Maternal Antecedents to Adolescent Girls' Neural Regulation of Emotion

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The purpose of this study was to investigate contributions of maternal emotional resources to individual differences in adolescents' functional connectivity during emotion regulation. Participants included 35 adolescent girls who completed an implicit emotion regulation task during fMRI. Mothers reported on the quality of their adult attachment and emotional awareness when youth were in elementary school. Higher anxious attachment and lower emotional awareness were significantly correlated with more positive amygdala–right ventrolateral prefrontal cortex connectivity, a pattern linked in prior research with ineffective emotion regulation and emotional difficulties. Further, there was an indirect effect of anxious attachment on adolescent connectivity through emotional awareness. These results suggest that compromised maternal emotional resources in childhood may be linked to atypical neural processing of emotions.

Adolescence is typically described as a period of transition when shifts occur in emotion regulation, cognition, neural structure/function, and emotional sensitivity (Ernst, Pine, & Harden, 2006; Somerville, Jones, & Casey, 2010; Steinberg, 2008). Specifically, adolescents tend to experience negative affect more frequently and intensely than adults, while their potential to self-regulate emotion matures more gradually (Somerville et al., 2010). Indeed, seminal theory and research on adolescent brain development suggest that elevated subcortical neural reactivity to emotional and stressful stimuli may constitute a source of risk for heightened emotional arousal (Ernst et al., 2006; Somerville et al., 2010). This reactivity is often regulated by cognitive control functions within the prefrontal cortex (Buhle et al., 2014; Ochsner et al., 2012), which have a strong potential for change during this period. Indeed, research examining the development of neural regulation of emotion in youth suggests a general improvement in cognitive control skills and maturation of regulatory circuits during adolescent development (Giuliani & Pfeifer, 2015; McRae et al., 2012; Pitskel, Bolling, Kaiser, Crowley, & Pelphrey, 2011; Silvers, Shu, Hubbard, Weber, & Ochsner, 2015; Somerville & Casey, 2010). There are, however, individual differences in the development of these circuits, with some youth developing regulatory skills sooner, while others maintain immature regulatory circuits for longer periods (Casey, Jones, & Hare, 2008; Hare et al., 2008). While research investigating sources of these differences is nascent, maternal attributes are important to consider, as disrupted emotion processing typically emerges in the context of maladaptive family environments (Goodman & Gotlib, 1999; Joormann, Cooney, Henry, & Gotlib, 2012). To elucidate how maternal functioning may affect these differences, the present study explored whether maternal emotional resources, including adult attachment and emotional awareness, contribute to individual differences in adolescent neural regulation of emotion.

Neural Correlates of Emotion Regulation

Successful emotion regulation depends on the interplay between subcortical limbic regions, such as the amygdala, and cortical regions that support

executive function, such as the prefrontal cortex (PFC; Ochsner & Gross, 2005). The amygdala serves as an affective detection system that underlies reactivity to emotionally evocative stimuli, whereas the PFC is part of a network of regions that guide emotion regulation (Buhle et al., 2014; Ochsner & Gross, 2005). In particular, the ventrolateral PFC (VLPFC) has been implicated in the selection (or suppression) of responses that are aligned (or interfere) with an individual's emotion regulation goals (Lieberman et al., 2007; Ochsner et al., 2012). Prior research suggests that the VLPFC plays a role in emotion valuation and salience (Dolcos, LaBar, & Cabeza, 2004; Dolcos & McCarthy, 2006) as well as regulatory control (Giuliani & Pfeifer, 2015). Specifically, the right VLPFC has been implicated during inhibition (Berkman, Burklund, & Lieberman, 2009; for a review, see Chikazoe, 2010), explicit emotion regulation (Ochsner, Silvers, & Buhle, 2012), and implicit emotion regulation (Flannery, Giuliani, Flournoy, & Pfeifer, 2017; Lieberman et al, 2007). Indeed, the rVLPFC is commonly activated across various emotion regulation-specific tasks, such as cognitive reappraisal, suppression, distraction, and affect labeling (for a review, see Berkman & Lieberman, 2009). Evidence supporting the role of the VLPFC as a regulatory region also stems from research examining VLPFC activity relative to amygdala activity. For instance, heightened activation in the VLPFC and diminished activation in the amygdala is observed during tasks that require engagement in reappraisal to reduce negative affect (Silvers et al., 2016). Furthermore, in a study that examined task-specific activation during an emotional go/no-go task, rVLPFC activity was greater during negatively valenced successful inhibition relative to successful response trials, while amygdala activity was significantly reduced during inhibition relative to response trials (Berkman et al., 2009).

Although early research on neural processing of emotions in adolescence primarily focused on examining isolated regions of interest, critiques of this approach (Pfeifer & Allen, 2012) emphasize the importance of considering the coordination between different regions, such as the amygdala and PFC, as reflected in functional connectivity analysis. In adults, negative connectivity between the amygdala and rVLPFC during cognitive reappraisal is associated with less self-reported negative affect (Ochsner, Bunge, Gross, & Gabrieli, 2002), suggesting that this pattern reflects a process wherein heightened ventral PFC activity serves to suppress activation of the amygdala, thereby dampening emotion reactivity (Hare et al., 2008).

