

# Neural Reactivity to Emotional Stimuli Prospectively Predicts the Impact of a Natural Disaster on Psychiatric Symptoms in Children

Autumn Kujawa, Greg Hajcak, Allison P. Danzig, Sarah R. Black, Evelyn J. Bromet, Gabrielle A. Carlson, Roman Kotov, and Daniel N. Klein

## ABSTRACT

**BACKGROUND:** Natural disasters expose entire communities to stress and trauma, leading to increased risk for psychiatric symptoms. Yet, the majority of exposed individuals are resilient, highlighting the importance of identifying underlying factors that contribute to outcomes.

**METHODS:** The current study was part of a larger prospective study of children in Long Island, New York ( $n = 260$ ). At age 9, children viewed unpleasant and pleasant images while the late positive potential (LPP), an event-related potential component that reflects sustained attention toward salient information, was measured. Following the event-related potential assessment, Hurricane Sandy, the second costliest hurricane in United States history, hit the region. Eight weeks after the hurricane, mothers reported on exposure to hurricane-related stress and children's internalizing and externalizing symptoms. Symptoms were reassessed 8 months after the hurricane.

**RESULTS:** The LPP predicted both internalizing and externalizing symptoms after accounting for prehurricane symptomatology and interacted with stress to predict externalizing symptoms. Among children exposed to higher levels of hurricane-related stress, enhanced neural reactivity to unpleasant images predicted greater externalizing symptoms 8 weeks after the disaster, while greater neural reactivity to pleasant images predicted lower externalizing symptoms. Moreover, interactions between the LPP and stress continued to predict externalizing symptoms 8 months after the hurricane.

**CONCLUSIONS:** Results indicate that heightened neural reactivity and attention toward unpleasant information, as measured by the LPP, predispose children to psychiatric symptoms when exposed to higher levels of stress related to natural disasters, while greater reactivity to and processing of pleasant information may be a protective factor.

**Keywords:** Event-related potentials, Externalizing, Internalizing, Natural disaster, Stress, Vulnerability

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Exposure to stress in childhood and adolescence prospectively predicts increases in both internalizing and externalizing symptoms across development [for a review (1)]. At the same time, most children experience some level of stress and remain resilient; thus, identifying vulnerability factors that moderate the association between stress and the development of psychopathology is of paramount public health importance (2,3).

Natural disasters are one stressor linked to increased risk of both internalizing (e.g., posttraumatic stress, depression, anxiety) and externalizing symptoms (e.g., oppositional and aggressive behavior) that may persist for months or even years after the disaster (4–11). Individuals who experience a greater number of disaster-related stressors tend to exhibit higher levels of symptoms (10,12,13). Nonetheless, only a minority of those exposed to natural disasters will develop serious psychological symptoms (14).

Natural disasters are circumscribed in time and affect entire communities; thus, they are less likely than other stressors to

be confounded with pre-existing child and family characteristics. Examining children exposed to disasters can provide insights into neural mechanisms underlying risk and resilience (15,16). However, as disasters typically occur with little warning, it is often impossible to determine whether factors that moderate children's responses reflect vulnerabilities that predispose to symptoms or consequences of stress exposure.

Most studies have focused on psychosocial factors that influence reactivity to stress in youth experiencing natural disasters. For example, child temperament and symptoms of psychopathology before the disaster predict symptoms following the disaster (13,15,17,18). In addition, social influences contribute to responses to disasters: greater social support is a protective factor, whereas negative family dynamics predict poorer outcomes (11,18,19).

A few prospective functional magnetic resonance imaging (fMRI) studies have evaluated neural processes that predispose to developing symptoms in response to trauma, including war and terrorism (20,21) and general life stress (22) but

not natural disasters. The little existing evidence suggests that amygdala hyperreactivity to threat may contribute to risk (20–22). For example, in a small fMRI study of adolescents, greater amygdala reactivity to threatening images prospectively predicted increased posttraumatic stress symptoms after the Boston Marathon bombing (20). In addition, a large fMRI study of adults indicated that greater amygdala reactivity to threat interacted with stressful life events 1 to 4 years later to predict increased internalizing symptoms (22).

The late positive potential (LPP) is an event-related potential (ERP) component that provides a neural measure of emotional processing that can be reliably assessed across development (23). The LPP is a relative positivity in the ERP that begins as early as 200 ms after stimulus onset and is increased for emotional compared with neutral stimuli; this emotional modulation of the LPP is pronounced throughout the duration of picture presentation and reflects sustained attention toward motivationally salient information (24–26).

