Child Maltreatment and Neural Systems Underlying Emotion Regulation

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Objective: The strong associations between child maltreatment and psychopathology have generated interest in identifying neurodevelopmental processes that are disrupted following maltreatment. Previous research has focused largely on neural response to negative facial emotion. We determined whether child maltreatment was associated with neural responses during passive viewing of negative and positive emotional stimuli and effortful attempts to regulate emotional responses.

Method: A total of 42 adolescents aged 13 to 19 years, half with exposure to physical and/or sexual abuse, participated. Blood oxygen level–dependent (BOLD) response was measured during passive viewing of negative and positive emotional stimuli and attempts to modulate emotional responses using cognitive reappraisal.

Results: Maltreated adolescents exhibited heightened response in multiple nodes of the salience network, including amygdala, putamen, and anterior insula, to negative relative to neutral stimuli. During attempts to decrease responses to negative stimuli relative to passive viewing, maltreatment was associated with greater recruitment of superior frontal gyrus, dorsal anterior cingulate cortex, and frontal pole; adolescents with and without maltreatment down-regulated amygdala response to a similar degree. No associations were observed between maltreatment and neural response to positive emotional stimuli during passive viewing or effortful regulation.

Conclusion: Child maltreatment heightens the salience of negative emotional stimuli. Although maltreated adolescents modulate amygdala responses to negative cues to a degree similar to that of non-maltreated youths, they use regions involved in effortful control to a greater degree to do so, potentially because greater effort is required to modulate heightened amygdala responses. These findings are promising, given the centrality of cognitive restructuring in trauma-focused treatments for children.

Key Words: child maltreatment, child abuse, trauma, emotion regulation, amygdala

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Child maltreatment is among the most robust risk factors for child psychiatric disorders.[1,2] A majority of US children have been exposed to interpersonal violence by the time they reach adolescence, and as many as 1 in 4 experience more severe forms of maltreatment.[3,4] Population-based studies indicate that children who have been maltreated are at elevated risk for multiple forms of psychopathology that persist into adulthood.[2,5]

Despite the strong associations of child maltreatment with psychopathology, information on neurodevelopmental mechanisms underlying these associations remains limited. Disruptions in emotion regulation are frequently posited to be a central mechanism linking child maltreatment with the onset and maintenance of psychopathology.[6] Existing functional neuroimaging studies of child maltreatment and emotional responses have largely examined associations between maltreatment and amygdala response to negative facial emotion. The amygdala detects salient cues in the environment, such as facial displays of emotion,[7,8] and is involved in detection of potential threats.[9,10] Exposure to threatening environments early in development might lead to changes in amygdala response to negative emotional cues due to heightened salience of negative emotional information as a marker of potential threats.[11] Indeed, 2 prior studies have shown that children exposed to violence exhibit heightened amygdala response to facial displays of anger.[12,13] However, the amygdala responds to both positive and negative emotional cues.[7,8] It is unknown whether heightened amygdala response following child maltreatment is specific to potential threats or reflects heightened sensitivity to emotional salience more generally. Prior research suggests that child maltreatment is associated with more intense emotional reactions to a wide range of stressors and environmental cues.[6,14-16] Moreover, in a study examining neural response to both faces presented preattentively, heightened right amygdala response to both happy and angry faces was observed in children exposed to violence,[13] suggesting that maltreatment might be associated with elevated sensitivity to a wide range of emotional cues. Here we examine neural response to both negative and positive emotional cues in youths exposed to maltreatment.

Child maltreatment might also influence neural systems that modulate amygdala response to emotional cues,

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although surprisingly little research has examined this possibility. Emotion regulation involves automatic processes that occur implicitly and without effort and involve ventromedial prefrontal cortex (vmPFC) modulation of the amygdala; these processes include fear extinction,[17] habituation to stress,[18] and modulation of responses to conflicting emotional cues.[19] An additional set of brain regions is involved in effortful emotion regulation processes that are engaged in explicitly and require cognitive resources, such as cognitive reappraisal.[20] Use of cognitive reappraisal engages the dorsal anterior cingulate (ACC) and regions in the lateral prefrontal cortex (PFC) that are involved in cognitive control.[20-22] Activation in these cognitive control regions during reappraisal modulates amygdala activity either through projections to the vmPFC[23] or regions of the lateral temporal cortex that alter semantic representations of an emotional stimulus.[20] Reduced resting-state functional connectivity between the vmPFC and amygdala has been observed in maltreated adolescent females,[24] suggesting potential disruptions in systems involved in automatic emotion regulation. Although some studies have observed poor cognitive control in maltreated children and adolescents,[25,26] we are unaware of previous research examining whether maltreatment influences neural systems involved in the effortful control of emotion.