Developmental Changes and Individual Differences in Neural Regulation of Emotion

During adolescence, there is a gradual trend toward improved regulation stemming from changes in prefrontal function. Specifically, findings from several studies suggest age-related increases in activation in regions of the PFC, including the VLPFC (Giuliani & Pfeifer, 2015; McRae et al., 2012), the dorsal anterior cingulate cortex (Pitskel et al., 2011), and the medial and middle frontal gyri (Pitskel et al., 2011) during self-regulation and emotion regulation. Recent research also suggests a normative developmental change in the functional association between the amygdala and the PFC. Specifically, amygdala–medial PFC functional connectivity during the presentation of fearful faces relative to baseline shifts from more positive connectivity in childhood to more negative connectivity by adolescence and young adulthood (Gee et al., 2013b). Supporting this trend, age also predicts more negative connectivity between the amygdala and right lateral PFC during active emotion regulation (Silvers et al., 2015). Thus, a pattern of negative connectivity may reflect the emergence of more mature top-down regulation of the amygdala by the PFC during adolescence (Hare et al., 2008).

Despite the normative developmental shift to negative connectivity across adolescence, there are individual differences in rates of maturation that may signal emotion regulation difficulties. In adolescence, more positive amygdala–ventral PFC connectivity is associated with less effective neural and behavioral regulation of emotion, as reflected in weaker habituation of amygdala activity (Hare et al., 2008), greater stress-reactive rumination (Fowler, Miernicki, Rudolph, & Telzer, 2017), and lower trait mindfulness (Creswell, Way, Eisenberger, & Lieberman, 2007). Prior studies also reveal that positive amygdala–ventral PFC connectivity in adolescence is associated with emotional distress, including higher levels of concurrent trait anxiety (Hare et al., 2008), generalized anxiety disorder (Monk et al., 2008), and depressive symptoms (Fowler et al., 2017), as well as subsequent anxiety symptoms (Davis, Miernicki, Telzer, & Rudolph, 2019). Thus, positive functional connectivity during affect labeling seems to reflect a less effective pattern of neural regulation of emotion

that is linked to compromised psychological and emotional functioning.

Predictors of Adolescent Neural Regulation of Emotion

Although research documents developmental and individual differences in the neural regulation of emotion, less is known regarding factors that contribute to these differences. The behavioral process of emotion regulation unfolds throughout childhood, especially in the context of parent socialization (Morris, Silk, Steinberg, Myers & Robinson, 2007). Family environment plays an important role in the acquisition of emotion regulation strategies in various ways. Parents teach their children strategies for coping with stress and emotion (Eisenberg, Cumberland, & Spinrad, 1998; Kliewer, Fearnow, & Miller, 1996; Monti, Rudolph, & Abaied, 2014), and children also learn through social referencing, modeling, and observations of interactions between their parents (Eisenberg et al., 1998; Morris et al., 2007). These avenues for learning set the emotional tone for daily interactions between family members and can shape children's emotion regulation (Abaied & Rudolph, 2014). Beyond parenting behaviors (modeling) and interactions (socialization), maternal characteristics also have been identified as a risk factor for atypical emotional development (Goodman & Gotlib, 1999). However, relatively little research investigates links between maternal characteristics and neural regulation of emotion. To address this gap, the present research aimed to identify individual differences in maternal emotional resources, particularly maternal adult attachment and emotional awareness, that may contribute to adolescent neural regulation of emotion.

Maternal attachment. The first goal of this study was to examine whether adult attachment in mothers predicts individual differences in neural regulation of emotion in adolescents. Adult attachment describes the emotional bond between adults and their attachment figures. Healthy attachment serves to promote specific behaviors that aid individuals during times of emotional distress (Hazan & Shaver, 1994). These behaviors are shaped by internal working models, which guide an individual's feelings, expectations, and cognitions about themselves and others. Differences in this perceived sensitivity of others during stressful situations underlie three dimensional styles of attachment: secure, insecure anxious, and insecure

avoidant (Hazan & Shaver, 1987). Adults who have a secure working model of attachment recognize that others are available during times of distress and actively deal with negative emotions. Adults with anxious attachment typically view others as insufficiently responsive to their needs, and they experience heightened emotionality and affective intensity (Cassidy, 2000; Hazan & Shaver, 1987; Mikulincer, Shaver, & Pereg, 2003). This propensity for emotional arousal paves the way for susceptibility to distress when they perceive others as being unavailable (Monti & Rudolph, 2014). On the other hand, adults with avoidant attachment engage in little self-disclosure with others, are uncomfortable with negative emotions, and minimize their expressions of distress. Because avoidantly attached individuals tend to withdraw from emotionally evocative situations, these individuals limit their intimacy with others and tend to deny or distance themselves from negative emotions (Cassidy, 2000; Mikulincer et al., 2003).

These emotion-linked styles of attachment may interfere with emotional resources available for caregiving. According to Bowlby (1982/1969), the attachment and caregiving systems often compete against each other, such that parents' own emotional needs may inhibit their ability to appropriately respond and attend to their child's needs. Indeed, insecure styles of adult attachment are associated with less responsivity, sensitivity, and ability to identify infant and child distress signals (Jones, Cassidy, & Shaver, 2015; Leerkes & Siepak, 2006; Van IJzendoorn, Kranenburg, Zwart-Woudstra, Van Busschbach, & Lambermon, 1991). This inability to accurately perceive and interpret signals may disrupt parents' socialization of emotion and, subsequently, children's emotional development. Supporting this idea, several studies have demonstrated that insecure adult attachment (as measured by the adult attachment interview or self-reports) predicts deficits in mothers' socialization of emotion and children's emotion regulation (Abaied & Rudolph, 2010; Gentzler, Ramsey, & Black, 2015; van IJzendoorn et al., 1991). In particular, insecure adult attachment predicts fewer engagement coping suggestions (e.g., problem solving and emotion expression) concurrently and over time in mothers of school-age children (Abaied & Rudolph, 2010). In turn, fewer maternal engagement coping suggestions predict greater salivary alpha amylase reactivity (suggestive of heightened emotional arousal) in children during a social challenge (Monti, Abaied, & Rudolph, 2014). Other studies of mothers' internal models of attachment

also link insecure attachment to children's observed negative affect, avoidance, and anxiety during parent–infant interactions and during a parent–child problem-solving session (Crowell & Feldman, 1988).

