies suggest that there may be specificity with regard to the timing and type of SLEs and their impact on neurodevelopment. For instance, in adolescents, lifetime self-relevant stressors (events involving physical appearance and academic achievement)

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were associated with enhanced neural activation to threatening stimuli, but no associations were found with accident-, familial-, and illness-related stressors (Gollier-Briant et al., 2016). In a separate investigation, cumulative SLEs across childhood and adolescence were associated with reduced ventral striatal activation to reward in adulthood, though the effects were stronger for early and interpersonal compared to later and physical/non-social stressors (Hanson et al., 2015).

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It is important to note that most of these SLEs may be at least somewhat dependent on the individual's behavior, making it difficult to draw inferences about causality. In addition, in most studies neural functioning was examined only after, and not prior to, the stressful events. Thus, it is unclear whether neurobiological differences are an effect of the stressor or a continuation of pre-existing neural functioning. For example, in adults exposed to stress associated with military service, amygdala reactivity measured prior to exposure and reductions in hippocampal volume following exposure have both been shown to predict post-traumatic stress disorder-related symptoms (Admon et al., 2009; Admon et al., 2013).

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It is also unclear whether the effects of ELS and common life events on neurodevelopment are similar to those of natural disasters. In addition to their increasing impact on youth, research on natural disasters is important because their fateful nature provides a unique opportunity to elucidate the effects of environmental stress on neurodevelopment. Unlike ELS and most common life events, the occurrence of natural disasters are entirely outside participants' control, eliminating questions about the direction of causality and effects of third variables. However, due to their unforeseeable nature, data on neural structure and function are rarely available prior to the disaster. In the present study, we had the rare opportunity to build on a pre-existing study of child development in a region that was directly affected by a natural disaster, enabling us to extend our understanding of the association between a discrete and fateful environmental stressor and the development of neural systems associated with threat and reward.

Parenting

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Theoretical models (e.g. Bowlby, 1973) propose that the ways in which an individual is treated by caregivers during childhood produce internal working models of the self, others, and environment, which then guide how they think, feel, and behave in later contexts, particularly stressful ones. Positive parenting (warm, responsive, and instructive) communicates the availability and predictability of resources in the environment, promotes a child's perceived sense of mastery over the environment, and predicts a lower likelihood of youth developing a depressive disorder (Milevsky, Schlechter, Netter & Keehn, 2007). In contrast, negative parenting (highly critical, punitive, and intrusive) increases children's perceptions of, while also undermining their perceived sense of control over, environmental threats, and predicts high levels of anxiety disorders and avoidance-related behaviors (Hudson & Rapee, 2004). Thus, particular parenting styles may serve to exacerbate or buffer against the impact of stressful events, including natural disasters, on the neurodevelopment of threat and reward systems.

Indeed, studies aimed at determining predictors of vulnerability and resilience in children who have been exposed to stress and adversity support the key role of the caregiving environment on child development (Masten, 2001, Masten & Narayan, 2012). More specifically, bio-ecological models of disaster exposure in youth suggest that a child's susceptibility to disaster exposure and its biological correlates is influenced by salient features of the environment, like parenting (Weems, 2015). However, empirical studies in this area have focused on child symptom and functioning outcomes, rather than effects on neurodevelopment, and contextual measures have tended to focus on parental psychopathology and functioning rather than parenting styles and practices (e.g. Spell et al., 2008). Despite theoretical and empirical evidence that parenting, in comparison to caregiver adjustment, has a more direct influence on child adjustment in the context of stressful life circumstances (DeGarmo, Patterson & Forgatch, 2004), surprisingly very few studies of the effects of natural disasters on children have focused explicitly on parenting styles and practices. One study found that low levels of parental acceptance and higher levels of firm control were associated with increased anxiety symptoms in children after Hurricane Katrina (Costa, Weems & Pina, 2009).