Abnormalities in the LPP are associated with internalizing disorders, such as anxiety and depression (27–33), as well as externalizing symptoms in both youth and adults (34,35). Cross-sectional research suggests the LPP may measure emotional processing styles that contribute to vulnerability for psychopathology. For example, offspring of parents with fear disorders (i.e., panic disorder, social anxiety disorder, and specific phobia) and children with fearful temperament showed enhanced LPPs to unpleasant stimuli (36,37). In addition, blunted LPPs to emotional stimuli have been observed in youth at risk for depression based on both parental history of depression and temperament style (37–39). Importantly, there is evidence that individual differences in processing and coping with emotions contribute to children's responses to stress (40), suggesting that the magnitude of the LPP may moderate effects of stress on the development of symptoms. However, no research has investigated whether neural processing of emotion, as measured by the LPP, prospectively predicts changes in symptoms in children, either alone or in conjunction with stress.

The current study examined neural reactivity to emotional images as a vulnerability for psychiatric symptoms following a natural disaster. Hurricane Sandy struck the Long Island, New York, region on October 29, 2012, destroying 100,000 homes, and is estimated to be the second costliest hurricane in United States history, after Hurricane Katrina (41). As part of a pre-existing study, a large sample of 9-year-old children completed an emotional processing task in which ERPs were recorded as participants viewed pleasant, neutral, and unpleasant images prior to the hurricane. In addition, mothers reported on child internalizing and externalizing symptoms. Approximately 8 weeks after Hurricane Sandy, participants' mothers completed a questionnaire assessing exposure to hurricane-related stressors and children's symptoms. To assess long-term impact, mothers completed questionnaires again approximately 8 months after the hurricane. We evaluated neural reactivity to emotional images (i.e., LPP) as a prospective predictor of symptoms after the hurricane, both as a main effect and as an interaction with hurricane-related stress. We hypothesized that an enhanced LPP to unpleasant images would predict a greater increase in symptoms and, consistent with vulnerability-stress models (3), that these effects

would be most apparent among children who experienced higher levels of stress. Additional exploratory analyses evaluated whether the LPP to pleasant images also predicted symptoms.

## METHODS AND MATERIALS

### Participants

Participants were 9- to 12-year-olds from a larger prospective community sample of children, initially recruited between 3 to 6 years old. All children living with at least one English-speaking biological parent and free of significant medical or developmental disabilities were eligible (42). A total of 323 children completed the emotional interrupt electroencephalogram (EEG) task and prehurricane symptom measures, were in the area at the time of Hurricane Sandy, and completed the 8-week posthurricane questionnaire. Of these participants, 63 were excluded for excessively noisy EEG data; fewer than 15 correct, artifact-free trials per condition; and/or poor accuracy (<65%) on the emotional interrupt task. The excluded sample had higher mother-reported internalizing ( $t_{321} = 2.70, p = .01$ ; mean difference = 2.47) and externalizing symptoms ( $t_{321} = 3.13, p < .01$ ; mean difference = 2.93) than the included sample before the hurricane, and the groups continued to differ on symptoms at the initial posthurricane assessment ( $p < .05$ ) but did not significantly differ on hurricane-related stress ( $p = .16$ ). The final sample included 260 children with a mean age of 9.16 (SD = .34) at the EEG assessment and 10.41 (SD = .78) at the 8-week posthurricane assessment. Participants were 45.8% female; 89.6% Caucasian, 6.9% African American, 3.1% Asian, and .4% Native American; 8.1% identified as Hispanic/Latino.

### Procedure

Study protocols were approved by the Institutional Review Board at Stony Brook University. Informed consent was obtained from all parents and verbal assent was obtained from children. Participants and one parent visited the laboratory as close as possible to the child's ninth birthday to complete the EEG assessment and measures of the child's symptoms. Following the hurricane, mothers were asked to complete an online questionnaire to assess hurricane-related stressors and the child's symptoms. On average, these questionnaires were completed 8.52 weeks (SD = 1.55) following the hurricane and 53.58 weeks (SD = 31.69) after the EEG assessment. Seven months after the hurricane, mothers were again asked to report on current child symptoms. On average, this questionnaire was completed 7.69 months (SD = .81) after the hurricane (58 mothers did not complete the follow-up questionnaire, leaving data for 202 children).

### Measures

**Emotional Interrupt Task.** Before the hurricane, participants completed a version of the emotional interrupt paradigm (43,44) previously used to measure the LPP in youth (37,45). Sixty developmentally appropriate pictures from the International Affective Picture System (46) were presented: 20 pleasant images (e.g., children playing, cute animals), 20 neutral images (e.g., people in neutral situations, household

objects), and 20 unpleasant or threatening images (e.g., sad/angry people, aggressive animals, weapons). See [Supplement](#) for image numbers. Each image was randomly presented once in each of two blocks for a total of 120 trials. Each trial began with an 800-ms fixation, then an image for 1000 ms followed by a target for 150 ms and the same picture for an additional 400 ms. The target was an arrow pointed to the left or right, and participants pressed the left or right mouse button to indicate the direction of the arrow. Intertrial interval varied randomly between 1500 and 2000 ms.