Collectively, this theory and research suggest that insecure adult attachment in mothers may lead to compromised emotional processing in their offspring. However, research has not yet examined the effects of maternal adult attachment on regulatory processes in the brain. Studying neural processes involved in emotion regulation may tap into implicit regulatory difficulties that are less accessible using behavioral measures. In this study, we focused on implicit emotion regulation, defined as the modification of emotional responses without the need for conscious regulation or explicit intentions (Koole & Rothermund, 2011). Studying functional connectivity as a neural signature of implicit emotion processing in adolescence may provide insight into regulatory difficulties that are less evident in observable aspects of emotional functioning until later in development (Scheuer, et al., 2017), allowing us to identify early predictors of less effective emotion processing. As a first step toward meeting this goal, this study explored whether maternal adult attachment predicts adolescent neural regulation of emotion. Specifically, we hypothesized that insecure adult attachment (anxious and avoidant) in mothers would predict less effective emotion regulation in adolescents as reflected in a pattern of more positive functional connectivity between the amygdala and rVLPFC during an implicit emotion regulation task.

Maternal emotional awareness. The second goal of this study was to examine whether emotional awareness in mothers predicts individual differences in neural regulation of emotion in adolescents. Emotional awareness involves the ability to identify one's emotions and describe one's emotions to others (Salovey, Mayer, Goldman, Turvey, & Palfai, 1995). Research indicates that low levels of emotional awareness in adults may represent a risk factor for poor emotional functioning (Gohm & Clore, 2002; Monti & Rudolph, 2014) and ineffective parent socialization practices (Monti et al., 2014), possibly leading to children's development of maladaptive emotion regulation. Indeed, caregivers who understand their emotions may be equipped to allocate more resources toward providing adaptive coping strategies to their child, whereas caregivers who are low in clarity may spend more energy attempting to understand how

they feel, thus depleting their emotional resources and leaving fewer available for caregiving. Consequently, caregivers with deficits in emotional awareness may be less optimal agents for guiding children's emotional development. These socialization practices work with other facets of emotional learning, such as modeling and observation, to shape the family environment and alter how children learn to modulate the intensity and expression of emotions (Goodman & Gotlib, 1999; Morris et al., 2007). Supporting these ideas, research links higher levels of maternal emotional awareness with more adaptive emotion regulation in children (Meyer, Raikes, Virmani, Waters, & Thompson, 2014). However, research to date has not examined the effect of maternal emotional awareness on adolescent neural regulation of emotion. To address this gap, this study examined whether maternal emotional awareness predicts adolescent neural regulation of emotion. Specifically, we hypothesized that lower emotional awareness in mothers would predict less effective emotion regulation in adolescents as reflected in more positive amygdala–rVLPFC functional connectivity during an implicit emotion regulation task.

Indirect effect via maternal emotional awareness. The third goal of this study was to examine whether there is an indirect effect of maternal insecure attachment on adolescent functional connectivity via maternal emotional awareness. Individuals who are avoidantly attached tend to recruit strategies that promote cognitive and emotional distancing (*deactivating strategies*; see Cassidy & Kobak, 1988). This distancing can include various methods of disengagement, such as inattention to threat, suppression of distressing thoughts, inability to recognize negative affect, and denial of fear (Mikulincer et al., 2003). Disengaging from emotion through either voluntary or involuntary responses may undermine emotional awareness. In contrast, individuals who are anxiously attached tend to engage in dysregulated responses that intensify their negative affect (e.g., magnifying emotional responses, preoccupation/rumination) during times of stress (*hyperactivating strategies*; see Cassidy & Kobak, 1988; Roisman, 2007). This negative emotional intensity may pave the way for frequent rumination and overreliance on partners for affect regulation (Mikulincer et al., 2003). However, chronic engagement of negative emotions paired with low self-efficacy for emotion regulation may similarly undermine awareness of one's emotions. Indeed, prior research suggests that both avoidant and anxious attachment predict poor emotional awareness

concurrently (Mallinckrodt & Wei, 2005) and over time (Monti & Rudolph, 2014). Based on this evidence, we hypothesized that maternal insecure attachment would have an indirect effect on positive amygdala–rVLPFC functional connectivity in adolescents via lower levels of maternal emotional awareness.

Study Overview

This study used a longitudinal, multimethod design to elucidate possible maternal contributors to adolescent neural regulation of emotion. The focus was on adolescent girls, given observed gender differences in neural processing of emotion. Specifically, relative to males, females exhibit stronger neural activation in subcortical and prefrontal regions during the passive viewing of negative emotional stimuli as well as less efficient neural regulation of emotion (for a review, see all Whittle, Yucel, Yap, & Allen, 2011). Additionally, mothers who engage in less active coping themselves and give fewer active coping suggestions to their children have daughters who also report less active coping, although this does not hold for sons (Kliewer et al., 1996), suggesting that mothers' socialization of coping is reflected in similar coping patterns in daughters to a greater extent than sons. Indeed, girls are more susceptible than boys to the effects of maternal emotional attributes, as reflected in significantly higher rates of internalizing problems in daughters than sons of depressed mothers (Goodman et al., 2011).