Although no studies have examined the impact of parenting behaviors on neurodevelopment in the context of disasters, there is evidence that variation in parental care outside of extreme caregiving scenarios, such as severe deprivation and abuse, influences the neurodevelopment of reward and threat sensitivity. Higher levels of parental warmth have been associated with neural reactivity suggesting increased reward sensitivity and approach motivation (Bernier, Calkins & Bell, 2016, Euser et al., 2013). In contrast, higher levels of parental hostility and authoritarian parenting prospectively predicted an increased error-related negativity (ERN)—an event-related potential (ERP) indexing error monitoring, sensitivity to threat, and risk for anxiety—in children (Brooker & Buss, 2014; Meyer et al., 2015). These studies suggest that there is some specificity in how parenting influences the neurodevelopment of reward and threat systems, such that positive parenting is more tightly linked to the development of neural reactivity to reward, whereas negative parenting is more closely linked to the development of neural reactivity to threat.

Despite evidence that life stress and the caregiving milieu both influence the development of neural systems underlying reward and threat processing, only a handful of studies have brought together these areas of research to simultaneously examine the impact of stress and parenting on brain development. These studies sampled children from socioeconomically disadvantaged families, and the findings have been mixed. In one study, harsh parenting and greater neighborhood disadvantage had independent effects on distinct aspects of amygdala reactivity to angry, neutral, and fearful expressions (Gard et al., 2017). In another study, reductions in hippocampal volume associated with exposure to poverty were mediated by parenting characterized by low support/high hostility (Luby et al., 2013). In a third study, positive parenting was found to buffer the negative effects of disadvantage on frontal lobe development, suggesting that the caregiving context may influence how and whether stress impacts neurodevelopment (Whittle et al., 2017). However, given the established relationship between poverty and parenting behaviors (Blair et al., 2011), it may be necessary to examine stressful events that are relatively independent from parenting to resolve such discrepancies.

The aforementioned studies focused on positive and negative parenting practices in general, rather than parenting that directly promotes reward sensitivity/approach behaviors and threat sensitivity/avoidance behaviors. Promotion-oriented and prevention-oriented parenting styles are types of motivationally-based parenting styles that may be instrumental in shaping neural circuitry underlying reward and threat processing because they are characterized by the extent to which behavior is motivated to approach reward or to avoid threat when self-regulation is required (Higgins, 1997). Promotion-oriented parenting focuses on positive and desired outcomes while attempting to avoid the absence of positive opportunities like unrealized prospects or non-gains. Thus, children who receive high levels of promotion parenting may have a more resilient reward system and be less vulnerable in the face of stressful life events. In one study, higher promotion-focused parenting was shown to play protective role for children characterized by a heightened reactivity to negative stimuli during a fear-eliciting task (Kessel et al., 2013). Prevention-oriented parenting fosters threat sensitivity and focuses on safety and avoiding negative outcomes and losses, and may render a child's neural system supporting threat processing more vulnerable when stressful life events are unavoidable.

The current study

We extended prior research by leveraging an ongoing investigation of child development in a region that was directly affected by Hurricane Sandy, a Category 1 storm system that struck the New York tri-state area on October 25th, 2012 and was one of the costliest hurricanes in American history. Specifically, using a pre-post design, we examined the relationships of environmental stress and parenting style with changes in neural systems associated with reward and threat processing.

To examine reward and threat sensitivity, we measured the reward-related positivity (RewP) and the ERN (Bress et al., 2015; Meyer et al., 2013). The RewP is a positive deflection in the ERP signal over frontocentral sites that occurs approximately 300 ms after feedback indicating monetary gain that is absent or reduced for feedback indicating monetary loss (Gehring & Willoughby, 2002). The RewP is correlated with activation in reward-related brain regions, including ventral striatum and medial prefrontal cortex (Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011), as well as self-report and behavioral measures of reward sensitivity (Bress & Hajcak, 2013).