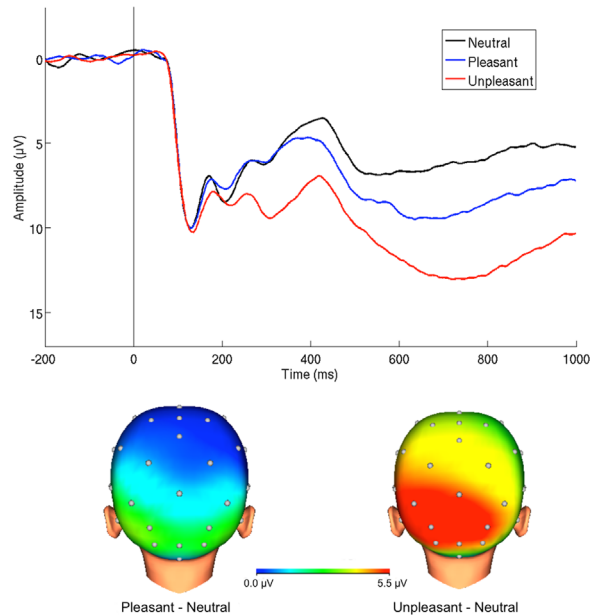
### Electroencephalogram Data Acquisition/Analysis.

EEG was recorded using a 34-channel Biosemi system (32 channel cap plus Iz and FCz; 10/20 system; Biosemi, Amsterdam, The Netherlands). Ground electrode was formed by the common mode sense and driven right leg electrodes. Two electrodes were placed on the left/right mastoids, and electrooculogram was recorded from facial electrodes 1 cm above and below the right eye, 1 cm to the left of the left eye, and 1 cm to the right of the right eye. Data were digitized at 24-bit resolution with a least significant bit value of 31.25 nV and a sampling rate of 1024 Hz, using a low-pass fifth order sinc filter with  $-3$  dB cutoff points at 208 Hz.

Offline analysis was performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). Data were converted to an averaged mastoid reference, band-pass filtered from .1 to 30 Hz, segmented for each trial 200 ms before picture onset to 1000 ms after onset. Data were corrected for eye blinks (47), and artifacts were removed using semiautomated procedures to identify voltage step of more than  $50 \mu\text{V}$  between sample points, voltage difference of  $300 \mu\text{V}$  within a trial, and voltage difference of less than  $.50 \mu\text{V}$  within 100-ms intervals. Visual inspection was used to remove additional artifacts. Data were baseline corrected to 200 ms before stimulus onset.

ERPs were averaged across unpleasant, pleasant, and neutral trials. To ensure that children were attending to the images, only correct trials were included in averages. The LPP was scored as the mean amplitude where the differences between emotional and neutral images were maximal (Figure 1): 400 to 1000 ms after feedback at a pooling of occipital and parietal sites (O1, O2, Oz, PO3, PO4, P3, P4, Pz) (29). The emotional (pleasant or unpleasant) minus neutral difference score was computed and used for analyses to isolate neural activity modulated by emotional content.

**Hurricane-Related Stress.** Mothers completed a 13-item questionnaire assessing experiences that are common during hurricane-related disasters with potential impacts on children. The items were drawn from questionnaires administered in studies of Hurricane Ike (48) and Hurricane Katrina (49). Reports of hurricane-related experiences have previously been demonstrated to be stable across time (50). Eight items (life disrupted by hurricane, children fearing for safety, difficulty finding food or warmth, difficulty finding gasoline, children complaining more than usual, damage to home or possessions, family's safety threatened, and financial hardship) were rated on a 5-point scale (1 = not at all affected; 5 = extremely affected). Two items were rated on duration (time school was closed, time without power), and three items were rated as



**Figure 1.** Event-related potentials (negative up) at occipitoparietal sites and scalp distributions depicting reactivity to emotional compared with neutral images 400 to 1000 ms after onset in the overall sample.

present/absent (evacuating the home, using Federal Emergency Management Agency services, and injury or robbery of family or friends). To create an overall sum of exposure severity (ranging from 0 to 13), nondichotomous items were rescored such that 1 = present and 0 = absent. For items rated on a 5-point scale, scores of 3+ indicating moderate-extreme difficulty were scored as 1. Very commonly endorsed items (i.e., life disrupted, difficulty finding gasoline) required a higher threshold (scores of 4+ and 5+, respectively) to be scored as present to ensure sufficient variability. For duration items, scores indicating 1 week or longer were scored as 1. The final scale demonstrated good internal consistency (Cronbach's  $\alpha = .72$ ).

**Child Psychiatric Diagnoses and Symptoms.** For rates of prehurricane clinical disorders, one parent and the child were interviewed by advanced clinical psychology doctoral students or Master's level clinicians using the Schedule of Affective Disorders and Schizophrenia for School-Age Children (51) at the age 9 assessment [see (52) for more information].