We examined this question in the current study. Specifically, we investigated neural function during passive responses to negative and positive emotional stimuli, and active attempts to modulate such responses with cognitive reappraisal strategies, among adolescents with and without exposure to child maltreatment. Because child maltreatment is associated with heightened attention to threat and likely

TABLE 1 Distribution of Socio-Demographics and Psychopathology by Maltreatment Status (N = 42)

	Maltreated Children		Controls			
Characteristic	**%**	**n**	**%**	**n**	χ^2	***p***
Female	61.9	13	61.9	13	0.00	1.00
Race/ethnicity					17.06*	.002
White	9.52	2	52.38	11		
Black	22.7	8	19.05	4		
Latino	23.81	5	14.29	3		
Asian/Pacific Islander	0.00	0	14.29	3		
Other/biracial	28.57	6	0.00	0		
Parent educational attainment					9.12*	.028
High school or less	19.05	4	4.76	1		
Some college	28.57	6	4.76	1		
College degree	14.29	3	47.62	10		
Graduate school	28.57	6	28.57	6		
Right handed	85.7	18	85.7	18	0.00	1.00
Lifetime internalizing disorder[a]	33.33	7	4.76	1	4.91*	.027
Specific phobia	4.76	1	4.76	1		
Social phobia	0.00	0	0.00	0		
SAD	4.76	1	0.00	0		
Panic disorder	0.00	0	0.00	0		
GAD	14.29	3	0.00	0		
PTSD	9.52	2	0.00	0		
Major depression	14.29	3	0.00	0		
Lifetime externalizing disorder[b]	33.33	7	0.00	0	7.68*	.006
ADHD	14.29	3	0.00	0		
ODD	4.76	1	0.00	0		
CD	14.29	3	0.00	0		
	Mean	**(SD)**	**Mean**	**(SD)**	***t***	***p***
Age	16.26	(1.43)	16.89	(1.35)	1.07	.29
WASI total score	100.33	(15.81)	105.00	(12.23)	0.76	.45
Internalizing symptoms[a]	26.71	(13.07)	12.88	(6.69)	−4.35	<.001
Externalizing symptoms[b]	19.67	(9.70)	8.06	(4.48)	−4.78	<.001

Note: ADHD = attention-deficit/hyperactivity disorder; CD = conduct disorder; GAD = generalized anxiety disorder; ODD = oppositional defiant disorder; PTSD = posttraumatic stress disorder; SAD = separation anxiety disorder; WASI = Wechsler Abbreviated Scale of Intelligence.

[a]*Internalizing disorders include specific phobia, social phobia, separation anxiety disorder, panic disorder, generalized anxiety disorder, posttraumatic stress disorder, and major depression.*

[b]*Externalizing disorders include attention-deficit/hyperactivity disorder, oppositional defiant disorder, and conduct disorder.*

*$p < .05$, 2-sided test.

increases the salience of negative emotional cues, we predicted that child maltreatment would be associated with elevated amygdala response during passive viewing of negative stimuli but not positive stimuli. Given this prediction, we expected that greater cognitive resources would be required for maltreated adolescents to modulate emotional responses to negative stimuli. As such, we predicted that maltreatment would be associated with greater recruitment of PFC regions during effortful attempts to modulate responses to negative stimuli and heightened amygdala response during effortful regulation, suggesting poor amygdala modulation. In contrast, we did not expect to find differences in neural responses as a function of maltreatment during attempts to increase emotional responses to positive stimuli.

METHOD

Sample

A sample of 42 adolescents aged 13 to 19 years (mean = 16.57 years, SD = 1.41 years; 61.9% female) participated. Participants were recruited from a study of adolescents with and without child maltreatment exposure.[27] From this sample, we recruited 21 adolescents (13 female) with exposure to physical and/or sexual abuse. A control participant with the same age, sex, handedness, and no maltreatment exposure was matched to each maltreated participant. Exclusion criteria included psychiatric medication use (with the exception of stimulant medications for attention-deficit/hyperactivity disorder [ADHD], which were discontinued 24 hours before the scan for 1 participant), braces, claustrophobia, active substance dependence, pervasive developmental disorder, inability to speak English, and presence of active safety concerns. The maltreated and control groups were equivalent in age, IQ, and distribution of sex and handedness; all females were postmenarchal. Maltreated participants had elevated internalizing and externalizing disorders, lower parental educational attainment, and were more likely to be nonwhite. See Table 1 for sample socio-demographic characteristics.

Child Maltreatment

Child abuse was assessed using the Childhood Trauma Questionnaire (CTQ), a self-report measure,[28] and the Childhood Experiences of Care and Abuse (CECA), an interview administered by trained research assistants.[29] The CTQ assesses frequency of physical, sexual, and emotional abuse during childhood and has excellent psychometric properties including internal consistency, test–retest reliability, and convergent and discriminant validity with interviews and clinician reports of maltreatment.[28] The CECA assesses multiple aspects of caregiving experiences, including physical and sexual abuse. Interrater reliability for maltreatment reports is excellent, and validation studies find high agreement between siblings on reports of maltreatment.[29] Participants who reported physical or sexual abuse during the CECA interview or who had a score on the physical or sexual abuse subscales of the CTQ above a validated threshold[30] were classified as maltreated. A maltreatment severity score was computed by summing items from the CTQ physical and sexual abuse subscales, given that our sample was recruited based on exposure to these specific forms of abuse.