The ERN is a negative deflection in the ERP signal at frontocentral sites that occurs approximately 50 ms after the commission of an error. There is a general consensus that the ERN indexes the activity of a performance monitoring system that serves to adjust the individual's behavior to meet environmental demands, however, recent conceptualizations also point to the ERN's affective relevance and relationship to threat sensitivity (Proudfit, Inzlicht & Mennin, 2013). As the commission of an error prompts defense system activation (e.g. skin conductance response, pupil dilation, and potentiated startle reflex), and the ERN is correlated with these physiological indices as well as with anxiety symptoms and traits, it has been theorized to index threat reactivity (Hajcak, 2012). However, other theories provide competing explanations of the ERN's functional significance. For example, conflict monitoring theory suggests that the ERN is elicited by the detection and processing of

cognitive conflict (Gehring & Fencsik, 2001), and reinforcement learning theory (Holroyd & Coles, 2002) suggests that the ERN may have an evaluative function which signals when an event is worse than expected. However, these perspectives may not be mutually exclusive, as the negative affective experience of conflict motivates the immediate initiation of cognitive control (Inzlicht, Bartholow & Hirsch, 2015). Evidence from ERP source localization studies indicates that the ERN originates in the anterior cingulate cortex, a region of the frontostriatal system implicated in numerous complex functions including error and performance monitoring, decision-making, and punishment processing (Carter & van Veen, 2007). The ACC is comprised of two functional subdivisions: the dorsal, or cognitive, part which projects onto the motor cortex and prefrontal cortex (PFC), and the rostral, or affective, part which projects onto the amygdala, nucleus accumbens, hypothalamus, and insula (Carlson et al., 2013). While some studies have found that the dACC is the principal generator of the ERN, consistent with the notion that the ERN may be linked to more cognitive processes (Ridderinkhof et al., 2004), other studies have found the ERN to be generated by the rostral, or more affective, region of the ACC (Taylor et al., 2007) lending support to the view that variation in the ERN may reflect individual differences in the integration of affective and cognitive processes during error detection (Weinberg, Reisel & Hajcak, 2012).

Both ERP components demonstrate good internal consistency and test-retest reliability and are stable over a two-year period (Bress et al., 2015; Levenson et al., 2017; Meyer et al., 2014), suggesting that they reflect trait-like differences in reward and threat sensitivity, respectively. At the same time, the RewP and the ERN are also relatively malleable. Environmental influences like uncertainty have been shown to reduce the RewP (Nelson, Kessel, Jackson & Proudfit, 2015). Similarly, punishment (Riesel et al., 2012), uncertainty (Jackson, Nelson & Hajcak, 2015), and harsh parenting (Meyer et al., 2015) have been shown to enhance the ERN.

We hypothesized that Hurricane Sandy-related stress exposure would alter neural indices of children's reward sensitivity (RewP) and threat sensitivity (ERN). As parenting behaviors have been shown to influence whether and how stress impacts neurodevelopment (Whittle et al., 2017), and both stress and negative parenting styles enhance threat sensitivity (e.g. Brooker & Buss, 2014; Meyer et al., 2015), whereas stress and the absence of positive parenting styles diminish reward sensitivity (Bernier, Calkins & Bell, 2016; Euser et al., 2013), we also hypothesized that promotion and prevention parenting would moderate these associations. Specifically, we predicted that children who were exposed to high levels of hurricane-related stress would show reductions in the RewP, particularly in the context of low promotion-focused parenting, and increases in the ERN, particularly in the context of high prevention-focused parenting.

Method

Participants

The sample was derived from a larger longitudinal, community study of families with a 3-year old child (N = 609; Olino et al., 2010) initially recruited from commercial mailing lists. Children were eligible to participate in the larger study if they did not have a significant

medical condition or developmental disability and were living with at least one English-speaking biological parent.