To measure change in symptoms, mothers completed the Child Behavior Checklist (CBCL), a 113-item parent-report measure of behavioral and emotional problems in children (53). To measure the broad range of possible reactions in children following a disaster, analyses focused on the higher order externalizing and internalizing scales. Mothers completed the CBCL on three occasions: age 9 assessment to control for prehurricane symptoms, approximately 8 weeks after the hurricane, and approximately 8 months following the hurricane.

### Data Analysis

Hierarchical regression analyses were computed to examine predictors of symptoms following Hurricane Sandy. Variables

were centered to evaluate interactions. Prehurricane internalizing and externalizing symptoms and child sex were entered into step 1, followed by main effects of hurricane-related stress, unpleasant and pleasant LPP in step 2, and interactions between stress and LPP in step 3. To account for nonnormality and heteroscedasticity in CBCL symptoms, we computed heteroscedasticity-consistent standard errors and *p* values (HC3) (54) for all regression analyses.

## RESULTS

### Clinical Characteristics

At the assessment before the hurricane, 15.4% (*n* = 40) of the sample met current criteria for an internalizing or externalizing disorder. Specifically, .4% had depression, 8.8% anxiety (.8% separation anxiety disorder, 2.3% social anxiety disorder, 3.8% specific phobia, 3.1% generalized anxiety disorder), 6.5% attention-deficit/hyperactivity disorder, 1.5% oppositional defiant disorder, and .4% conduct disorder.

Descriptive statistics and correlations between measures are presented in Table 1. Both externalizing,  $t_{259} = 7.09, p < .001$ , and internalizing,  $t_{259} = 5.92, p < .001$ , symptoms decreased from prehurricane to posthurricane, possibly due to repeated administration of the questionnaire (55), indicating that the hurricane did not increase symptoms overall. Rates of borderline or clinical levels of symptoms on externalizing and internalizing CBCL scales at the 8-week posthurricane assessment were 4.2% and 4.6%, respectively. Male subjects exhibited higher posthurricane externalizing symptoms than female subjects, but sex was not related to prehurricane externalizing symptoms or to internalizing symptoms at any assessment. Externalizing and internalizing symptoms were moderately to strongly correlated at each assessment and across time. Associations between hurricane-related stress and internalizing and externalizing symptoms 8 weeks following the hurricane were modest but significant.

### Behavioral Measures

Accuracy was lower for both unpleasant (mean [*M*] = 84.8%, SD = 8.98) and pleasant (*M* = 84.9%, SD = 9.12) compared with neutral trials (*M* = 89.0%, SD = 7.53) ( $t_{259} = 8.75, p < .001$  and  $t_{259} = 8.30, p < .001$ , respectively). Reaction time (RT) was longer for both unpleasant (*M* = 610.31 ms, SD = 154.05) and pleasant (*M* = 609.91 ms, SD = 151.40) compared with neutral trials (*M* = 581.17 ms, SD = 139.57) ( $t_{259} = 10.04, p < .001$  and  $t_{259} = 10.34, p < .001$ , respectively). Hierarchical multiple regression analyses were computed to evaluate whether emotional interference on behavioral responses (e.g., unpleasant RT minus neutral RT) predicted symptoms following the hurricane. None of the main effects of RT or accuracy or interactions with stress were significant in predicting symptoms ( $ps > .12$ ).

### LPP Predicting Posthurricane Symptoms

Results of multiple regression analyses to evaluate effects of the LPP on symptoms 8 weeks following the hurricane are presented in Table 2. For externalizing symptoms, the main effects of stress, unpleasant LPP, and pleasant LPP were significant but were qualified by significant stress × unpleasant LPP,  $t_{259} = 2.71, p < .01$ , and stress × pleasant LPP,  $t_{259} = -2.85, p < .01$ , interactions. An enhanced unpleasant LPP predicted greater externalizing symptoms with high (+1 SD) stress (simple slope = .21, SE = .06,  $t = 3.73, p < .001$ ) and average stress (simple slope = .11, SE = .03,  $t = 3.44, p < .001$ ) but not low (−1 SD) stress ( $p = .63$ ). An enhanced pleasant LPP predicted lower externalizing symptoms with high (simple slope = −.23, SE = .07,  $t = -3.48, p < .001$ ) and average stress (simple slope = −.12, SE = .04,  $t = -2.67, p < .001$ ) but not low stress ( $p = .90$ ) (Figures 2 and 3).

For internalizing symptoms, more hurricane-related stress,  $t_{259} = -2.37, p = .02$ , and larger LPPs to unpleasant stimuli,  $t_{259} = 2.12, p = .04$ , predicted greater symptoms. The stress × unpleasant LPP interaction approached significance for internalizing symptoms ( $p < .10$ ). See the Supplement for analyses of CBCL subscales and scatter plots.