To examine the longitudinal impact of maternal characteristics on individual differences in neural regulation of emotion in adolescent girls, maternal adult attachment and emotional awareness were measured when youth were in middle childhood via self-report questionnaires. Self-reports of adult attachment are thought to reflect individual differences in sensitivity and responsiveness to relationship partners, which may be an indicator for how parents view and respond to their children. Consistent with this idea, these self-reports are significantly associated with caregiving in parent–child relationships (Jones et al., 2015). Neural regulation of emotion, as reflected in functional coordination between the amygdala and rVLPFC, was assessed using fMRI while adolescents completed an affect labeling task (Lieberman et al., 2007).

Consistent with prior research (Torre & Lieberman, 2018), we use the term "implicit emotion regulation" to convey the idea that affect labeling alters emotional response without the intent of the individual. Individuals who engage in affect labeling report diminished levels of negative affect as well as reductions in

autonomic responses (for a review, see Torre & Lieberman, 2018). Similar to cognitive reappraisal, affect labeling is associated with decreases in amygdala activity (Torre & Lieberman, 2018) and negative amygdala–rVLPFC connectivity (Lieberman et al., 2007; Payer, Baicy, Lieberman, & London, 2012). Furthermore, the two forms of emotion regulation exhibit common activation in regions of the VLPFC (Payer et al., 2012). Together, these findings suggest that both automatic regulation via affect labeling and intentional emotion regulation reduce negative affect and share similar underlying neural substrates.

In this study, the affect labeling task taps implicit emotion regulation during the presentation of emotional faces by contrasting two conditions: an affect labeling condition with a passive viewing one. We hypothesized that (1) maternal anxious and avoidant attachment (assessed in third and fourth grades) would predict a more positive pattern of amygdala–rVLPFC connectivity in adolescence (following ninth grade); (2) low maternal emotional awareness (assessed in fourth and fifth grades) would predict a more positive pattern of amygdala–rVLPFC connectivity in adolescence; and (3) maternal insecure attachment would have an indirect effect on positive amygdala–rVLPFC connectivity via lower levels of maternal emotional awareness. To examine the specificity of effects, we compared patterns of activation by emotional valence. We anticipated that relative to positive emotions, negative emotions would require stronger recruitment of the rVLPFC to regulate amygdala activity, suggesting that maternal emotional resources would have a stronger effect on children's response to negative emotions. We also examined whether amygdala–rVLPFC connectivity was associated with a behavioral index of emotion regulation—task performance during the labeling condition—to help validate the idea that positive functional connectivity serves as an indicator of less effective emotion regulation.

METHODS

Participants and Procedures

Participants included 35[1] adolescent girls (M age = 15.51, SD = 0.37; 71.4% White; 22.9% African

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[1]Participants were drawn from a sample of 44 girls who completed the affect labeling task following the ninth grade. The 35 youth included in the present analyses were selected based on completion of maternal behavioral measures from third grade through fifth grade, omitting one girl who was identified as a multivariate outlier using the Mahalanobis distance test.

TABLE 1
Descriptive Statistics and Intercorrelations among the Variables

Variable	M	SD	1	2	3	4	5
1. Anxious Attachment (third and fourth grades)	1.66	.74	–				
2. Avoidant Attachment (third and fourth grades)	2.08	.71	.75**	–			
3. Emotional Awareness (fourth and fifth grades)	4.08	.51	−.71**	−.67**	–		
4. Functional Connectivity: Negative Emotions			.34*	.10	−.45**	–	
5. Functional Connectivity: Positive Emotions			−.28	−.29	.07	.01	–

Note. *$p < .05$. **$p < .01$.

American; 2.9% Hispanic; and 2.9% American Indian/Native Alaskan) and their mothers who were part of a longitudinal study. The participants represented a range of family annual income levels (22.9% earning <$30,00; 20.0% earning between $30,000 and $75,000; and 57.1% earning >$75,000) and female caregiver education levels (11.4% earned a high school degree or less, 42.9% completed some college or an associate's degree, and 45.8% completed college or a professional degree). Families were originally recruited for a larger study through several urban and rural school districts in the Midwest when youth were in second grade. Questionnaires were completed annually by youth and parents; the parents were provided with monetary compensation for their participation, and children received a small gift. During the summer following ninth grade[2], a subset of girls from this longitudinal sample participated in a laboratory visit during which they completed an implicit emotion regulation task while undergoing functional magnetic resonance imaging.

Measures

Table 1 provides descriptive and psychometric information on the measures.

Maternal adult attachment. To assess maternal attachment, mothers completed the Parent Relationship Style Questionnaire when youth were in the third and fourth grades of the longitudinal study. The 13 items were specifically designed to assess two dimensions of insecure attachment: anxious attachment (five items; e.g., "I worry about being abandoned") and avoidant attachment (eight items; e.g., "I am somewhat uncomfortable being close with others"). Mothers rated on a 5-

point scale (*Not at All* to *Very Much*) how well these descriptions reflected their personal relationships. This measure was originally developed by Simpson, Rholes, and Nelligan (1992) and was later revised by Griffin and Bartholomew (1994). Scores were computed as the mean of each subscale. Because the attachment scores in third and fourth grades were significantly correlated ($rs = .68 – .86$, $ps < .001$), composite scores of maternal anxious attachment ($\alpha s = 0.89$ and 0.84) and maternal avoidant attachment ($\alpha s = 0.89$ and 0.88) across the two grades were used for analysis. Concurrent validity of this measure has been established through correlations with various aspects of relationship functioning, such as the way individuals appraise, interpret, and understand their experiences in close relationships, especially under conditions of threat (Roisman et al., 2007; Simpson et al., 1992).