Follow-up assessments are being conducted at 3-year intervals. Hurricane Sandy struck Long Island at the end the age 9 assessment allowing us to use it as a pre-disaster baseline. Six weeks after the hurricane, 347 mothers (80.5% of women whose children completed the age 9 assessment prior to Hurricane Sandy and still resided on Long Island when the hurricane struck) completed a 13-item webbased survey modeled on the impact of Hurricanes Ike (Norris, Sherrieb & Galea, 2010) and Katrina (Galea et al., 2007). The items covered experiences such as evacuation, damage to home, safety threatened, financial hardship, difficulty finding gasoline, difficulty getting food, water, or warmth, loss of power, and school closure. Total scores ranged from 0 to 11 ($M = 2.28$, $SD = 2.18$), and the scale showed adequate internal consistency ($\alpha = .73$; see Kopala-Sibley et al. 2016, for further details). Questionnaires were completed an average of 8.4 ($SD = 1.5$) weeks after the hurricane.

Eight to ten months after the hurricane, the 51 children from the lowest and 48 children from the highest ends of the exposure distribution were invited to the lab to repeat the pre-Sandy ERP assessments of the RewP and the ERN. The children also completed a questionnaire that retrospectively assessed perceived motivationally-relevant parenting styles. Of the 99 children, 16 were excluded from analyses based on the pre-Hurricane Sandy assessment EEG data¹ and additional 9 children were excluded from analyses based on post-Hurricane Sandy assessment EEG data.² Thus, the final analytic sample consisted of 74 children, 39 with low levels of stress exposure ($M = 1.03$, $SD = 0.74$) and 35 with high levels of stress exposure ($M = 5.83$, $SD = 2.02$).

Measures

Parenting.—The adolescent version of the *Regulatory Focus Questionnaire (RFQ)* (Higgins et al., 2001; Strauman et al., 2006) was administered to measure perceived promotion- and prevention-focused parenting over the child's lifetime. Items are rated on a 5-point scale, with 1 indicating "definitely false" and 5 indicating "definitely true". Scores on the three item approach-focused parenting scale (Cronbach's $\alpha = 0.63$) reflect the extent to which parents socialized youth to construe situations in terms of approach goals like being motivated by accomplishments and rewards. Scores on the four item avoidance-focused parenting scale ($\alpha = 0.71$) reflect the extent to which parents socialized children over their lifetime to construe situations in terms of avoidance goals like being motivated by possible punishment and feeling good about following rules.³

¹Nine children were excluded based on flanker EEG data (4 due to achieving an accuracy level of less than 55%; 1 due to having an ERP value more than 3 standard deviations from the overall mean data; and 4 due to poor quality EEG recordings) and 7 due to poor quality doors EEG recordings.

²Four were excluded based on flanker EEG data (1 due to technical error; 1 due to task refusal, 1 due to having 5 or fewer artifact-free trials; and 1 due to excessively noisy EEG data); and 5 were excluded due to poor quality doors EEG recordings.

³Principle components analyses (PCA) with a VARIMAX rotation on the RFQ led to some minor alterations to the scales originally proposed by Straumann and colleagues (2006). Item-loadings with values greater than .45 were used to create the factor scales. Results are virtually identical when we repeated the analyses with original scales constructed by Straumann and colleagues (2006). However, Cronbach's alphas for those scales were much poorer

Doors task.—At the pre- and post-Hurricane Sandy assessments, the RewP was measured using the doors task (for more details see: Foti & Hajcak, 2009), which has been shown to elicit a RewP with strong psychometric properties and good concurrent validity (Bress & Hajcak, 2013; Carlson et al., 2011; Levinson, Speed, Infantolino, & Hajcak, 2017). Participants were instructed to click either the left or right mouse button when presented with images of two doors, to guess which had a monetary prize. They were told they could win \$0.50 or lose \$0.25 on each trial and win up to \$5 total. At the beginning of each trial, participants were presented with images of two doors, which remained on the screen until the participant responded. Next, a fixation mark (+) appeared for 1000 ms, and feedback was presented for 2000 ms. A win was indicated by a green “↑”, and a loss, by a red “↓”. Thirty win and 30 loss trials were presented in a random order.