Psychopathology

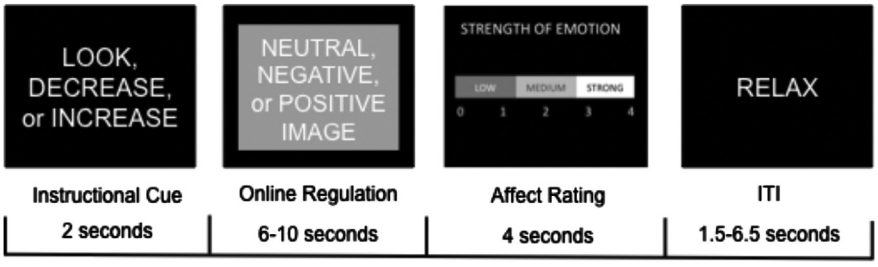
Participants completed the Diagnostic Interview Schedule for Children Version IV (DISC-IV)[31] to assess lifetime and past-year mental disorders. These interviews assessed the presence of internalizing disorders (specific phobia, social phobia, separation anxiety disorder, panic disorder, generalized anxiety disorder, posttraumatic stress disorder [PTSD], major depression) and externalizing disorders (ADHD, oppositional defiant disorder, conduct disorder). Table 1 provides information on psychopathology according to maltreatment.

Functional Magnetic Resonance Imaging (fMRI) Task

Participants engaged in a widely used event-related task to assess neural markers of emotional reactivity and regulation[20,22] that has previously been used with children.[32] Task design and contrasts for analysis were based on substantial prior literature.[20] Participants viewed neutral, negative, and positive images from the International Affective Picture System (IAPS).[33] Before each image, participants saw an instructional cue to "look," "decrease," or "increase" (Figure 1). During look trials, participants were instructed to allow their emotions to unfold naturally and not to engage in active strategies to modify their emotional response. During decrease and increase trials, participants engaged in specific cognitive reappraisal strategies to reduce their emotional response to negative stimuli or enhance their response to positive stimuli, respectively. Participants rated subjective emotional intensity after each trial on a 5-point Likert scale.

Participants completed a training session before scanning, at which they received instructions about how to respond to each cue, observed examples completed out loud by an experimenter, and

FIGURE 1 Emotion regulation task. Note: Stimuli were presented in 4 runs lasting 9 minutes each. The average valence and arousal of images and the number of faces within each image were equivalent for trials using negative stimuli (look and decrease) and trials using positive stimuli (look and increase). The instructional cue appeared for 2 seconds, the emotional stimulus appeared for 6 to 10 seconds, the rating screen appeared for 4 seconds, and the intertrial interval (ITI) lasted from 1.5 to 6.5 seconds. The emotional stimulus and ITI were jittered by sampling durations in the following manner: 50% of the fastest, 25% of the middle duration, and 25% of the fastest duration.



completed 45 practice trials using stimuli different from those used in the functional magnetic resonance imaging (fMRI) task. On decrease trials, participants were instructed to think about the image in a way that made it psychologically more distant (e.g., imagine the scene as far away, that the situation did not involve them, that the people in the image were actors), and on increase trials were instructed to think about the image in a way that made it psychologically closer (e.g., imagine the scene as close to them, that the situation is real, that they know the people in the image). These strategies have been used in previous studies of this task.[22,32,34]

Stimuli were presented in 4 runs lasting 9 minutes each. The average valence, arousal, and number of faces within each image were equivalent for look negative and decrease trials and for look positive and increase trials (all p>.45). The task included 26 trials of each type. The emotional stimulus and intertrial interval (ITI) were jittered (see Figure S1, available online).

Image Acquisition

Scanning was performed on a 3T Siemens Trio scanner at the Harvard Center for Brain Science, using a 32-channel head coil (see Supplement 1, available online, for acquisition parameters).