**Table 1. Descriptive Statistics and Bivariate Correlations Between Study Variables**

	1	2	3	4	5	6	7	8	9	10
1 Sex	–									
2 Prehurricane CBCL-EXT	−.06	–								
3 Prehurricane CBCL-INT	.01	.48 <sup>a</sup>	–							
4 Hurricane Stress	−.07	.10	.00	–						
5 Unpleasant LPP	−.01	.00	−.08	.06	–					
6 Pleasant LPP	.01	−.01	−.07	.01	.49 <sup>a</sup>	–				
7 Posthurricane CBCL-EXT	−.15 <sup>b</sup>	.56 <sup>a</sup>	.25 <sup>a</sup>	.19 <sup>c</sup>	.09	−.10	–			
8 Posthurricane CBCL-INT	−.03	.27 <sup>a</sup>	.42 <sup>a</sup>	.18 <sup>c</sup>	.09	−.05	.66 <sup>a</sup>	–		
9 8-Month CBCL-EXT	−.17 <sup>b</sup>	.63 <sup>a</sup>	.36 <sup>a</sup>	.04	.02	−.14 <sup>b</sup>	.82 <sup>a</sup>	.46 <sup>a</sup>	–	
10 8-Month CBCL-INT	−.10	.39 <sup>a</sup>	.60 <sup>a</sup>	.03	.02	−.09	.55 <sup>a</sup>	.63 <sup>a</sup>	.65 <sup>a</sup>	–
M (SD)		3.97 (4.59)	3.45 (4.24)	2.38 (2.30)	5.53 (6.53)	2.34 (6.37)	2.20 (3.81)	1.95 (3.20)	2.55 (4.31)	2.05 (3.44)

CBCL-EXT, Child Behavior Checklist Externalizing Scale; CBCL-INT, Child Behavior Checklist Internalizing Scale; LPP, late positive potential; M, mean.

<sup>a</sup>*p* < .001.

<sup>b</sup>*p* ≤ .05.

<sup>c</sup>*p* < .01.

To evaluate whether effects were driven by children with clinical disorders before the hurricane, we computed these models excluding 40 children with clinical diagnoses before the hurricane. Both the stress  $\times$  unpleasant LPP,  $b = .04$ ,  $t_{219} = 2.40$ ,  $p = .02$ , and stress  $\times$  pleasant LPP,  $b = -.04$ ,  $t_{219} = -2.18$ ,  $p = .03$ , interaction effects on externalizing symptoms remained significant.

Given evidence of developmental changes in the scalp distribution of the LPP (23), we also evaluated the LPP prediction models separately for the LPP at parietal (P3, P4, and Pz) and occipital (O1, O2, and Oz) sites. The stress  $\times$  unpleasant LPP and stress  $\times$  pleasant LPP interactions were significant for externalizing symptoms at both parietal and occipital sites (Supplement). For internalizing symptoms, the stress  $\times$  unpleasant LPP interaction reached significance at occipital,  $b = .04$ ,  $t_{259} = 2.03$ ,  $p = .04$ , but not parietal sites. An enhanced unpleasant LPP at occipital sites predicted greater internalizing symptoms at high (simple slope = .17, SE = .06,  $t = 2.71$ ,  $p < .01$ ) and average (simple slope = .08, SE = .03,  $t = 2.61$ ,  $p < .01$ ) but not low levels of stress ( $p = .98$ ) (Figure 4).

We also examined models controlling for income and time between the age 9 and hurricane assessments with no substantive change in results, and additional exploratory analyses examined interactions with sex and the LPP to neutral images (Supplement).

### LPP Predicting Symptoms 8 Months Following the Hurricane

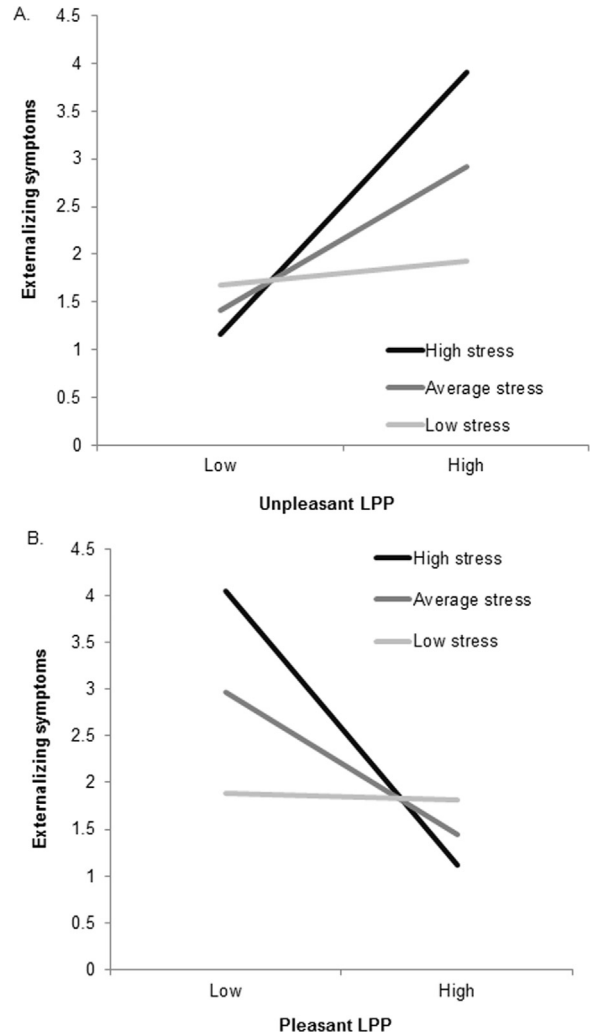
Models evaluating long-term impact on symptoms 8 months following the hurricane are presented in Table 3. The main