Flanker task.—At the pre- and post-Hurricane Sandy assessments, youth completed an arrow version of the Eriksen flanker task (Eriksen & Eriksen, 1974). On each trial, five horizontally aligned arrowheads were presented for 200 ms, followed by an intertrial interval that varied randomly between 2300 to 2800 ms. Half of the trials were compatible (“<<<<<” or “>>>>>”) and half were incompatible (“<<<<<” or “>><<>”); the order of trials was randomly determined. Participants were told to press the right mouse button if the center arrow was facing to the right and to press the left mouse button if the center arrow was facing to the left. Participants completed 11 blocks of 30 trials (330 trials total) and received feedback based on their performance at the end of each block.

EEG data acquisition and processing.—EEG was recorded using a 34-channel Biosemi ActiveTwo system based on the 10/20 system (32-channel cap with Iz and FCz added). Electrooculogram and mastoid activity were also recorded. During acquisition, the Common Mode Sense and the Driven Right Leg electrodes formed the ground electrode. The data were digitized at 24-bit resolution with a Least Significant Bit value of 31.25nV and a sampling rate of 1024 Hz, using a low-pass fifth order sinc filter with –3dB cutoff points at 208 Hz. Off-line analysis was performed using BrainVision Analyzer (Version 2.0.4; GmbH; Munich, DE; Brain Products). Data were converted to an average mastoid reference and were band-pass filtered with cutoffs of 0.01 and 30 Hz and 0.1 Hz and 30 Hz for the doors and flanker tasks, respectively. The EEG was segmented for each trial for the flanker task beginning 500 ms prior to the response and continuing for 800 ms after the response and for the doors task beginning 500 ms before feedback onset and continuing for 1000 ms after onset. The EEG was corrected for eye blinks (Gratton, Coles, & Donchin, 1983). Artifact rejection was completed using semi-automated procedures and the following criteria: a voltage step greater than 50 μ V between sample points, a voltage difference of 300 μ V within a trial, and a voltage difference of less than 0.50 μ V within 100 ms intervals. Visual inspection was used to remove remaining artifacts.

For the doors task, data were baseline corrected using the average activity in the 500 ms interval prior to feedback. At the pre- and post-Hurricane Sandy assessment, ERPs were separately averaged across gain and loss trials and were scored at a pooling of FCz and Cz between 275ms and 375 ms and 250 ms and 350 ms following feedback, when the gain minus loss difference waves were maximal at each assessment, respectively. The RewP

was calculated by subtracting the difference between the mean amplitude on gain relative to loss trials (see Figure 1).

For the flanker task, ERP averages were created for error and correct trials and a baseline average activity from –500 to –300 ms prior to the response was subtracted from each data point. For both the pre- and post-Hurricane Sandy assessments, the ERN and correct-related negativity (CRN) were scored as the average voltage in the window between 0 ms and 100 ms after response commission on error and correct trials, respectively, where the ERN minus CRN difference wave was maximal. Consistent with the scalp distribution of the difference wave, the CRN and ERN were quantified at a pooling of Fz, FCz, and Cz. The delta ERN (–ERN), thought to reflect error-specific activity, was calculated by subtracting the CRN from the ERN (see Figure 2).

Data analysis.—Hierarchical multiple regression analyses were computed to examine the effects of Hurricane Sandy-related stress exposure, promotion- and prevention-focused parenting, and the interactions between Hurricane Sandy-related stress exposure and parenting style on the RewP and the –ERN from pre- to post- Hurricane Sandy⁴.

Results

Table 1 displays descriptive statistics and bivariate correlations between all study variables.

Post-hurricane RewP.

