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SPECIAL ISSUE: STRESS AND CHALLENGE

Threat Responsivity Predicts Posttraumatic Stress Disorder Hyperarousal Symptoms in Children after Hurricane Florence

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Abstract

Following a traumatic event, posttraumatic stress disorder (PTSD) symptoms are common. Considerable research has identified a relationship between physiological responses during fear learning and PTSD. Adults with PTSD display atypical physiological responses, such as increased skin conductance responses (SCR) to threatening cues during fear learning (Orr et al., 2000). However, little research has examined these responses in childhood when fear learning first emerges. We hypothesized that greater threat responsivity in early acquisition during fear conditioning before Hurricane Florence would predict PTSD symptoms in a sample of young children following the hurricane. The final sample included 58 children in North Carolina who completed fear learning before Hurricane Florence—a potentially traumatic event. After the hurricane, we assessed severity of hurricane impact and PTSD symptoms. We found that threat responsivity as measured by differential SCR during fear learning before the hurricane predicted PTSD hyperarousal symptoms and that hurricane impact predicted PTSD symptoms following the disaster. This exploratory work suggests that prospective associations between threat responsivity and PTSD symptoms observed in adulthood may be replicated in early childhood. Results are discussed in the context of the current COVID-19 crisis.

Keywords Posttraumatic stress disorder · Threat responsivity · Skin conductance · Natural disaster · Development

In September of 2018, Hurricane Florence wreaked havoc across North Carolina and caused approximately $17 billion in damage and 41 fatalities (Stradling & Bennett, 2018). A natural disaster like Hurricane Florence results in property damage and loss of life, putting those affected, particularly children, at risk for developing posttraumatic stress disorder (PTSD) symptoms (Hiller et al., 2016; Lai et al., 2013; Smith et al., 2007). In childhood, PTSD is positively correlated with impaired performance in school and poorer social functioning (Smith et al., 2007). For young children, PTSD symptoms are sorted into three clusters: intrusion symptoms, such as recurrent memories or dreams about the traumatic event; avoidance symptoms, such as avoiding the location where the event occurred; and increased arousal symptoms, such as hypervigilance (American Psychiatric Association [APA], 2013). These symptoms and associated affective and cognitive changes can manifest in a variety of ways ranging from anhedonia to dissociation (APA, 2013). Individuals also may display hypersensitivity to perceived threats and maladaptive fear responses that may occur and persist in safe situations (APA, 2013; Fani et al., 2012; Glover et al., 2011). The downstream effects of PTSD emphasize the importance of identifying children with PTSD symptoms so that evidence-based treatment can be implemented early to prevent negative outcomes.

After exposure to a traumatic event, approximately 25% of adults develop PTSD, most within 3 months following trauma (Santiago et al., 2013). PTSD is most prevalent 1 month after a traumatic event, at which time it may be diagnosed if symptoms have persisted since trauma exposure (APA, 2013; Hiller et al., 2016; Santiago et al., 2013). In the time following diagnosis, prevalence decreases and stabilizes after 3 months post-trauma for adults (Hiller et al., 2016; Santiago et al., 2013). Some studies have suggested that following a natural disaster, children may be especially at risk for PTSD symptoms (Jaycox et al., 2010; Lai et al., 2013). Traumatic threat to a caregiver also is especially impactful for children and may increase

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the likelihood of PTSD symptoms (Scheeringa & Zeanah, 1995).

Not all children and adults develop symptoms of PTSD after exposure to a traumatic event. One potential explanation for why that is suggests that some individuals are more at risk for PTSD symptoms due to premorbid differences in fear learning, or the learned association between a previously neutral stimulus and an aversive stimulus (Fani et al., 2012; Jovanovic & Norrholm, 2011; Lanius et al., 2010; Lissek & van Meurs, 2015). However, it is important to note that there is not yet sufficient evidence to identify the direction of causality between atypical fear learning and PTSD symptom development.

Threat responsivity, or physiological reactivity to an aversive stimulus, has been used to assess the fear responses of individuals with and without anxiety across a range of studies (Busso et al., 2014; Evans et al., 2019; Guthrie & Bryant, 2005; Lissek et al., 2006; Lissek et al., 2005; Löw et al., 2008; Löw et al., 2015; McTeague et al., 2010; McTeague et al., 2009; Orr et al., 2012; Pole et al., 2009). Threat responsivity can be assessed in the lab through a classical conditioning paradigm, called fear learning, which conditions responses to stimuli. During fear learning, a conditioned stimulus, the CS+, is paired with an aversive stimulus, such as a loud noise (the unconditioned stimulus [US]). Through exposure to these pairings, individuals learn to associate the CS+ with the US, and it becomes a threat cue. Another stimulus, the CS−, is never paired with the aversive stimulus and serves as a safety cue. Skin conductance response (SCR) often is used to index threat responsivity during fear conditioning paradigms. Studies that employ these paradigms examine whether participants show differences in SCR to the CS+ compared with the CS−. In the current study, we operationalize threat responsivity as SCR to the CS+ subtracting SCR to the CS−.

Multiple studies have demonstrated that fear learning changes across age. Children were better able to differentiate between the CS+ and the CS− with age, as indicated by SCR (Gao et al., 2010). This more accurate differentiation was attributed to an increase in both automatic and controlled processes as the children developed (Gao et al., 2010). In support of this finding, older children could better discriminate between the CS+ and the CS− than younger children in a sample of 8- to 13-year-olds, as measured by eye-blink startle (Glenn et al., 2012). Although little research has been conducted in young children, there is some evidence that children as young as age 3 years exhibit greater SCR to the CS+ relative to the CS− during fear conditioning (Gao et al., 2010). Furthermore, in a previous investigation of adversity exposure in the same sample of children in the present study, we demonstrated that children as young as age 4 years with a history of threat exposure exhibited greater SCR to the CS+ when controlling for the CS− than children without a history of threat (Machlin et al., 2019).