**Table 2. Hierarchical Multiple Regression Analyses Prospectively Predicting Symptoms Following Hurricane Sandy (n = 260)**

Predictor	Posthurricane CBCL-EXT			Posthurricane CBCL-INT		
	$\Delta R^2$	$\beta$	b (HC-SE)	$\Delta R^2$	$\beta$	b (HC-SE)
Step 1	.33			.18		
Sex		.12	.89 (.38) <sup>a</sup>	.03	.20 (.37)	
Prehurricane CBCL-INT		-.01	-.01 (.06)	.38	.29 (.13) <sup>a</sup>	
Prehurricane CBCL-EXT		.56	.46 (.09) <sup>b</sup>	.09	.06 (.06)	
Step 2	.04			.05		
Hurricane stress		.12	.20 (.09) <sup>a</sup>	.16	.23 (.10) <sup>a</sup>	
Unpleasant LPP		.16	.10 (.03) <sup>c</sup>	.16	.08 (.04) <sup>a</sup>	
Pleasant LPP		-.17	-.10 (.04) <sup>a</sup>	-.10	-.05 (.04)	
Step 3	.03			.03		
Stress $\times$ unpleasant LPP		.15	.04 (.015) <sup>c</sup>	.17	.04 (.025) <sup>d</sup>	
Stress $\times$ pleasant LPP		-.19	-.05 (.02) <sup>c</sup>	-.12	-.03 (.02)	
Total Model	.40			.25		

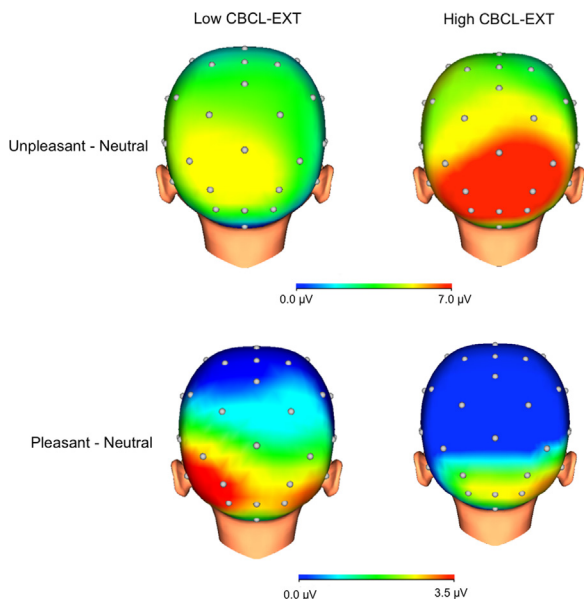
CBCL-EXT, Child Behavior Checklist Externalizing Scale; CBCL-INT, Child Behavior Checklist Internalizing Scale; HC-SE, heteroscedasticity-consistent standard error; LPP, late positive potential.

<sup>a</sup> $p \leq .05$ .  
<sup>b</sup> $p < .001$ .  
<sup>c</sup> $p < .01$ .  
<sup>d</sup> $p < .10$ .



**Figure 2.** Interactions between stress and unpleasant late positive potential (LPP) predicting externalizing symptoms following the hurricane (A), and stress and pleasant LPP predicting externalizing symptoms following the hurricane (B).