There was a main effect of the pre-Hurricane Sandy RewP, such that a greater (i.e., more positive) RewP before Hurricane Sandy predicted a greater RewP after Hurricane Sandy (see Table 2). There were no significant main effects of the pre-Hurricane Sandy –ERN, Hurricane Sandy-related stress exposure, or promotion- or prevention-focused parenting on the post-Hurricane Sandy RewP. However, the interaction between Hurricane Sandy-related stress exposure and promotion-focused parenting significantly predicted the post-Hurricane Sandy RewP. Among children with high levels of Hurricane Sandy-related stress exposure, reduced promotion-focused parenting was associated with a decreased RewP post-Hurricane Sandy, $b=5.01$, $SE=1.79$, $t(34)=2.80$, $p<.001$. However, among children with low levels of Hurricane Sandy-related stress exposure, the association between promotion-focused parenting and the RewP was not significant, $b=-1.43$, $SE=1.11$, $t(38)=-1.28$, $p=.20$. There was no significant interaction between Hurricane Sandy-related stress exposure and prevention-focused parenting in relation to post-Hurricane Sandy RewP (see Figure 3).

Post-hurricane ERN.

There was a main effect of the pre-Hurricane Sandy –ERN, such that an enhanced –ERN before Hurricane Sandy predicted a larger –ERN after Hurricane Sandy (Table 2). There were no significant main effects of Hurricane Sandy-related stress exposure or promotion- or prevention-focused parenting on the post-Hurricane Sandy –ERN. However, the interaction between Hurricane Sandy-related stress exposure and prevention-focused parenting

⁴Results were identical when four separate models including each interaction each were run.

significantly predicted children's post-Hurricane Sandy ERN. As shown in Figure 3, among children with high levels of Hurricane Sandy-related stress exposure, greater prevention-focused parenting was associated with an enhanced ERN post-Hurricane Sandy, $b = -2.00$, $SE = .99$, $t(34) = -2.01$, $p < .05$. However, among children with low levels of Hurricane Sandy-related stress exposure, there was no association between avoidance-focused parenting and the ERN, $b = .31$, $SE = .89$, $t(38) = .35$, $p = .73$. There was no significant interaction between Hurricane Sandy exposure and promotion-focused parenting to predict the post-Hurricane Sandy ERN.

Discussion

The present study examined whether Hurricane Sandy-related stress exposure interacted with prevention- and promotion-focused parenting styles to influence the development of neural reward and threat processing. Among children with high levels of Hurricane Sandy-related stress, lower levels of promotion-focused, but not prevention-focused, parenting was associated with a decreased RewP after Hurricane Sandy. Moreover, among children with high levels of Hurricane Sandy-related stressors, higher prevention-focused, but not promotion-focused, parenting was associated with an increased ERN following the hurricane. In contrast, among children with low levels of Hurricane Sandy-related stress exposure, there were no significant associations between either prevention-focused or promotion-focused parenting with the RewP or the ERN, respectively, after Hurricane Sandy.

Previous research has indicated that both exposure to stress (e.g. Hanson et al., 2015) and parenting (e.g. Meyer et al., 2014) practices can have an impact on reward and threat processing. However, this is the first study to examine the joint impact of a fateful life event and parenting style on neural reward and threat processing. In contrast to previous studies, hurricane-related stress and parenting style were not significantly associated with neural reactivity to reward or threat on their own. Rather, the degree to which Hurricane-Sandy-related stressors impacted the development of neural reward and threat processing was contingent upon motivationally-relevant parenting styles. These results are consistent with a bio-ecological model (Weems, 2005), which proposes that an individual's susceptibility to stress from natural disasters depends on the social context.

Few studies (e.g., Swartz, Williamson & Hariri, 2015) have examined the effect of stress on neural reward and threat processing taking into account prior neural functioning. Moreover, previous studies of ELS and SLEs have examined stressors that could be confounded with participant behavior. By examining a fateful SLE in the context of an ongoing longitudinal study, we were able to both minimize the contribution of preexisting participant characteristics on the occurrence of the stressor and rule out the possibility that the observed effects reflected prior neural functioning. These are particularly timely findings given the paucity of research examining the effects of natural disasters on children's neural functioning (see Weems, 2015) and the increasing occurrence and severity of such events.