Differences in fear learning also are associated with symptoms of PTSD. Adults with PTSD exhibit exaggerated fear-potentiated startle to the CS+ (Fani et al., 2012) and greater differential SCR over fear acquisition and extinction than controls (Orr et al., 2000; Peri et al., 2000). As in adults with PTSD, SCR to the CS+ during fear learning was positively correlated with PTSD symptoms in children ages 8 to 13 years with PTSD (Gamwell et al., 2015), and children with anxiety showed greater SCR to the CS+ than those without anxiety during fear conditioning (Jovanovic et al., 2014), indicating greater threat responsivity among these individuals. Associations between fear learning and distinct PTSD symptom clusters also have been indicated in adults: fear-potentiated startle to a safety transfer trial during fear conditioning is positively associated with PTSD hyperarousal symptoms (Jovanovic et al., 2010). However, this association was not replicated in children; instead, SCR to the CS+ was positively correlated with intrusion and avoidance symptoms (Gamwell et al., 2015).

Three prospective studies on police and firefighters suggest that differences in threat responsivity may precede disorder acquisition. In these studies, greater SCR measured before trauma exposure to loud, startling noises predicted PTSD symptoms after exposure (Guthrie & Bryant, 2005; Orr et al., 2012; Pole et al., 2009). However, only a few studies have measured this relationship prospectively. Although there is limited relevant research in youth, one study found that physiological reactivity to the Trier Social Stress Test collected before the Boston Marathon Bombings predicted PTSD symptoms following the bombings in adolescents. This association was moderated by the amount of news media adolescents were exposed to surrounding the bombings (Busso et al., 2014). This study suggests that threat responsivity may prospectively predict PTSD symptoms in youth. However, no research has examined threat responsivity as a prospective predictor of PTSD symptoms in children.

In the current study, we investigated the presence of PTSD symptoms in a sample of preschool-age children following Hurricane Florence, a potentially traumatic event. We measured the level of the hurricane's impact on the children through parent self-report questionnaires. A year before the hurricane, we assessed threat responsivity via skin conductance responses in a fear conditioning paradigm. We used these responses as a predictor of PTSD symptoms post-hurricane, controlling for baseline anxiety, age, gender, and race. Due to the prior differences found between physiological responses to each of the PTSD symptom clusters (Gamwell et al., 2015; Jovanovic et al., 2010), we examined the association between threat responsivity and each cluster. We hypothesized that greater threat responsivity in early acquisition during fear conditioning would predict PTSD symptoms

following Hurricane Florence in a sample of young children impacted by the hurricane. We focused our hypothesis on early acquisition because we previously found a relationship in this sample between greater SCR to the CS+ during early acquisition and trauma experienced in the home (Machlin et al., 2019). Given prior results (Busso et al., 2014), we hypothesized that this prospective relationship would be driven by children more significantly impacted by the hurricane.

Methods

Participants

Sixty-five children ages 4 to 7 years and their primary caregivers were recruited in North Carolina over one and a half years. First, families were targeted by emailing listservs, posting on Craigslist, and reaching out to participants in other studies. To ensure a diverse sample, families with racial or ethnic minority status, a primary caregiver without a college education, or that scored above a clinical cutoff on the Child Abuse Potential Inventory (Milner, 1994) were recruited. Findings from this study regarding associations among adversity exposure, cognitive outcomes, emotion regulation, and skin conductance in response to fear learning have already been reported (Machlin et al., 2019; Milojevich et al., 2020). These reports did not include analysis of the longitudinal follow-up data analyzed here. Caregivers gave informed consent to participate in the study and children gave written or verbal assent. We excluded participants if they had a major medical condition, a neurological illness, were not sufficiently fluent in English to complete questionnaires, or if they had a pervasive developmental disorder.

Of the original sample of 65 families, 60 participated in the follow-up survey. However, two participants did not complete the questions regarding hurricane impact and PTSD symptoms, leaving a sample of 58 with complete questionnaire data. Of those 58, seven children were missing threat responsivity physiological data due to technological issues, five refused to complete the threat responsivity task, two were dropped due to poor physiological file data quality, one aborted the task, and one was allergic to the materials and thus did not complete the task, leaving a final fear learning subsample of 42 children. The sample of 58 was used in the analysis predicting PTSD symptoms from level of impact of the hurricane on the child while the sample of 42 was used in the threat responsivity analyses.

Procedure

At baseline, participants completed a 3-hour lab visit. During this visit, the primary caregiver completed questionnaires reported on elsewhere (Machlin et al., 2019; Milojevich et al., 2020). The child completed an interview with a researcher about adverse experiences, a fear learning paradigm, and several cognitive assessments not reported on here. Approximately 1 year after the in-person visit, a follow-up survey was sent to the families via Qualtrics to assess the impact of Hurricane Florence. Families were compensated for their participation and all procedures were approved by the institutional review board at the University of North Carolina at Chapel Hill.

Threat Responsivity

The fear learning paradigm used to assess threat responsivity which children completed at baseline (Machlin et al., 2019; Milojevich et al., 2020) employed a block design (Fig. 1). Other block design paradigms have previously been found to effectively condition differential responding in young children (Jovanovic et al., 2014; Silvers et al., 2016; van Rooij

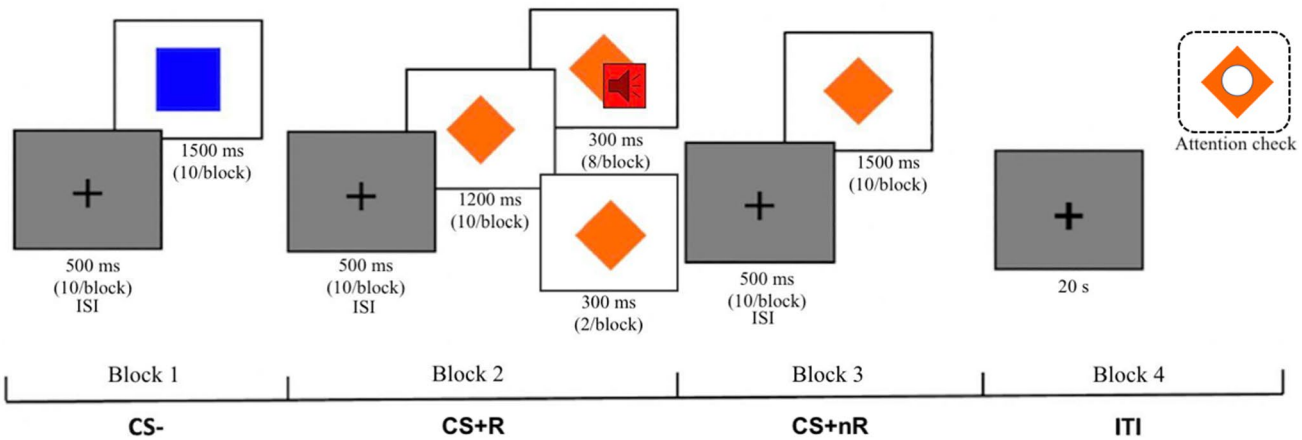

Fig. 1 Blocks one through four (set 1) of fear acquisition were uniform across participants