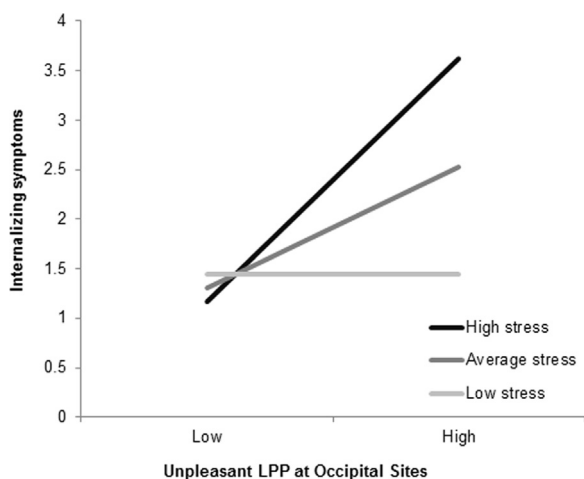
effects of stress reported 8 weeks after the hurricane were no longer significant in predicting symptoms ( $ps > .80$ ). Both the stress  $\times$  unpleasant LPP,  $t_{201} = 2.15$ ,  $p = .03$ , and stress  $\times$  pleasant LPP,  $t_{201} = -1.98$ ,  $p < .05$ , interactions remained significant predictors of externalizing symptoms. Similar to the earlier assessment, an enhanced unpleasant LPP predicted greater externalizing symptoms with high (simple slope = .21, SE = .07,  $t = 3.11$ ,  $p < .01$ ) and average stress (simple slope = .11, SE = .05,  $t = 2.44$ ,  $p = .02$ ) but not low stress ( $p = .86$ ). An enhanced pleasant LPP continued to predict lower externalizing symptoms at high (simple slope =  $-.23$ , SE = .07,  $t = -3.16$ ,  $p < .01$ ) and average stress (simple slope =  $-.14$ , SE = .05,  $t = -2.62$ ,  $p < .01$ ) but not low stress ( $p = .50$ ). None of the LPP effects reached significance for internalizing symptoms, though the main effect of unpleasant LPP approached significance ( $p = .08$ ).



**Figure 3.** Scalp distributions depicting reactivity to unpleasant (top) and pleasant (bottom) compared with neutral images among children with high (above median) exposure to stress. Children on the left exhibited low (below median) externalizing symptoms (Child Behavior Checklist Externalizing Scale [CBCL-EXT]) after the hurricane controlling for symptoms before the hurricane ( $n = 37$ ), whereas children on the right exhibited high (above median) CBCL-EXT symptoms ( $n = 38$ ).

### DISCUSSION

The current study evaluated neural reactivity to pleasant and unpleasant images as a prospective predictor of children’s symptoms after Hurricane Sandy. A larger LPP to unpleasant images predicted greater internalizing and externalizing symptoms 8 weeks after the hurricane, whereas an enhanced LPP to pleasant images predicted lower externalizing symptoms. Moreover, the LPP interacted with hurricane-related stress to



**Figure 4.** Interaction between stress and unpleasant late positive potential (LPP) scored at occipital sites (O1, O2, Oz) predicting externalizing symptoms following the hurricane.

**Table 3. Hierarchical Multiple Regression Analyses Prospectively Predicting Symptoms 8 Months After the Hurricane ( $n = 202$ )**

Predictor	8-Month Follow-up CBCL-EXT			8-Month Follow-up CBCL-INT		
	$\Delta R^2$	$\beta$	$b$ (HC-SE)	$\Delta R^2$	$\beta$	$b$ (HC-SE)
Step 1	.41			.38		
Sex		.10	.84 (.49) <sup>a</sup>		.07	.50 (.40)
Prehurricane CBCL-INT		.08	.09 (.10)		.55	.48 (.09) <sup>b</sup>
Prehurricane CBCL-EXT		.57	.53 (.10) <sup>b</sup>		.11	.08 (.06)
Step 2	.03			.01		
Hurricane stress		-.01	-.02 (.09)		.01	.02 (.09)
Unpleasant LPP		.14	.10 (.05) <sup>c</sup>		.13	.07 (.04) <sup>a</sup>
Pleasant LPP		-.19	-.13 (.05) <sup>c</sup>		-.12	-.06 (.05)
Step 3	.01			.01		
Stress $\times$ unpleasant LPP		.13	.04 (.02) <sup>c</sup>		.10	.02 (.02)
Stress $\times$ pleasant LPP		-.14	-.04 (.02) <sup>c</sup>		-.10	-.02 (.02)
Total Model	.45			.40		

CBCL-EXT, Child Behavior Checklist Externalizing Scale; CBCL-INT, Child Behavior Checklist Internalizing Scale; HC-SE, heteroscedasticity-consistent standard error; LPP, late positive potential.

- <sup>a</sup> $p < .10$ .
- <sup>b</sup> $p < .001$ .
- <sup>c</sup> $p \leq .05$ .

predict changes in externalizing symptoms. For children exposed to higher levels of stress, enhanced reactivity to unpleasant images predicted greater symptoms, and enhanced reactivity to pleasant images predicted lower externalizing symptoms. Interactions between the LPP and stress were most apparent for externalizing, rather than internalizing, symptoms, with the interaction between stress and unpleasant LPP only reaching significance for internalizing symptoms when scored at occipital sites. Both unpleasant and pleasant LPPs continued to predict long-term effects on externalizing symptoms 8 months after the hurricane, though effects were no longer apparent for internalizing symptoms. Importantly, the effects of the LPP in predicting symptoms were apparent at both high and average stress exposure, indicating that neural processing of emotional information shapes responses to even moderate levels of stress.