Consistent with our hypotheses, our results suggest that exposure to high levels of Hurricane-related stressors can enhance threat-related neural processes, but only when

parents demonstrate high levels of prevention-focused parenting. Such parenting is characterized by behaviors that foster threat sensitivity and emphasize focus on safety and avoiding negative outcomes and losses. Parents who exhibit this parenting style may inadvertently highlight dangerous and threatening aspects of stressors or may have socialized their children in a manner that increases their children's perception of threat associated with stressful events, making them vulnerable to stress-related neural changes that underlie enhanced threat processing.

Our results also suggest that high levels of exposure to hurricane-related stressors may attenuate a normative developmental increase in neural sensitivity to reward (as indicated by the RewP) as the children approach adolescence, but only when parents demonstrate low levels of promotion-focused parenting. Parenting that does not emphasize positive and desired outcomes may hinder children's abilities to detect appetitive and safety cues in the environment that may buffer against pernicious effects of stress. Interestingly, we also found that in the context of *high* levels of promotion-focused parenting, children who experienced high levels of exposure to hurricane-related stress exhibited an *increased* RewP following Hurricane Sandy. This suggests that promotion-focused parenting may not only serve as a protective factor but may also bolster resilience in the face of adversity. Emphasizing adventurous, competence-enhancing aspects of stressful situations may make challenges such as the lack of electricity and the suspension of routines such as going to school fun and exciting.

As the RewP can change in both directions depending on the degree of promotion-focused parenting a child receives in the context of a fateful life event, our findings raise the possibility that the RewP is somewhat plastic, or differentially susceptible (Belsky, 2016), to environmental inputs in a for-better-or-worse-manner. Based on evidence that late childhood is characterized by a global shift in cognition, motivation, and social behavior, Del Giudice (2014) has hypothesized that this shift is accompanied by heightened neural plasticity in which the brain is collecting input from the environment in order to promote development that serves to increase biological fitness within that milieu.

Youth who live through natural disasters experience higher rates of psychiatric problems that can continue into adulthood (Neria & Shultz, 2012). Altered neural reactivity to reward and threat may be two mechanisms through which disasters lead to adverse outcomes. A blunted

RewP and enhanced ERN are both prospectively associated with depressive and anxiety disorders in youth (Meyer et al., 2015; Nelson et al., 2016) and the ERN predicts increases in anxiety-related symptoms in response to stressful and traumatic life events (Meyer et al., 2017). It remains to be seen whether the present study's observed alterations in the RewP and ERN persist, and whether they relate to subsequent psychopathology and functioning. To address these questions, we will continue to study these children in order to examine the long-term impact of the disaster, parenting, and the role of altered neural reactivity to reward and threat and risk for psychopathology.

A limitation of the current study is that our parenting measure was assessed retrospectively after the hurricane and only through child report. In addition, although hurricane-related stress exposure was unrelated to measures of parenting style, the RewP and the ERN,

relying solely on parent report of stress exposure could have introduced some individual differences in perception on the assessment of a fateful event. Finally, the sample size is modest and drawn from one region of the US after a singular disaster. Replication studies using larger samples from other regions experiencing different fateful events are needed to expand our understanding of the complex relationships found in this study.

In sum, the present study provides novel evidence that motivationally-relevant parenting styles (children's perceptions of promotion-focused and prevention-focused parenting) and exposure to natural disaster-related stress interact to alter neural reactivity to reward and threat in children. These findings highlight the importance of considering the parenting context when examining the effects of significant events on neural activity. They also point to the possibility that motivationally-relevant parenting behaviors may be a potential intervention target to prevent stress-related alterations in reward- and threat-related neural processes in youth exposed to major life events.

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Figure 1. Topographic map of activity of the RewP (gain minus loss) on the left; and stimulus-locked ERP waveforms for gain and loss trials, as well as the difference waves at electrodes FCz and Cz on the right at the pre- (top) and post- (bottom) Hurricane Sandy assessments.

Figure 2.