Maternal emotional awareness. To assess parent emotional awareness, mothers completed a questionnaire (Monti & Rudolph, 2014) when youth were in the fourth and fifth grades of the longitudinal study. This measure assesses two facets of emotional awareness: clarity of emotions (five items; e.g., "I almost always know exactly how I'm feeling") and ability to describe emotions (five items: e.g., "I am able to describe my feelings easily"). Emotional clarity items were drawn from the Trait Meta-Mood Scale (Salovey et al., 1995), and emotional description items were drawn from the Toronto Alexithymia Scale (Bagby, Parker, & Taylor, 1994). Mothers rated on a 5-point scale (*Not at All* to *Very Much*) the extent to which each item described their emotions. Emotional awareness was computed as the mean of the subscales, with higher scores indicating more emotional awareness. Because the emotional awareness scores in fourth and fifth grades were significantly correlated ($r = .59$, $p = .001$), composite scores across the two grades ($\alpha s = .86$ and $.75$) were used for analysis.

[2]Two adolescents completed the laboratory visit during the summer following 10th grade due to prior ineligibility for the fMRI scan (i.e., metal braces).

Adult reports of emotional awareness have strong reliability in addition to convergent and discriminant validity (Bagby, Taylor, & Parker, 1994; Salovey et al., 1995).

Youth affect labeling task. During the fMRI scan session administered the summer following ninth grade, participants completed a modified implicit emotion regulation task (Lieberman et al., 2007), which included two conditions: passive viewing and affect labeling. During the passive viewing condition, participants were asked to simply observe emotionally expressive faces (*observe*; Figure 1a). During the affect labeling condition, participants were instructed to choose the correct label from a pair of words that corresponded with the presented expression (*label*; Figure 1b). The faces depicted negative (anger, sadness, fear) and positive (e.g., happy, calm, surprise) emotions. Blocks were presented by valence, and participants completed two blocks of each emotional valence (negative and positive) for each of the two conditions for a total of eight blocks. Each block included six trials, and each trial lasted six seconds with a 10-second rest period between blocks. Blocks were randomized across participants. Faces were on display for 3900 ms per trial during the viewing conditions, and participants were given 3900 ms to respond per trial during the labeling conditions. Correct responses were measured as the successful matching of the emotion label to the presented expression. Accuracy was calculated by taking the number of correct matches over the total number of labeling trials (12) for each of the negative and positive conditions. The photographs were selected from a standardized collection of faces (the NimStim), and all the photographs were women of European and African American descent (Tottenham et al., 2009).

Data Acquisition and Analysis

fMRI data acquisition. Imaging data were collected during the implicit emotion regulation task using a 3-Tesla Siemens Trio MRI scanner. The task included T2*-weighted echoplanar images (EPI) [slice thickness = 3 mm; 38 slices; TR = 2 s; TE = 25 ms; matrix = 92 × 92; FOV = 230 mm; voxel size 2.5 × 2.5 × 3 mm^3]. Structural scans consisted of a T2*weighted, matched-bandwidth (MBW), high-resolution, anatomical scan (TR = 4 s; TE = 64 ms; matrix = 192 × 192; FOV = 230; slice thickness = 3 mm; 38 slices) and a T1* magnetization-prepared rapid-acquisition gradient echo (MPRAGE;
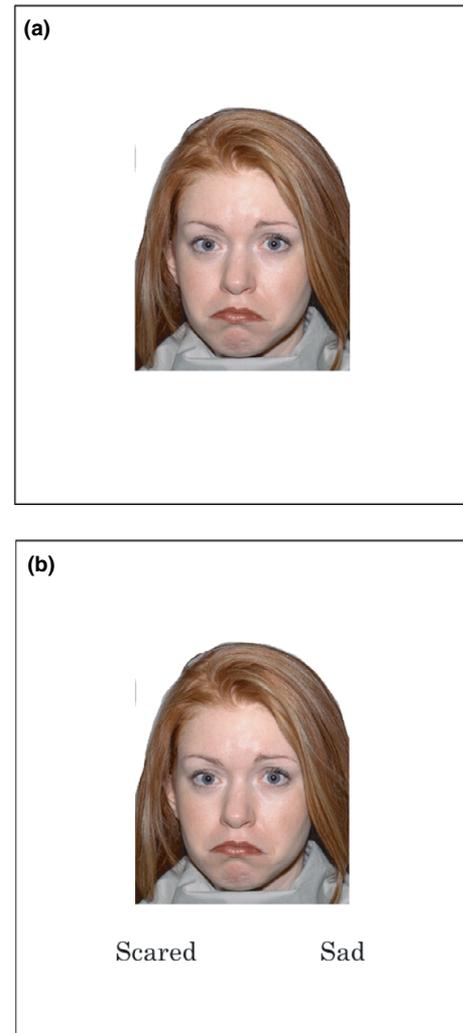

FIGURE 1   (a) Observe condition of the emotion regulation task. (b) Label condition of the emotion regulation task.

TR = 1.9 s; TE = 2.3 ms; matrix = 256 × 256; FOV = 230; sagittal plane; slice thickness = 1 mm; 192 slices).

fMRI data preprocessing and analysis. Statistical Parametric Mapping (SPM8; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK) was used to preprocess the fMRI data. Images were spatially realigned to correct for head motion. Volumes that were >2.5 mm of motion in any direction were included in a separate regressor of no interest; only one volume from one participant met this threshold for movement. Realigned functional data were coregistered to the MPRAGE, which was then segmented into cerebrospinal fluid, gray matter, and white matter. Functional and T2 structural images were then normalized and transformed into a

standardized stereotactic space as determined by the Montreal Neurological Institute. Functional data were smoothed by applying an 8mm Gaussian kernel, full-width at half-maximum, to increase the signal-to-noise ratio.