et al., 2017). A block design allowed us to minimize task length for young and easily distractible participants while preserving threat responsivity effects (Silvers et al., 2016).

Stimuli were either a blue square and orange diamond or a blue diamond and orange square. Shape pairs were counterbalanced across participants and shapes within each pair were randomly assigned to be the CS+ and the CS−. Participants were told that they would see two shapes on the screen and sometimes hear a loud sound. If the sound upset them, they were to tell the researcher to stop. They were informed that there would be a dot on top of some shapes and to press a key quickly for these shapes.

During acquisition, there were 16 blocks: 12 trial blocks and four inter-trial interval (ITI) blocks. There were four CS+ reinforced (CS+R) blocks in which the CS+ was reinforced with the US, four CS+ nonreinforced (CS+nR) blocks in which the CS+ was not reinforced with the US, four blocks of the CS− in which there was no US, and four ITI blocks of fixation. Each trial block contained 10 presentations in a row of one kind of stimulus (e.g., the CS−), and a fixation cross lasting 500 ms was presented at the beginning of each block before the first stimulus presentation. The CS+ and CS− were presented for 1,500 ms at a time. Each ITI block lasted 20 seconds. The US was an aversive loud, metallic, high-frequency sound (Neumann et al., 2008; Silvers et al., 2016) of 80 dB, although the volume was decreased if children exhibited too much distress to continue. We used delay conditioning in the CS+R blocks such that the US was present for the last 300 ms that the CS+ was presented; they then co-terminated. The reinforcement rate was 80% in the CS+R blocks alone, 0% in the CS+nR blocks alone, and therefore averaged 40% across the CS+R and CS+nR blocks. The first four blocks comprised one set (a grouping of blocks) of exposures to the four types of stimuli and the order of these four blocks (set one; CS−, CS+R, CS+nR, ITI) was fixed across participants, as displayed in Fig. 1. The remaining 12 blocks of acquisition (sets 2 through 4) and the 12 total blocks of extinction (4 sets each comprised of 1 CS− block, 1 CS+nR block, and 1 ITI block) were randomized within each set to create two versions of the paradigm, which were counterbalanced across participants. After acquisition and extinction, participants completed a survey to assess US-CS+ contingency awareness, meaning approximately one minute elapsed between acquisition and extinction. To ensure attention, a dot was overlaid on 20% of the stimuli in each trial block during acquisition and extinction and participants pressed a key to "catch the dot."

Measures

Physiological We collected SCR during the fear conditioning paradigm using Mindware BioLab 3.1.5. A researcher attached two gel electrodes to the palm of the participant's nondominant hand to measure skin conductance at 1,000 Hz. Mindware was used to automatically identify SCR peaks and troughs. Next, a trained researcher visually inspected the data and marked peaks and troughs not identified by Mindware, and removed peaks and troughs misidentified by Mindware. SCR was defined as the amplitude of the response (minimum response: a change in skin conductance of 0.05 microsiemens (μs) from trough to peak on the y-axis) in the 1 to 5 seconds after stimulus onset. If the minimum response was not observed, no SCR was counted for that trial. Unusable data were visually characterized as rough and jagged static with no smooth SCR waves.

In order to compare SCR across participants, we calculated a range correction for SCR by dividing each SCR amplitude by the participant's overall maximum skin conductance (Lykken & Venables, 1971; Machlin et al., 2019). Then, for each stimulus (CS+nR, CS−, and CS+R), we averaged across early acquisition (the first 2 sets), late acquisition (the last 2 sets), early extinction (the first 2 sets), and late extinction (the last 2 sets) (Blanchette & Richards, 2013). Finally, we created differential SCR amplitude variables by subtracting the average SCR to the CS- from the average SCR to the CS+nR in early acquisition, late acquisition, early extinction, and late extinction.

Posttraumatic Stress Disorder PTSD symptoms were measured in the follow-up survey using the UCLA PTSD Reaction Index (UCLA PTSD RI) questions that assess Criteria B, C, and D PTSD symptoms according to the DSM-IV (Steinberg et al., 2004). Items, such as "My child feels jumpy or startles easily, for example, when he/she hears a loud noise or when something surprises him/her," were included, and parents indicated how often it had been true for their child in the past month on a scale from 0 (*none*) to 4 (*most*).

Because prior research found prospective associations between SCR and PTSD symptoms (Guthrie & Bryant, 2005; Orr et al., 2012; Pole et al., 2009), we examined continuous measures of PTSD symptoms. A symptom count score for overall PTSD symptoms was constructed from a count of all non-zero responses to the PTSD symptom questions, and symptom count scores for each of the three symptom clusters (B, C, and D) were constructed from counts of non-zero responses to their respective criterion questions. The UCLA PTSD RI has been found to have good convergent validity and test-retest reliability (Cronbach's alpha = 0.93) (Steinberg et al., 2004).