Image Processing

T1-weighted scans were processed using FreeSurfer version 5.3.[35] Preprocessing and statistical analysis of fMRI data was performed in Nipype.[36] The fMRI preprocessing included spatial realignment, slice–time correction, and spatial smoothing (6-mm full width at half maximum [FWHM]), implemented in FSL. Data were inspected for artifacts using artifact detection software (ART). Volumes with motion >2-mm or >3-SD change in signal intensity were excluded from analysis, and 6 rigid-body motion regressors were included in person-level models. Person- and group-level models were estimated in FSL. A component-based anatomical noise correction method[37] was used to reduce noise associated with physiological fluctuations. Following estimation of person-level models, the resulting contrast images were normalized into standard space, and anatomical co-registration of the functional data with each participant's T1-weighted image was performed using surface-based registration in FreeSurfer, which provides better alignment than other methods in children.[38] Normalization was implemented in Advanced Normalization Tools (ANTs) software.

fMRI Analysis

Regressors were created by convolving a boxcar function of phase duration and amplitude one with the standard hemodynamic response function for each phase of the task (instructional cue, stimulus, and rating) separately for neutral, negative, and positive stimuli for look, decrease, and increase trials. A general linear model was constructed for each participant. Individual-level estimates of blood oxygen level–dependent (BOLD) activity were submitted to group-level random effects models. We applied the standard analysis approach used in prior studies of this task[20,34] to create the following pairwise contrasts: passive viewing of negative (look negative > neutral trials) and positive (look positive > neutral) stimuli; and regulation of emotional responses to negative (decrease > look negative) and positive (increase > look positive) stimuli. Cluster-level correction in FSL ($z > 2.3$, $p < .05$) was applied.

We examined differences in BOLD response during contrasts of interest as a function of maltreatment in whole-brain analysis. We also examined amygdala activation using a region-of-interest (ROI) analysis, which is a standard analysis approach in studies using this task.[20,22] ROIs for trials involving negative stimuli were created by masking functional activation during the look negative > neutral contrast in the entire sample with a structural mask of the amygdala from the Harvard–Oxford Sub-cortical Atlas in FSL (separately for left and right amygdala, 20% threshold). This procedure was repeated for functional activation from the look positive > neutral contrast for trials involving positive stimuli. Parameter estimates were extracted from these ROIs for each participant, and group differences were examined using analysis of covariance. We controlled for highest parent educational attainment, race/ethnicity, and current internalizing and externalizing psychopathology symptoms in all behavioral, whole-brain, and ROI analyses of group differences based on maltreatment.

RESULTS

Behavioral Results

In the total sample, self-reported emotional intensity was higher during look negative ($t_{41} = 21.32$, $p < .001$) and look positive ($t_{41} = 20.06$, $p < .001$) trials than look neutral trials, lower during decrease than look negative trials ($t_{41} = -12.08$, $p < .001$), and higher during increase than look positive trials ($t_{41} = 8.05$, $p < .001$) (Table 2).

No differences were found in self-reported emotional intensity for any trial type as a function of maltreatment ($F_{1,36} = 0.04$–3.25, $p = .08$–$.85$; see Table S1, available online). The change in self-reported emotional intensity from look negative to decrease trials ($F_{1,36} = .01$, $p = .94$) and look positive to increase trials ($F_{1,36} = .58$, $p = .34$) did not vary by maltreatment.

Neural Response to Passive Viewing of Emotional Stimuli

Negative Stimuli. In the total sample, significant activation was observed for the look negative > neutral contrast in regions involved in salience processing (bilateral putamen, thalamus, amygdala), self-reflection and social cognition (bilateral precuneus, posterior cingulate, medial PFC, middle temporal gyrus, temporal pole), and cognitive control (right superior frontal gyrus, middle frontal gyrus) (see Table S2, available online; see also Figure 2). Amygdala response based on ROI analysis for all task contrasts is given in Table S3, available online. Amygdala response was greatest during increase trials followed by look positive, look negative, and decrease trials.