The general linear model (GLM) was used to perform statistical analyses for each participant's data; regressors included the two conditions: passive viewing and affect labeling. Each trial was convolved with the canonical hemodynamic response function. High-pass temporal filtering with a cutoff of 128 s was applied to remove low-frequency drift. Estimates from the GLM were then used to create the linear contrasts. Our goal was to examine emotion regulation, so we focused on the *label >observe* contrast because of the notion that putting thoughts into words (affect labeling) helps recruit top-down control processes. This labeling effectively mitigates emotion reactivity in the amygdala (Hariri, Bookheimer, & Mazziotta, 2000), whereas simply observing an emotional face would maintain emotion reactivity (Lieberman et al., 2007). Contrasts were created separately for negative and positive emotions to examine the specificity of neural regulation to negative versus positive emotions.

Connectivity between the amygdala and rVLPFC was the focus given research linking patterns of amygdala–rVLPFC connectivity during this task with emotion regulation. Psychophysiological interactions (PPI) were used to examine neural connectivity, with the bilateral amygdala as the seed region. Time courses used for correlation were averaged time series from anatomical ROIs. The amygdala region of interest (ROI) was defined by combining the left and right anatomically defined amygdala in the AAL atlas of the WFU PickAtlas. The automated gPPI toolbox in SPM (gPPI; McLaren, Ries, Xu & Johnson, 2012) was used (1) to extract the deconvolved times series from the bilateral amygdala ROI for each participant, creating the physiological variables, (2) to convolve each trial type with the canonical HRF to create the psychological regressor, and (3) to multiply the time series from the psychological regressors with the physiological variable to create the PPI interaction. The rVLPFC was defined as the Pars Triangularis and Pars Orbitalis using the AAL atlas in the WFU PickAtlas (Maldjian, Laurienti, Kraft, & Burdette, 2003; Tzourio-Mazoyer, et al., 2002), and was further restricted to be ventral to $z = 0$, including a total of 606 voxels. Parameter estimates of signal intensity were extracted from the PPI analysis.

RESULTS

Correlations Among Maternal Emotional Resources

Bivariate correlations were examined among the maternal emotional resources variables (see Table 1). There was a significant positive correlation between maternal anxious attachment and maternal avoidant attachment. Both insecure attachment styles were significantly positively correlated with lower levels of maternal emotional awareness.

Maternal Emotional Resources as Predictors of Adolescent Neural Responses

Bivariate correlations. To investigate whether maternal emotional resources were associated with neural activation, we examined bivariate correlations between maternal attachment and emotional awareness and adolescent functional connectivity, separately for negative and positive emotions (see Table 1). Maternal anxious attachment, but not avoidant attachment, was significantly correlated with more positive amygdala–rVLPFC functional connectivity in the context of negative emotions, but not positive emotions (Figure 2). Further, maternal emotional awareness was significantly correlated with less positive amygdala–rVLPFC functional connectivity in the context of negative emotions, but not positive emotions (Figure 3). Because there were no significant effects for maternal avoidant attachment or for functional connectivity in the context of positive emotions, further analysis focused on anxious attachment and amygdala–rVLPFC functional connectivity in the context of negative emotions[3].

Path analysis. Path analysis was conducted using the PROCESS macro in SPSS (Hayes, 2013) to examine the indirect effect of maternal anxious attachment on adolescent functional connectivity through maternal emotional awareness. This analysis was conducted using bootstrapping with 500 samples. Consistent with our hypothesis, after

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[3]Follow-up analyses were conducted using amygdala–left VLPFC connectivity to examine whether the specificity of effects for negative emotions was due to our focus on the right hemisphere, which is particularly sensitive to negative emotions. No significant associations were found between insecure maternal attachment, maternal emotional awareness, or labeling accuracy and amygdala–left VLPFC connectivity in the context of negative emotions ($ps> .08$) or positive emotions ($ps> .18$).
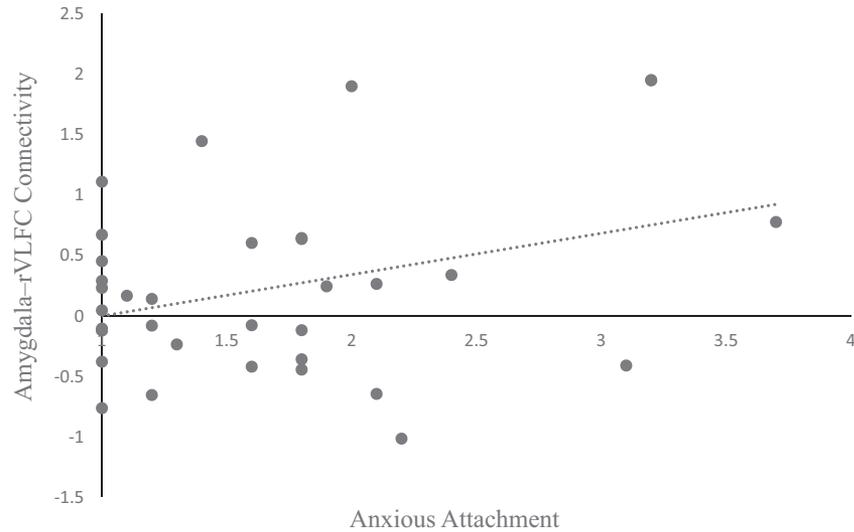
FIGURE 2   Maternal anxious attachment predicting amygdala–rVLPFC functional connectivity.
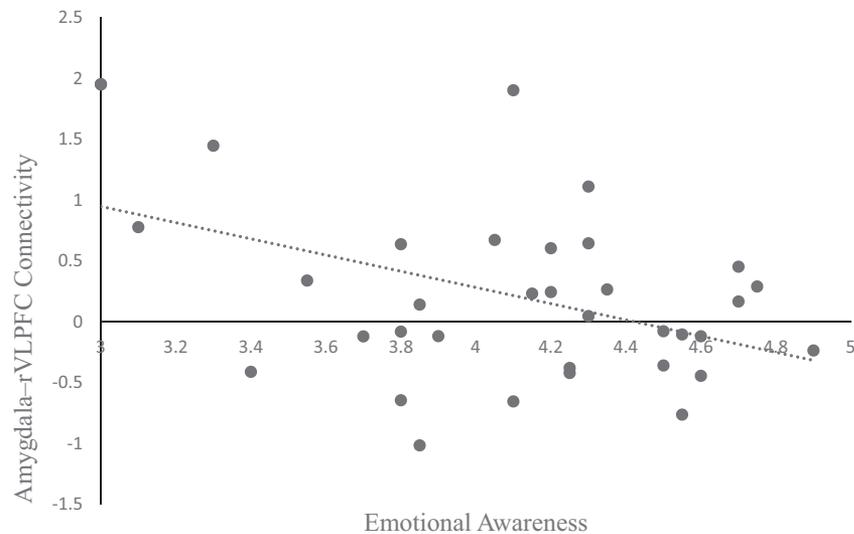