Child psychopathology Child psychopathology was assessed at baseline using the Diagnostic Interview Schedule for Children – Young Child (DISC-YC) (Shaffer et al., 2000). Trained research assistants and graduate students

administered the DISC to caregivers to assess their child's symptoms of psychopathology. The DISC was scored by the program's algorithm. The DISC-YC is an adaptation of the DISC-parent version designed for children ages 3 to 8 years (Lavigne et al., 2009; Rijlaarsdam et al., 2015). It has been found to be a reliable and valid measure of child psychopathology (test-retest reliability for anxiety and depression scales = 0.57-0.81) and is commonly used to assess psychopathology in young children (Lavigne et al., 2009; Rijlaarsdam et al., 2015; Ringoot et al., 2017). To control for baseline anxiety, we constructed a dichotomous variable in which children who met at least one criterion for an anxiety disorder (Generalized Anxiety Disorder, PTSD, Social Phobia, Separation Anxiety Disorder, and Specific Phobia) received a one and children who did not meet criteria for an anxiety disorder received a zero. We used this categorical variable to control for previous anxiety.

Caregiver psychopathology Caregiver psychopathology was assessed at baseline using the Symptom Checklist-90 (SCL-90) (Derogatis et al., 1973). The SCL-90 contains 90 items assessing psychopathology via self-report. It has been found to a be a reliable and valid measure of psychopathology (Bonicatto et al., 1997). We averaged responses to the questions on the SCL-90 and used this variable to control for baseline caregiver psychopathology (Cronbach's alpha = 0.98).

Impact of Hurricane Florence The survey was sent out approximately 1 month after the hurricane hit the region. We collected responses from parents up to 3 months following the disaster. To construct the hurricane impact variable, we first summed across answers to the following questions: "How many people in your immediate family or people you live with were injured or killed by Hurricane Florence?"; "How many people in your extended family were injured or killed by Hurricane Florence?"; and "On a scale of 1 (*no damage at all*) to 5 (*severe damage*), did Hurricane Florence damage your home (e.g., flooding, broken windows, roof damage)?" Data were recoded for the last question from "0" to "4" to match the other responses. We then constructed a dichotomous categorical hurricane impact variable for use in our analyses, such that scores greater than or equal to one on the sum of responses across these three questions were considered "high impact," whereas "low impact" was a score of zero.

Statistical Analyses

We ran multiple linear regression analyses to determine whether level of hurricane impact on the children could predict PTSD symptoms or PTSD symptom clusters. We then ran multiple linear regression analyses to determine whether threat responsivity (CS+nR subtracting CS-) in early acquisition before the hurricane could predict PTSD symptoms or PTSD symptom clusters. We also examined the interaction between threat responsivity and hurricane impact level to determine whether hurricane impact could moderate threat responsivity to predict PTSD symptoms or PTSD symptom clusters following the hurricane.

Covariates in all analyses included age, gender, race, and previous DISC anxiety due to prior research that indicates age (Gao et al., 2010; Glenn et al., 2012), gender (Gamwell et al., 2015; Inslicht et al., 2013; Lonsdorf et al., 2015), race (Kredlow et al., 2018; Kredlow et al., 2017), and anxiety (Fani et al., 2012; Jovanovic et al., 2014; Lau et al., 2008; McTeague et al., 2010; Orr et al., 2000) impact threat responsivity during fear conditioning. To control for race, we constructed a dichotomous categorical variable in which white participants received a zero and non-white participants received a one. Additional controls (baseline caregiver psychopathology measured by the SCL-90 and baseline child threat exposure) also were tested in separate supplementary models and are reported on briefly. Analyses were run in IBM SPSS Statistics 26.0 and 27.0.

Results

Sample Characteristics

As previously described, 2 samples of the 65 recruited participants were used in our analyses. The threat responsivity subsample of 42 contained 21 females (50%) and 21 males (50%). Participants' ages ranged from 4 to 7 years ($M = 6.1$ years, $SD = 1.1$; Table 1). Of the sample of 42 children, 10 (23.8%) met criteria for at least one anxiety disorder on the DISC before the hurricane, whereas 33 (78.6%) met at least one criterion for an anxiety disorder on the DISC before the hurricane. Thirty-two of the 42 children (76.2%) reported one or more PTSD symptoms following the hurricane (range: 0–19, $M = 3.7$, $SD = 4.6$). Three children had high levels of PTSD symptoms, and thus were outliers, but were not excluded because they were the population of interest.

Families completed the survey between one and three months ($M = 67.3$ days, $SD = 10.4$) following the hurricane. Fifty-five of the 58 parents who completed the follow-up reported talking to their child about the hurricane, and 8 of 58 children reported a high level of hurricane impact. Of the subsample with threat responsivity data, 7 of 42 children reported a high level of hurricane impact. Regarding the two hurricane impact questions assessing the number of people in immediate and extended family injured or killed by the hurricane, responses to both questions ranged from 0 to 3 people. Recoded scores ranged from "0" to "1" on the transformed Likert scale in response to the question assessing

Table 1 Participant characteristics

N = 42	Minimum	Maximum	Mean	SD
Age (yr)	4.3	7.9	6.09	1.12
PTSD symptoms	0	19	3.74	4.59
Criterion B PTSD symptoms	0	6	1.14	1.70
Criterion C PTSD symptoms	0	8	0.71	1.88
Criterion D PTSD symptoms	0	5	1.88	1.63
Baseline caregiver psychopathology	0	1.9	0.35	0.51
	%	*n*		
Female	50.0	21		
High hurricane impact	16.7	7		
Baseline DISC anxiety	78.6	33		
Race/ethnicity				
White	52.4	22		
African American	31.0	13		
Asian	2.4	1		
Multiracial/Other	14.3	6		
Hispanic/Latino	11.9	5		
N = 58	Minimum	Maximum	Mean	*SD*
Age (yr)*	4.3	7.9	6.02	1.16
PTSD symptoms	0	19	3.60	4.60
Criterion B PTSD symptoms	0	6	1.10	1.69
Criterion C PTSD symptoms	0	8	0.67	1.83
Criterion D PTSD symptoms	0	5	1.83	1.66
Baseline caregiver psychopathology*	0	1.9	0.31	0.46
	%	*n*		
Female	56.9	33		
High hurricane impact	13.8	8		
Baseline DISC anxiety	77.6	45		
Race/ethnicity				
White	50.0	29		
African American	36.2	21		
Asian	1.7	1		
Multiracial/Other	12.1	7		
Hispanic/Latino*	12.3	7		

Note. *One participant did not report age, baseline caregiver psychopathology, or ethnicity. $N = 57$ for these characteristics.

damage to the home. The relationship between hurricane impact level and PTSD symptoms is depicted in Fig. 2. Adversity exposure (measured by z-scored threat exposure; $M = 0.0$, $SD = 2.3$) for the total sample is reported in previous papers (Machlin et al., 2019; Milojevich et al., 2020).