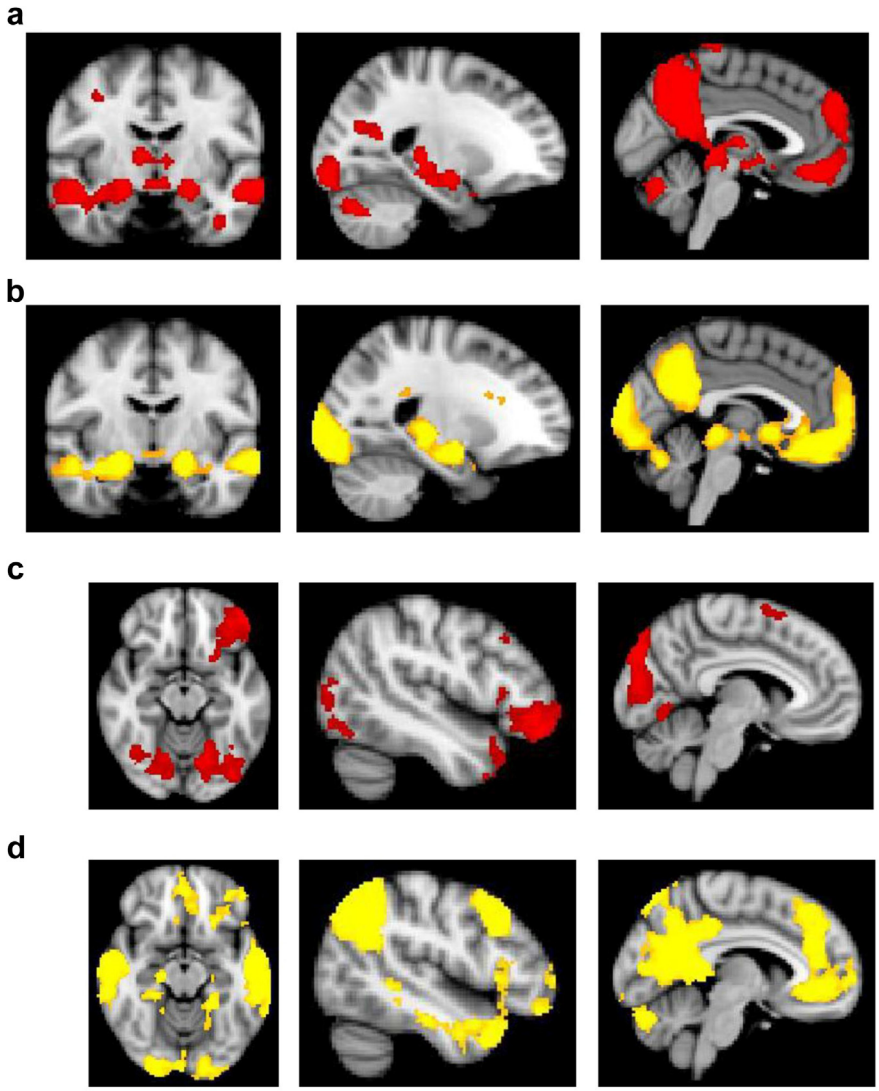
Positive Stimuli. Greater activation during the look positive > neutral contrast was observed in a nearly identical set

TABLE 2 Self-Reported Emotional Intensity by Trial Type for the Total Sample (N = 42)

Trial Type	Mean	(SD)	t_{41}	p
Look neutral	0.59	(0.42)	—	—
Look negative[a]	2.55	(0.51)	21.32*	<.001
Look positive[a]	2.33	(0.56)	20.06*	<.001
Decrease negative[b]	1.77	(0.50)	−12.08*	<.001
Increase positive[c]	2.93	(0.48)	8.05*	<.001

[a] *t Test compares these trials to look neutral trials.*
[b] *t Test compares these trials to look negative trials.*
[c] *t Test compares these trials to look positive trials.*
*p < .05, 2-sided test.

FIGURE 2 Neural response to passive viewing and effortful regulation of negative and positive emotional stimuli in the entire sample. (Panel a) Regions with significant blood oxygen level–dependent (BOLD) activation during look negative > look neutral trials. (Panel b) Regions with significant BOLD activation during look positive > look neutral trials. (Panel c) Regions with significant BOLD activation during decrease > look negative trials. (Panel d) Regions with significant BOLD activation during increase > look positive trials. Note: Cluster-level correction was applied in FSL, with $z > 2.3$ as our primary threshold and $p < .05$ as our cluster-level threshold.



of brain areas as for passive viewing of negative stimuli, including regions involved in salience processing (bilateral thalamus, amygdala), self-reflection and social cognition (bilateral precuneus, posterior cingulate, medial prefrontal cortex, middle temporal gyrus, temporal pole, fusiform gyrus), and also included the ventral striatum (Table S2, available online; see also Figure 2).

Maltreatment and Neural Response to Passive Viewing of Emotional Stimuli

Negative Stimuli. In the look negative > neutral contrast, maltreated adolescents exhibited greater activation than controls in regions involved in salience processing, including the bilateral putamen, thalamus, amygdala, and anterior insula (Table 3, Figure 3).

In ROI analysis, maltreated adolescents had greater activation in both left ($F_{1,36} = 5.50$, $p = .026$) and right ($F_{1,36} = 6.82$, $p = .014$) amygdala than non-maltreated adolescents (Table S3, Figure S1, available online). Greater severity of exposure to physical and sexual abuse was associated with elevated left ($\beta = 0.57$, $p = .042$) but not right ($\beta = 0.34$, $p = .23$) amygdala response.

No regions were more active for control than maltreated participants for the look negative > neutral contrast in whole-brain analysis or amygdala ROI analysis.

TABLE 3 Regions of the Brain Where Maltreated Adolescents Exhibited Greater Blood Oxygen Level–Dependent Signal Than Non-Maltreated Adolescents During Primary Task Contrasts

Trial Type	Region of Peak Activation	Cluster Size	x	y	z	z Value
Look negative > look neutral	Putamen[a] (R and L)	1,609 (L)	58	61	32	4.04
	Insula[a] (R and L)	1,550 (R)	61	65	41	3.51
	Amygdala[a] (R and L)		58	61	30	3.32
	Thalamus[a] (R and L)		53	53	36	3.19
	Extended amygdala[a] (R and L)		52	64	31	2.80
Decrease > look negative	Fusiform gyrus/inferior temporal gyrus[a] (R)	631	22	40	28	3.61
	Superior frontal gyrus[a] (R and L)		48	86	59	2.92
	Frontal pole[a] (R and L)		37	93	46	2.92
	Anterior cingulate[a] (R and L)		49	86	42	2.72
Look positive > look neutral	No significant clusters					
Increase > look positive	No significant clusters					

Note: Cluster-level correction applied in FSL, z > 2.3 was the primary threshold, and p < .05 was the cluster-level threshold. For regions with significant bilateral activation, the peak voxel is reported. Parent educational attainment, race/ethnicity, and internalizing and externalizing psychopathology were included as nuisance regressors in all analysis. L = left; r = right.