FIGURE 3   Maternal emotional awareness predicting amygdala–rVLPFC functional connectivity.

adding maternal emotional awareness to the model, the direct effect of maternal anxious attachment on positive functional connectivity ($\beta = 0.34$, $p < .05$) was no longer significant ($\beta = 0.039$, 95% CI = [−0.423, 0.500]). In addition, the indirect effect of anxious attachment on positive functional connectivity via emotional awareness was significant ($\beta = 0.31$, 95% CI = [0.034, 0.621]). Following Shrout and Bolger (2002), the strength of this effect was quantified by calculating the effect proportion (indirect effect/total effect). This analysis indicated that 91% of the total effect of maternal anxious attachment on positive functional connectivity was accounted for by low maternal emotional awareness.

Correlations between Neural and Behavioral Responses

Consistent with the idea that positive functional connectivity is an indicator of less effective emotion regulation, there was a significant association between positive amygdala–rVLPFC connectivity in the context of negative emotions and worse accuracy for labeling negative emotions ($r = −.35$, $p < .05$). There was no significant association

between functional connectivity in the context of positive emotions and accuracy for labeling positive emotions ($r = .07$, $p = .67$).

DISCUSSION

Although a significant body of research documents maternal contributions to child emotion processing (Goodman & Gotlib, 1999; Goodman et al., 2011), less is known about the extent to which maternal emotional attributes such as adult attachment and emotional awareness contribute to neural processing of emotion in offspring. The present research provides novel evidence that emotional resources of mothers predict individual differences in adolescent girls' neural regulation of emotion as reflected in functional connectivity between key emotion processing regions. Specifically, maternal anxious attachment predicted a pattern of neural regulation—namely positive connectivity between the amygdala and rVLPFC—previously linked to emotion regulation difficulties and emotional distress (Creswell et al., 2007; Hare et al., 2008; Monk et al., 2008) via lower levels of maternal emotional awareness, suggesting one pathway accounting for the intergenerational transmission of disrupted emotion processing.

Maternal Anxious Attachment and Adolescent Emotion Regulation

We found that earlier insecure maternal anxious attachment as measured in childhood predicted more positive amygdala–rVLPFC connectivity to negative emotions during an implicit emotion regulation task in adolescent female offspring. These patterns are consistent with prior theory and research linking self-reported adult attachment styles with children's emotion reactivity and regulation (Crowell & Feldman, 1988; Gentzler, Ramsey, & Black, 2015). Although this study is one of the first to examine the influence of maternal attachment on adolescents' neural regulation of emotion using a functional connectivity analysis, our results are consistent with other studies that have observed patterns of dysregulated amygdala activity in daughters of depressed mothers (Joormann et al., 2012) and children with a history of family adversity (e.g., parental deprivation; Tottenham et al., 2011). Importantly, our results are also consistent with a study that observed positive amygdala–rVLPFC functional connectivity during a similar affect labeling task in adults with a history of childhood family stress (Taylor, Eisenberger,

Saxbe, Lehman, & Lieberman, 2006). Indeed, there is strong evidence for the idea that exposure to caregiving adversity, whether in the form of maltreatment (Banihashemi, Sheu, Midei, & Gianaros, 2014; Dannlowski et al., 2013), maternal deprivation (Gee et al., 2013a), or harsh caregiving (Taylor et al., 2006), may result in long-term effects on children's neural structure and function. Anxiously attached mothers, characterized by their intense need for closeness and fear of abandonment, are likely to show excessive emotional responses to stress (Cassidy & Kobak, 1988). These characteristics may lead to impairments in children's emotional development by either pulling from resources available for caregiving or by culminating over time in less adaptive modeling and socialization of emotion. Future research should examine these possible pathways and determine whether the association between maternal adult attachment and offspring connectivity extends beyond the amygdala–rVLPFC circuitry to other regions in the frontoparietal or salience networks.