The participants missing threat responsivity data were not significantly different from the sample used in fear learning analyses regarding age, gender, race, PTSD symptoms, previous DISC anxiety, and hurricane impact level (p values > 0.08). Results were substantively unchanged when analyses additionally controlled for baseline caregiver psychopathology and baseline threat exposure and when substituting a continuous measure of baseline anxiety for the dichotomous measure reported here. If the range correction of SCR data is then square root transformed, results remain the same. Differential SCR during late acquisition and early and late extinction did not predict PTSD symptoms.

Threat Responsivity

Main effects and interactions regarding threat responsivity and threat exposure are previously reported by Machlin et al. (2019). Briefly, there was no main effect of CS type: there was no significant difference between SCR to the CS+nR and SCR to the CS−. Therefore, the present analyses were conducted with respect to threat responsivity. Additionally, 87% of children reported US-CS+ contingency awareness after fear acquisition. Children passed the attention check with 83.9% accuracy during acquisition. SCR across acquisition is illustrated in Fig. 3.

Hurricane Impact and PTSD Symptoms

Results of the linear regression analysis indicated that high hurricane impact level significantly predicted increased PTSD symptoms following the hurricane ($F(5, 51) = 1.95$, $p = 0.103$, $R^2 = 0.16$; $t = 2.79$, $p = 0.007$; Table 2). High hurricane impact level also significantly predicted Criterion B, intrusion symptoms ($F(5, 51) = 1.30$, $p = 0.280$, $R^2 = 0.11$; $t = 2.14$, $p = 0.037$), Criterion C, avoidance symptoms ($F(5, 51) = 2.16$, $p = 0.073$, $R^2 = 0.18$; $t = 2.90$, $p = 0.005$), and Criterion D, increased arousal symptoms ($F(5, 51) = 1.37$, $p = 0.252$, $R^2 = 0.12$; $t = 2.27$, $p = 0.028$). None of the other covariates significantly predicted PTSD symptoms.

Threat Responsivity and PTSD Symptoms

Results of the linear regression analysis indicated that differential SCR amplitude did not predict overall PTSD symptoms following the hurricane ($F(5, 36) = 0.94$, $p = 0.466$, $R^2 = 0.12$; $t = 1.33$, $p = 0.193$). None of the other covariates significantly predicted PTSD symptoms. Results of the linear regression analysis for Criterion D, increased arousal symptoms, indicated that greater differential SCR amplitude significantly predicted increased hyperarousal symptoms ($F(5, 36) = 1.85$, $p = 0.129$, $R^2 = 0.20$; $t = 2.47$, $p = 0.018$; Table 3; Fig. 4). None of the other covariates were significant. The regression analysis predicting Criterion B, intrusion symptoms ($F(5, 36) = 0.59$, $p = 0.706$, $R^2 = 0.08$), was not significant, nor was the regression predicting Criterion C, avoidance symptoms ($F(5, 36) = 0.56$, $p = 0.727$, $R^2 = 0.07$) (p values > 0.3).

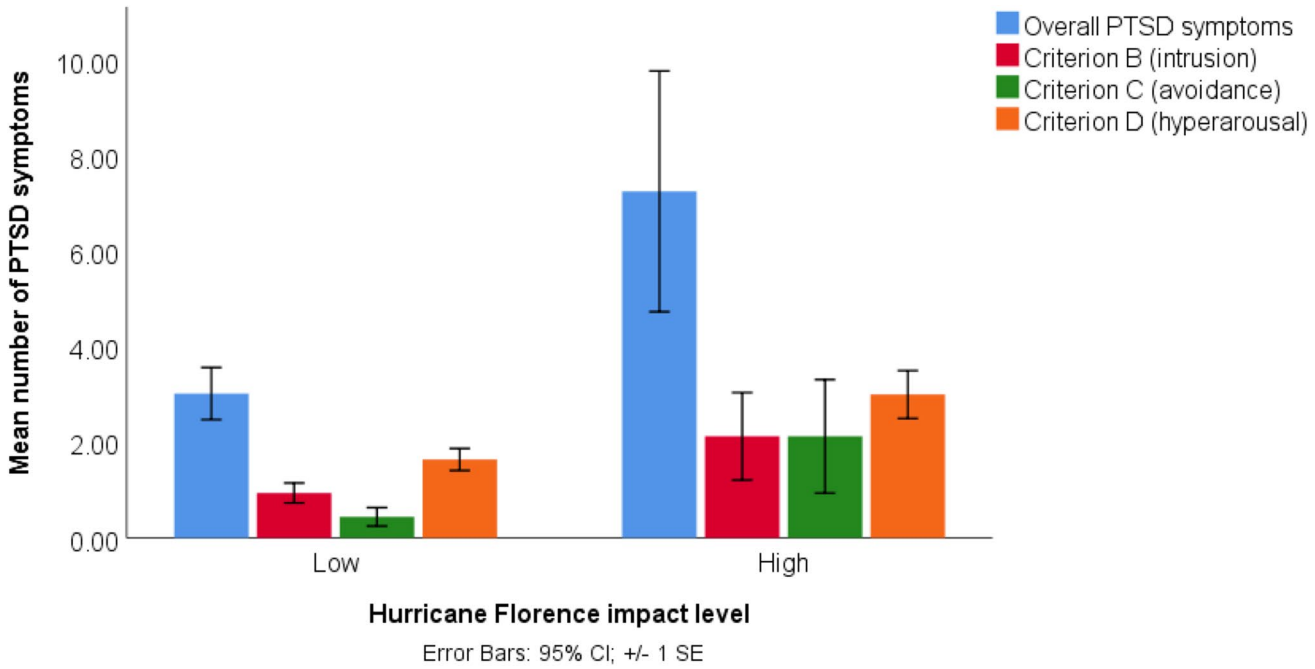

Fig. 2 Relationship between hurricane impact level and PTSD symptoms ($N = 58$). Low impact level $n = 50$ and high impact level $n = 8$