[a]*Denotes regions that were part of the same cluster.*

Positive Stimuli. No significant differences were observed between maltreated and control participants in neural response to positive relative to neutral stimuli in whole-brain analysis or amygdala ROI analysis (Table S3, Figure S1, available online).

Neural Response to Effortful Emotion Regulation

Negative Stimuli. In whole-brain analysis in the total sample, significantly greater BOLD signal during the decrease > look negative contrast was observed in multiple regions involved in cognitive control (bilateral superior frontal gyrus, left middle frontal gyrus, lateral orbitofrontal cortex, frontal pole) (Table 3, Figure 2). In ROI analysis, reduced activation was observed in left ($t_{41} = -2.14$, $p = .038$) and right ($t_{41} = -3.17$, $p = .003$) amygdala during effortful attempts to reduce responses to negative cues relative to passive viewing of negative emotional stimuli (Table S3, available online).

Positive Stimuli. Greater BOLD signal during the increase > look positive contrast in the total sample was observed in regions involved in cognitive control (bilateral middle and superior frontal gyri, anterior cingulate cortex [ACC]) and self-reflection (bilateral posterior cingulate, precuneus, medial PFC, left insula; Table 3, Figure 2). In ROI analysis, greater activation was observed during increase positive trials in left ($t_{41} = 1.97$, $p = .056$) and right ($t_{41} = 3.041$, $p = .004$) amygdala relative to passive viewing of positive emotional stimuli (Table S3, available online).

Maltreatment and Neural Response to Effortful Emotion Regulation

Negative Stimuli. In the decrease > look negative contrast, maltreated adolescents exhibited greater BOLD signal in regions of the PFC that were recruited during effortful regulation of responses to negative emotional stimuli in the total sample: bilateral superior frontal gyrus, frontal pole, and bilateral dorsal ACC (Table 3, Figure 4). No maltreatment-related differences in amygdala activation were observed in ROI analysis.

No regions were more active for control than maltreated participants for the decrease > look negative contrast in whole-brain analysis or amygdala ROI analysis.

Positive Stimuli. No maltreatment-related differences were observed in neural response to efforts to increase emotional response to positive stimuli in whole-brain analysis or amygdala ROI analysis.

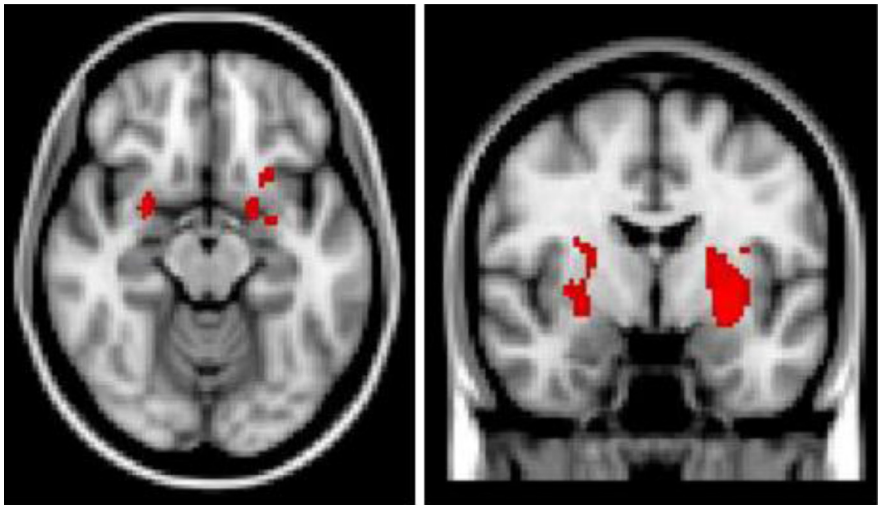
Brain–Behavior Associations

Finally, we examined whether self-reported affect was related to amygdala response during passive viewing and regulation trials. We found no associations between self-reported affect and amygdala response during look negative or positive trials. However, activation in the left amygdala in the decrease > look negative contrast was significantly associated with self-reported affect. Specifically, individuals who had greater left amygdala response in this contrast reported a smaller reduction in self-reported affect during decrease relative to look negative trials ($\beta = -0.36$, $p = .034$). Similarly, individuals who had greater left amygdala response in the increase > look positive contrast reported a greater increase in self-reported affect during increase relative to look positive trials ($\beta = 0.27$, $p = .036$). These brain–behavior associations did not vary according to maltreatment ($\beta = 0.0$–0.10, $p = .56$–$.99$).