The LPP reflects sustained attention toward salient information and activation of motivational systems in the brain (24,25,56). It has previously been demonstrated that attending to more emotional or arousing aspects of a stimulus enhances the LPP, while employing reappraisal or other emotional regulation strategies reduces the magnitude of the LPP (25,57–63). Thus, children with an enhanced LPP to unpleasant images likely attend more to negative or threatening aspects of a situation or have difficulties regulating negative emotional responses, processes that predispose to greater symptoms of psychopathology following stressors.

Consistent with interpretations of the LPP as reflecting attention toward emotional information, the LPP has been linked to activation in the visual cortex, as well as increased bidirectional coupling between occipitoparietal and frontal cortices in response to emotional stimuli (64–66). In combined fMRI-ERP studies, the LPP has also been correlated with activation in subcortical regions, including amygdala and insula (67,68). The current

results suggest that activation in this extensive brain network when processing emotional information contributes to risk for psychopathology, findings that may be consistent with previous evidence that heightened amygdala activation to threat is associated with greater risk of symptoms following stress (20–22).

In addition to reactivity to unpleasant information, our study is unique in examining the effects of processing pleasant stimuli on subsequent symptoms. The results suggest that neural reactivity to pleasant information may contribute to resilience in response to stress. Children with enhanced LPPs to pleasant images may demonstrate greater attentional allocation toward positive aspects of the environment, which is likely to be protective under conditions of higher stress. It is important to note, however, that blunted LPPs to emotional images appear to be a risk factor for depressive disorders in youth (37–39), possibly indicating tendencies for emotional disengagement. Thus, an alternative explanation is that withdrawal from positive stimuli increases risk for symptoms. Importantly, both the pleasant and unpleasant LPP demonstrated opposite and unique effects on externalizing symptoms, suggesting that they may measure distinct aspects of emotional processing that contribute to risk and resilience.

Interestingly, concurrent associations between the LPP and symptoms were not significant, but the effect of the LPP to emotional images in predicting symptoms following the hurricane was comparable in magnitude with the effects of hurricane-related stress. In addition, at the 8-month follow-up assessment, mother-reported stress exposure immediately following the hurricane was no longer a significant independent predictor of symptoms, though the LPP continued to predict externalizing symptoms. Taken together, these findings indicate that rather than being a correlate of psychiatric symptoms, individual differences in neural reactivity to emotion reflect a vulnerability contributing to both short- and longer-term outcomes following stress exposure.

A few limitations of the study should be noted. First, analyses focused on maternal report of stress exposure and symptoms, which are limited with regard to measuring child experiences, though parent reports may be more valid for externalizing symptoms (69). Second, the effects of the LPP on symptoms were small in magnitude; however, both the pleasant and unpleasant LPP accounted for unique variance in predicting externalizing symptoms, and outcomes of disasters likely depend on the combination of a range of risk and resilience factors (14). Third, as the current study focused on broad measures of internalizing and externalizing symptoms, additional work is needed to examine whether similar patterns are observed in predicting posttraumatic stress disorder symptoms specifically. Lastly, most of the children exhibited subclinical levels of symptoms after the hurricane, and as the posthurricane assessment relied on questionnaire measures rather than clinical interviews, we were unable to evaluate change in clinical diagnoses. Though subthreshold symptoms are a strong predictor of full-threshold disorders (70,71), additional work is needed to evaluate whether our results generalize to prediction of clinical disorders.

In conclusion, this is the first study to demonstrate that a neural measure predicts children's adjustment following exposure to a natural disaster and that these effects persist for at

least 8 months. These findings highlight the importance of considering individual differences in neural reactivity to both pleasant and unpleasant emotional information in identifying children at risk of developing symptoms after exposure to disasters, though future work should examine whether similar patterns are observed with other measures of emotional reactivity and optimize methods for screening and assessing individuals. The current findings also provide a specific neural marker to target for early intervention or prevention, with future research needed to develop interventions that impact the LPP.

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## ARTICLE INFORMATION

From the Department of Psychiatry (AK), University of Illinois at Chicago, Chicago, Illinois; Department of Psychology (GH, APD, SRB, DNK), Stony Brook University; and Department of Psychiatry (EJB, GAC, RK, DNK), Stony Brook University School of Medicine, Stony Brook, New York.

Address correspondence to Autumn Kujawa, Ph.D., University of Illinois at Chicago, 1747 W Roosevelt Road, Chicago, IL 60608; E-mail: akujawa@psych.uic.edu.

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