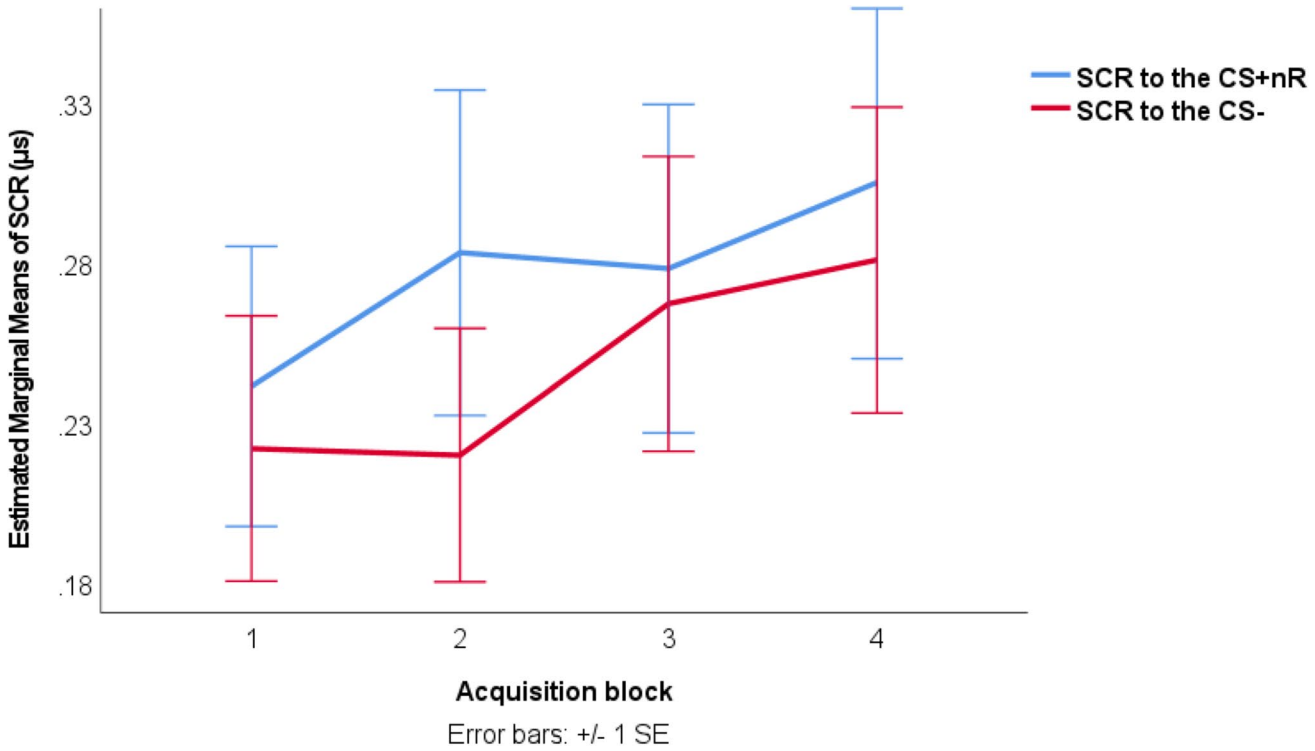

Fig. 3 SCR across acquisition for the eight blocks of the CS+nR and CS−. Each CS type appeared in a separate block but the SCR is overlaid here for ease of comparison ($N = 42$)

Table 2 Multiple regression analysis predicting PTSD symptoms from hurricane impact level (N = 58)

	B	SE B	β	t	p
Constant	1.03	3.50		0.30	0.769
Level of hurricane impact (low vs. high)	4.86	1.74	0.37	2.79	0.007
Baseline DISC anxiety	−0.65	1.45	−0.06	−0.45	0.656
Age (mo)	0.03	0.04	0.10	0.79	0.436
Gender	−1.37	1.23	−0.15	−1.12	0.269
Race	1.61	1.21	0.18	1.33	0.190

Note. High hurricane impact level also predicted PTSD symptom clusters. These regressions are reported solely in the text.

Table 3 Multiple regression analysis predicting Criterion D PTSD symptoms from differential SCR (N = 42)

	B	SE B	β	t	p
Constant	1.06	1.58		0.67	0.509
Differential SCR amplitude during early acquisition	2.38	0.96	0.38	2.47	0.018
Baseline DISC anxiety	0.00	0.63	0.00	0.00	0.997
Age (mo)	0.01	0.02	0.12	0.78	0.443
Gender	−0.62	0.51	−0.19	−1.22	0.232
Race	−0.03	0.49	−0.01	−0.06	0.956

Moderating Effect of Hurricane Impact

We examined the interaction between differential SCR amplitude and hurricane impact level using a linear regression to predict PTSD symptoms ($F(7, 34) = 1.16$, $p = 0.354$, $R^2 = 0.19$). The interaction was not significant ($p = 0.765$). We also examined the interaction between differential SCR amplitude and hurricane impact level using a linear regression to predict Criterion D PTSD symptoms ($F(7, 34) = 2.23$, $p = 0.056$, $R^2 = 0.32$). The interaction was not significant ($p = 0.252$).

Discussion

We hypothesized that greater threat responsivity in early acquisition during fear conditioning would predict PTSD symptoms following Hurricane Florence in children ages 4 to 7 years impacted by the hurricane. In support of this hypothesis, greater threat responsivity significantly predicted increased arousal PTSD symptoms in our sample. We also hypothesized that hurricane impact level would moderate threat responsivity during fear learning to predict PTSD symptoms following the hurricane. We found that this moderation was not significant.