DISCUSSION

Few studies have examined how maltreatment influences neural processes in children. Here, we found that child maltreatment is associated with elevated response in the amygdala and other nodes of the salience network in response to negative emotional stimuli. We also found that maltreated children recruited PFC regions involved in

FIGURE 3 Differences in neural response to passive viewing of negative emotional stimuli in maltreated and non-maltreated adolescents: regions with greater blood oxygen level–dependent (BOLD) activation during look negative > look neutral trials for maltreated participants relative to non-maltreated participants. Note: Cluster-level correction was applied in FSL with $z > 2.3$ as our primary threshold. Parent education, race/ethnicity, and current internalizing and externalizing psychopathology were included as nuisance regressors.



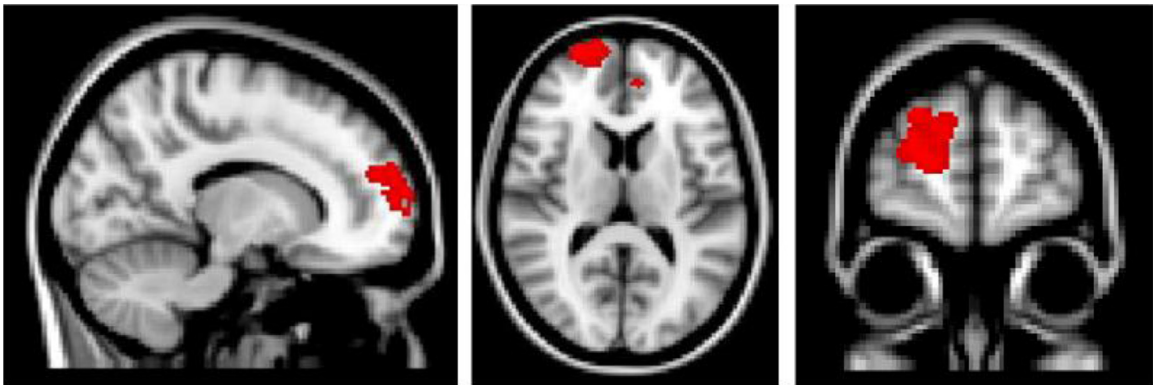
effortful control to a greater degree than non-maltreated youths during explicit regulation of responses to negative stimuli. Critically, however, maltreated youths were able to modulate amygdala response to negative cues during effortful regulation similarly to non-maltreated adolescents. This suggests that maltreated youths are able to effectively use cognitive reappraisal to modulate amygdala responses, despite having elevated amygdala reactivity to negative emotional stimuli.

Pronounced differences in neural response to negative emotional stimuli were observed as a function of child maltreatment. Maltreated adolescents exhibited greater activation in multiple nodes of the salience network[39] in response to negative emotional stimuli, including amygdala, thalamus, putamen, and anterior insula. Elevated amygdala response was confirmed with ROI analysis, and greater maltreatment severity was positively associated with left amygdala response to negative stimuli. These findings were robust to controls for internalizing and externalizing psychopathology, suggesting that elevated neural response to negative stimuli following child maltreatment is not simply the result of co-occurring psychopathology. Exposure to threatening experiences likely heightens the salience of negative emotional information due to the potential relevance for detecting novel threats. Indeed, exaggerated amygdala response to facial displays of anger have previously been observed in children exposed to violence,[12,13] consistent with event-related potential studies documenting amplified neural response to angry faces in abused children.[40,41]

We also found maltreatment-related differences in neural recruitment during effortful attempts to regulate emotional responses to negative stimuli. Relative to trials involving passive viewing of emotional stimuli, maltreated adolescents exhibited greater activation in superior PFC regions that are recruited during effortful regulation of emotion[20,22,32] than non-maltreated participants. Greater superior PFC recruitment as well as heightened activity in the dorsal ACC was observed in maltreated adolescents even after controlling for internalizing and externalizing psychopathology. This pattern suggests that modulation of negative emotional responses may require greater effort or more cognitive resources for maltreated youths, potentially as a result of the heightened amygdala response to negative emotional stimuli that we observed during passive viewing of negative images among maltreated adolescents. If maltreated youths must devote greater resources to modulating emotional responses, effective regulation may break down more easily in situations of high cognitive load or in the context of ongoing stress, which is consistent with evidence that the negative emotional effects of stressful events are heightened among those with maltreatment histories.[14,42]