Topographic map of activity of the ERN (error minus correct) on the left; and response-locked ERP waveforms for correct and error trials, as well as the difference waves at electrodes Fz, FCz and Cz on the right at the pre- (top) and post- (bottom) Hurricane Sandy assessments.

Figure 3.

Significant interactions between hurricane exposure and promotion-focused parenting and prevention-focused parenting in predicting the RewP (top) and ERN (bottom) post-Hurricane Sandy. Low and high promotion- and prevention-focused parenting are one standard deviation above and below the mean. Hurricane Sandy-related stress exposure is plotted as the moderator variable because it is dichotomous, however hypotheses focus on promotion and prevention parenting moderating the effects of Hurricane Sandy. RewP = reward positivity; ERN = error-related negativity.

Table 1
Descriptive Statistics and Pearson's Correlations/Phi Coefficients between Variables

	1	2	3	4	5	6	7	8	9	10
1. Male Gender (48.6%)	—	.16	.06	.03	-.20	-.13	.14	-.06	.24*	-.02
2. High Sandy Exposure(47.3%)		—	-.11	-.11	.02	.13	.03	.04	.07	.06
3. Pre-Sandy Age			—	.63***	-.28*	-.11	.01	.07	-.16	-.19
4. Post-Sandy Age				—	-.07	-.03	.20	.06	-.02	-.07
5. Prevention Parenting					—	.26**	.14	-.03	.07	.23*
6. Promotion Parenting						—	.11	-.01	.19	.17
7. Pre-Sandy ERN							—	.34**	.01	-.03
8. Post-Sandy ERN								—	.17	-.02
9. Pre-Sandy RewP									—	.38**
10 Post-Sandy RewP										—
	<i>M(SD)</i>	9.16(.35)	10.9(.75)	3.10(.70)	4.24(.87)	-3.52(4.59)	-4.40(4.58)	5.09(8.43)	6.00(7.37)	
	Range	8.83-10.67	9.58-12.42	1.5-5	1-5	-15.11-5.06	-16.93-5.15	-12.45-23.62	-12.33-22.53	

 $p < .001$

**
 $p < .01$

*
 $p < .05$

RewP = reward positivity; ERN = error-related negativity.

† Pearson's correlations were calculated to examine associations involving at least 1 continuous variable; phi coefficients were calculated to evaluate associations between 2 categorical variables

Table 2

Hierarchical regression analyses regressing Hurricane Sandy-related stress exposure, parenting style and their interaction on the post-Hurricane Sandy RewP(top) and ERN(below)

<i>RewP</i>		
	<i>Entry β</i>	<i>Partial r</i>
Step 1	$F(6,73) = 2.70, R^2 = .20^*$	
Male Gender	-.07	-.05
Sandy Exposure	.04	.01
Pre-Sandy RewP	.38**	.35**
Pre-Sandy ERN	-.04	-.10
Promotion Parenting	.04	-.16
Prevention Parenting	.18	.15
Step 2	$F(2,65) = 5.79, R^2 = .12^{**}$	
Sandy Exposure X Promotion Parenting	.53**	.39**
Sandy Exposure X Prevention Parenting	-.23	-.16
<i>Total Model $F(8,73) = 3.77, R^2 = 0.32^{**}$</i>		
<i>ERN</i>		
	<i>Entry β</i>	<i>Partial r</i>
Step 1	$F(6,73) = 2.72, R^2 = .20^*$	
Male Gender	-.22	-.23
Sandy Exposure	.08	.06
Pre-Sandy RewP	.24*	.20
Pre-Sandy ERN	.40***	.31***
Promotion Parenting	-.10	-.14
Prevention Parenting	-.12	.05
Step 2	$F(2,65) = 2.94, R^2 = .07$	
Sandy Exposure X Promotion Parenting	.27	.20
Sandy Exposure X Prevention Parenting	-.41*	-.28*
<i>Total Model $F(8,73) = 2.89, R^2 = 0.26^{**}$</i>		

 $p < .001$

**
 $p < .01$

*
 $p < .05$

RewP = reward positivity; ERN = error-related negativity