As expected, the level of the hurricane's impact on a child predicted their risk for overall PTSD symptoms as well as Criteria B, C, and D symptoms, such that children with a high level of impact were more likely to have symptoms. This finding is consistent with research on the impact of natural disasters, which has found that they may be especially

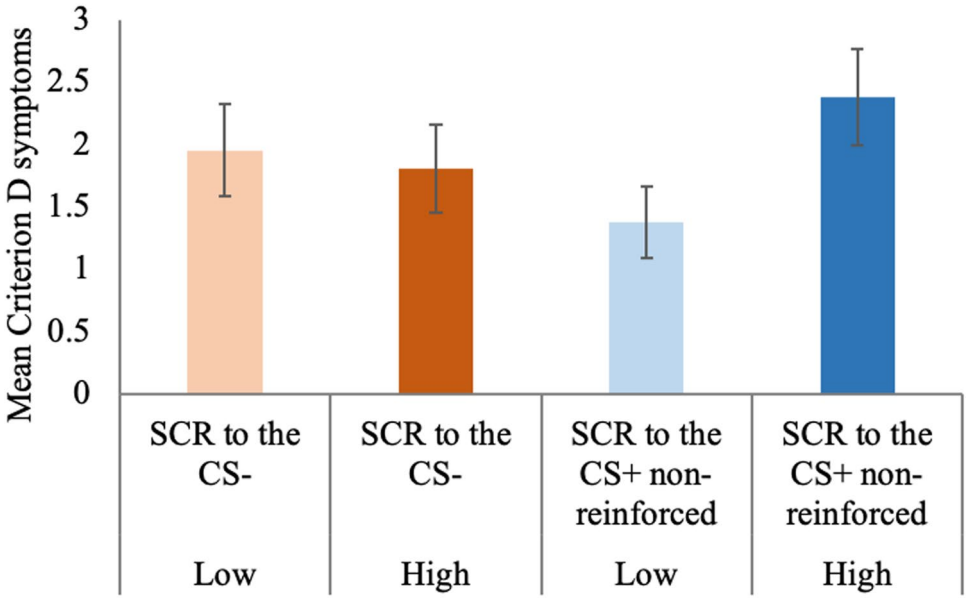

Fig. 4 Median split of SCR to the CS− and CS+nR across early acquisition in relation to mean Criterion D PTSD symptoms (errors bars: ±1 SE; $N = 42$)

impactful on children (Jaycox et al., 2010; Lai et al., 2013). In another study, children ages 4 years and younger who experienced a traumatic threat to their caregiver were more likely to develop PTSD than those who experienced trauma that did not threaten their caregiver (Scheeringa & Zeanah, 1995). While threat to caregiver is unmeasured in this sample, the relationship between hurricane impact and PTSD symptoms may be driven by children who experienced threat to caregiver trauma due to the hurricane. In the face of a natural disaster or potentially traumatic event, these findings suggest that parents and clinicians should monitor young children for atypical behavior that may be related to PTSD symptoms.

Importantly, we did not find a main effect of fear conditioning. However, we still examined the relationship between threat responsivity during the fear learning paradigm and PTSD symptoms. Prior research in children with anxiety has found that they demonstrate heightened arousal and responsivity to the CS+, as measured by SCR, which has been correlated with PTSD symptoms (Gamwell et al., 2015; Jovanovic et al., 2014). Additionally, prospective research in adults employing single-stimulus threat paradigms found that greater SCR to threatening stimuli predicted PTSD symptoms (Guthrie & Bryant, 2005; Orr et al., 2012; Pole et al., 2009). Thus, the present study contributes to a larger body of research in adults that suggests threat responsivity can predict PTSD symptoms and addresses the limited prior research in youth.

Threat responsivity did not predict overall PTSD symptoms following Hurricane Florence. However, greater threat responsivity significantly predicted PTSD Criterion D symptoms, which capture increased arousal. No prior research has examined this relationship in young children before, and this finding suggests that SCR can prospectively predict PTSD symptoms, specifically those of hyperarousal, following potential trauma in early childhood as it can in adulthood (Guthrie & Bryant, 2005; Orr et al., 2012; Pole et al., 2009). In addition, we found associations between threat responsivity and PTSD hyperarousal symptoms in early acquisition of the fear conditioning paradigm, rather than in late acquisition as has been found in older children (Gamwell et al., 2015; Jovanovic et al., 2014). This finding suggests that the unique characteristics of the sample (young age, prior adversity exposure) may have contributed to a distinct pattern of threat responsivity. This finding also may indicate a more specific positive association in young children, as compared to adults, between threat responsivity and PTSD hyperarousal symptoms, as opposed to general PTSD symptoms.

A possible explanation for our findings comes from research on parent-child agreement for child PTSD symptoms: one study found that parent-child agreement improved over time specifically for PTSD hyperarousal symptoms (Meiser-Stedman et al., 2007). Thus, greater differential SCR predicting PTSD hyperarousal symptoms after the hurricane may relate to more accurate parent reporting of child Criterion D symptoms than the other symptom clusters. This prospective association supports previous research in children that has found positive relations between increased SCR to the CS+ and PTSD symptoms (Gamwell et al., 2015), anxiety (Jovanovic et al., 2014), and previous threat exposure (Machlin et al., 2019). While one study (McLaughlin et al., 2016) found positive associations between maltreatment history and blunted SCR to the CS+ in older children and adolescents, it is important to note that this sample included a wider age range than our sample and aforementioned studies. Additionally, given that another prior study has found positive associations between SCR to the CS+ and other distinct PTSD symptom clusters (intrusion and avoidance) in children when examining child-reported PTSD symptoms (Gamwell et al., 2015), more research is warranted on the associations between threat responsivity and PTSD symptom clusters in children across development.

The moderation analyses showed that hurricane impact level did not moderate the relationship between differential SCR and PTSD symptoms. Busso et al. (2014) found a significant moderating effect of news media on the relationship between physiological reactivity and PTSD symptoms in adolescents. However, our sample consisted of young children, not adolescents, and we operationalized our moderator and predictor differently following a different potentially traumatic event. Additionally, although previous work has found differences in fear learning in relation to PTSD symptom clusters by gender (Gamwell et al., 2015), we did not find any effects of gender in our analyses. Future work should continue to examine moderators and predictors of the relationship between physiological reactivity and risk for PTSD symptoms.