Despite differences in recruitment of the PFC during effortful regulation, the reduction in amygdala activation during regulation relative to passive viewing of negative stimuli was similar for maltreated and non-maltreated participants. Although maltreated adolescents recruited the superior PFC and dorsal ACC to implement the emotion regulation skills that they learned before scanning to a greater degree than non-maltreated adolescents, they modulated their subjective emotional responses and amygdala response to negative stimuli to a similar degree. This suggests that maltreated children are able to effectively engage emotional control networks to modulate the amygdala when they are explicitly taught emotion regulation strategies. This is encouraging, given that empirically supported interventions for trauma-exposed children rely heavily on training in cognitive reappraisal.[43]

FIGURE 4 Differences in neural response to effortful attempts to regulate emotional response to negative stimuli in maltreated relative to non-maltreated adolescents: regions with greater blood oxygen level–dependent (BOLD) activation during decrease > look negative trials for maltreated participants relative to non-maltreated participants. Note: Cluster-level correction was applied in FSL with $z > 2.3$ as our primary threshold, and $p < .05$ as our cluster-level threshold. Parent education, race/ethnicity, and current internalizing and externalizing psychopathology were included as nuisance regressors.



Although no maltreatment-related differences were observed in neural response to positive stimuli during passive viewing or effortful attempts to increase positive emotional responses, these null findings should be interpreted with caution, particularly because they contrast with a prior study documenting elevated amygdala response to preattentively presented happy faces in children exposed to violence.[13] Future research is needed to determine whether alterations in neural responses to emotional stimuli among maltreated youths are specific to negative cues or general to both positive and negative stimuli.

The observed differences in neural recruitment during passive viewing and effortful regulation of negative emotional stimuli among maltreated youths may represent neurodevelopmental mechanisms linking child maltreatment with risk for psychopathology. Elevated amygdala reactivity has been observed in children with internalizing disorders[44,45] and predicts PTSD symptom onset following trauma exposure.[46,47] Greater recruitment of superior PFC regions during cognitive control of emotion and elevated dorsal ACC activation during cognitive control have also been observed in multiple forms of psychopathology.[48-50] Whether these patterns of neural activity ultimately place maltreated adolescents at greater risk for the onset of psychopathology represents a critical question for future research.

The current study is limited by a cross-sectional design that does not allow us to disentangle whether patterns of neural activation were present before the onset of psychopathology. Child maltreatment is strongly associated with risk for psychopathology,[1,2] which presents challenges for disentangling the effects of maltreatment versus psychopathology on neural function. We addressed this in the current study by controlling for psychopathology in all of our analyses; nevertheless, residual confounding is a possibility. Longitudinal studies are needed to determine whether neural processes associated with maltreatment are risk factors for psychopathology or consequences of disorder onset; studies of maltreated children who have not developed psychopathology can additionally shed light on processes involved in resilience. As noted above, null findings with regard to maltreatment and neural response to positive stimuli should be interpreted with caution and warrant replication in future studies that directly compare responses to negative, positive, and neutral stimuli. In addition, our maltreatment sample comprised adolescents with exposure to physical and/or sexual abuse but not solely emotional abuse. Emotional abuse is another common form of child maltreatment that has lasting consequences on mental health and neural structure and function.[51,52] Moreover, although we collected information on timing of exposure to maltreatment, this information was missing for approximately half of the maltreated sample, particularly for adolescents who were exposed to maltreatment as young children and could not accurately report on timing. Examining the impact of emotional abuse as well as timing and duration of maltreatment on responses to negative and positive emotional stimuli represents an important goal for future research. Finally, emotion regulation strategies were tested in a controlled environment after 1-on-1 instruction and practice before scanning. Although the techniques taught here are similar to those used in clinical settings, it may be that maltreated adolescents have greater difficulty regulating responses to negative emotional cues in more evocative real-world situations. In terms of methodological constraints, a limitation of cluster-level correction is that clusters may cross multiple anatomical regions, and it cannot be assumed that results are significant in all regions in a cluster.[53]

Child maltreatment appears to heighten the salience of negative emotional stimuli. Although maltreated adolescents are able to modulate amygdala activation to a degree similar to that of non-maltreated youths when taught specific emotion regulation strategies, they use PFC regions involved in effortful control of emotion to a greater degree to do so. Greater engagement of these regions might reflect that maltreated youths must devote greater cognitive resources to modulating emotional responses than non-maltreated children. Nevertheless, our findings suggest that training

in cognitive reappraisal strategies is likely to be an effective tool for reducing emotional reactivity to negative emotional stimuli among maltreated youths. &

CG Clinical Guidance

- Beginning therapy by introducing strategies for modulating arousal and negative emotional reactivity (e.g., relaxation training) before introducing cognitive restructuring and exposure therapy techniques is likely to be useful with youths who have been maltreated because they experience elevated reactivity to negative emotional cues.
- Cognitive restructuring techniques might need to be reviewed and practiced more frequently with maltreated youths because of the high level of cognitive resources required for them to modulate emotional responses using cognitive reappraisal.

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