Prospective research on PTSD in children is lacking because it requires a sample of children who have been exposed to a traumatic event and with whom pretrauma data have been collected (Garza & Jovanovic, 2017). While predictable trauma exposure is relatively common in adults (e.g., soldiers, first responders), it is fortunately less common in children, making this research difficult. The present research capitalized on an existing study, which allowed us to meet these criteria and form predictions between threat responsivity and hurricane-related PTSD symptoms, providing novel findings on the prospective relationship between fear learning and PTSD in young children. Because natural disasters affect children strongly, Hurricane Florence served as a useful tool to investigate prospective predictors of PTSD symptom development (Jaycox et al., 2010; Lai et al., 2013; Swenson et al., 1996).

A few limitations should be considered when interpreting these results. Because our sample was recruited from

central North Carolina, rather than from the coast where the hurricane's impact was greater, the sample did not capture children who were most affected by the hurricane. The assessment of child hurricane impact was also limited as the questions used to construct the hurricane impact variable assessed caregiver experience, which assumes that the child would have had knowledge of or exposure to the injuries, deaths, and home damage reported by the primary caregiver. While the child likely had similar hurricane exposure as their primary caregiver, future research should assess hurricane impact via child self-report.

In addition, given the limited research on the prevalence of PTSD symptoms in children over time, it is possible that we missed some children who would go on to develop symptoms after the follow-up survey was administered. Some research has suggested that parents underreport child PTSD symptoms; it is possible that our parent-report measure resulted in underestimates within these results (Hiller et al., 2016; Lai et al., 2013). Future work should include both child- and parent-report measures of PTSD symptoms for comparison. Furthermore, it is important to note that we assessed anxiety before the hurricane and PTSD symptoms after the hurricane using different scales. Thus, we could not create a direct comparison between scales when controlling for baseline anxiety.

Regarding the fear learning paradigm, children were exposed to the CS+ at twice the rate of the CS− during acquisition. Therefore, it is possible that differences in SCR to the CS+ versus CS− were found due to a familiarity effect. Little research has examined differences in SCR to familiar versus unfamiliar objects or shapes. However, a study exploring familiar and unfamiliar names found no differences in SCR (Ellis et al., 1999), whereas participants in another study on word familiarity exhibited longer SCR latencies to studied versus nonstudied words (Morris et al., 2008). Other work suggests that children and adults exhibit greater SCR to familiar versus unfamiliar faces (Bonifacci et al., 2015; Sharma et al., 2017). However, due to the lack of research on object familiarity and SCR, we cannot conclude whether the associations found between threat responsivity and PTSD symptoms were affected by rates of stimulus exposure.

Differences in rates of exposure to the CS+ and CS− also may have resulted in a nonassociative learning effect, such as habituation or sensitization, and detracted from fear conditioning, leading to a lack of a main effect. Research suggests that individuals with PTSD often exhibit slower skin conductance habituation (Orr et al., 2012), but little prospective research has examined this relationship. Future research should employ a paradigm in which children are exposed to the CS+ and CS− shapes the same number of times to eliminate this possible confound. In addition, the effectiveness of the fear conditioning paradigm may have been limited by the volume of the US. We set this volume to 80 dB based on the age of the participants, previous studies in older children that have used similar volumes (Neumann et al., 2008; Silvers et al., 2016), and a study that elicited fear conditioning in children as young as age 3 years with a 90 dB US (Gao et al., 2010). Another limitation of the paradigm was the measurement of SCR between blocks. Because there was no fixation time between blocks, it is possible that SCR to the last stimulus presentation from the previous block could have overlapped with the first stimulus presentation from the next block. However, this would have only occurred a few times throughout the paradigm relative to the total number of trials in fear conditioning.

This sample was also initially recruited as part of a pilot study enriched for adversity exposure—a variable that we previously demonstrated was related to fear learning (Machlin et al., 2019). Not all participants had adversity exposure, but the prevalence of exposure in this sample was higher than it would be in a random sample; it is possible that because the sample had significant prehurricane exposure to adversity, we were able to observe these associations in a relatively small group of participants. In addition, it is important to note that the smaller sample size of the study increases the likelihood of Type 1 error. However, the present study is only a preliminary probe into the associations between fear learning and PTSD symptoms in young children and can provide more impetus for future research in a larger sample.

To further explore the relationship between threat responsivity and PTSD symptoms, it would also be ideal to focus on larger-scale trauma, such as the COVID-19 pandemic, a current and relevant potentially traumatic event with a global impact. The pandemic has the potential to create long-lasting psychological damage (Raker et al., 2020). Assessments examining a sample of young women impacted by Hurricane Katrina suggest that belief that one's life or a relative's life was in danger, bereavement, and lack of medical care for a relative or oneself were strong predictors of poor health outcomes, such as PTSD symptoms, years after the disaster, which could translate to the pandemic (Raker et al., 2020).

A longitudinal study examining the impact of COVID-19 on children would be ideal to examine the relationship between threat responsivity and PTSD symptoms in a larger sample exposed to a far-reaching traumatic event. We have begun collecting threat responsivity data for a large study examining adverse experiences in early childhood during the COVID-19 pandemic. Thus, we may be able to explore findings with a larger sample following the pandemic. We would hypothesize that greater threat responsivity during fear learning before the COVID-19 pandemic would predict risk for PTSD symptoms in youth and that less exposure to the direct effects of the pandemic would serve as a protective factor against PTSD symptom development.

In the present study, we demonstrated that greater threat responsivity predicts PTSD increased arousal symptoms in children. We also demonstrated that exposure to a potentially traumatic event, such as a natural disaster, and heightened physiological reactivity during fear learning may increase the likelihood of PTSD symptom development. In addition, in the case of large-scale trauma, results suggested that limiting child exposure to the resulting destruction may prevent the onset of PTSD symptoms, although more research in a sample affected by wider-spread trauma is needed to confirm these findings. The present study provides a method for early identification of children who are at greater risk for developing PTSD symptoms, which may be applicable to the current COVID-19 pandemic.

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