Contrary to our predictions, maternal avoidant attachment was not significantly associated with amygdala–rVLPFC connectivity in adolescent female offspring. The implicit emotion regulation task serves as a form of linguistic processing of emotion stimuli, and it encourages engagement with stimuli through affect labeling. Avoidantly attached mothers who distance themselves from aversive emotional information may model or suggest disengagement strategies to their children (Abaied & Rudolph, 2010), which can contribute to children's own responses to negative emotion (Abaied & Rudolph, 2011), such as inattention to emotionally evocative stimuli. However, these children may still suffer from disruptions in neural regulation. Future research using paradigms that promote more explicit emotion reactivity (such as an *in vivo* mood induction; see Westermann, Spies, Stahl, & Hesse, 1996) may better capture the attention of children of avoidant individuals and require more regulatory processing, thereby elucidating the nature of functional connectivity between cortical and subcortical regions.

Maternal Emotional Awareness and Adolescent Emotion Regulation

We also found that lower levels of maternal emotional awareness predicted more positive amygdala–rVLPFC connectivity in the context of negative emotions in adolescent female offspring. Although prior research links maternal emotional

awareness with parent-reported emotion regulation in children (Meyer et al., 2014), and parent neural activity during an affect labeling task with child-reported emotional competence (Telzer et al., 2014), results from the current study provide novel evidence that maternal emotional awareness also is linked to children's neural regulation of emotion. Mothers with lower levels of emotional awareness may spend extra resources on attempting to understand how they feel rather than attending to caregiving responsibilities and adaptively socializing their children. Consequently, these caregivers are likely less suitable socializing agents and may transmit messages about emotions that interfere with the development of optimal emotional processing in their children. In fact, prior research suggests that mothers with low emotional awareness are more likely to promote strategies that encourage avoidance of emotions and less likely to promote coping strategies that encourage their children to address the source of their emotional reactions (Monti et al., 2014). The results of the current study suggest that exposure to lower levels of maternal emotional awareness during childhood may instill youth with a propensity for positive amygdala–rVLPFC functional connectivity, possibly an implicit marker of learned ineffective emotion regulation.

Indirect Effect via Maternal Emotional Awareness

Consistent with expectations and prior prospective longitudinal research (Monti & Rudolph, 2014), we found that both maternal anxious and avoidant attachment predicted compromised maternal emotional awareness. Anxiously attached individuals who recruit hyperactivating strategies (Roisman, 2007) and avoidantly attached individuals who recruit deactivating strategies (Mikulincer et al., 2003) both engage in maladaptive coping that may undermine their ability to understand and label emotions over time. Moreover, maternal anxious attachment had an indirect effect on amygdala–rVLPFC functional connectivity via lower levels of maternal emotional awareness. Because children depend on caregivers for the regulation of their emotions until late childhood or early adolescence (Bridges & Grolnick, 1995; Saarni & Crowley, 1990), absence of this support (such as fewer available maternal emotional resources) may impede appropriate amygdala–prefrontal cortex development. Indeed, studies suggest that the presence of parents can influence children's neural reactivity to emotional stimuli (Conner et al., 2012). Even

images of mothers can dampen typical amygdala reactivity and promote more effective (negative) amygdala–mPFC connectivity in youth relative to images of strangers (Gee et al., 2014). Importantly, children and adolescents who demonstrate negative amygdala–mPFC connectivity in the presence of their mother's image have lower separation anxiety and higher attachment security than those who exhibit positive connectivity (Gee et al., 2014), supporting the idea that negative connectivity reflects more effective regulation of emotion. Thus, this parental buffering effect may act as a necessary intermediary in place of the immature prefrontal cortex; with typical development, the prefrontal cortex is gradually able to take over the role of the parent and mitigate emotional reactivity (Tottenham, 2015). Compromised maternal emotional resources may be a source of risk for less effective emotional buffering, leading to disrupted amygdala–prefrontal cortex connectivity in offspring over time.

The results of the current study suggest that compromised maternal emotional resources may be linked to the development of potentially ineffective neural regulation of emotion. Elucidating this pathway is a first step toward understanding maternal contributions to neural regulation of emotion. However, it will be important for future research to examine the mechanisms through which maternal emotional resources become internalized by offspring as neural regulation of emotion. Given evidence suggesting that low emotional awareness may permeate other aspects of maternal adjustment (e.g., depression or maladaptive responses to stress; Gohm & Clore, 2002; Monti & Rudolph, 2014) and parenting (e.g., parent expressions of emotion, responses to child stress, socialization of emotion; Meyer et al., 2014; Monti, Rudolph, & Abaied, 2014; Morris et al., 2007), offspring of mothers with low emotional awareness may become sensitized to negative emotions, fail to learn effective emotion regulation skills, or perhaps develop biased perceptions of the world. Understanding how these psychological mechanisms contribute to neural development will be an important next step for future research.

Strengths, Limitations, and Future Directions

Using an implicit emotion regulation task to elicit individual differences in functional connectivity provides insight into automatic, and perhaps less accessible, responses to emotional stimuli by providing a subtle tactic for regulating emotions

(affect labeling). Moreover, affect labeling and instructions for more explicit types of regulation (cognitive reappraisal) produce common neural responses to aversive stimuli (Burklund, Creswell, Irwin, & Lieberman, 2014), suggesting that neural responses during this task are also relevant to explicit emotion regulation. Indeed, there was a significant association between positive amygdala–rVLPFC connectivity and poorer task performance during the negative emotion trials, providing evidence for a link between neural and behavioral responses on this implicit emotion regulation task. Furthermore, prior analyses with an overlapping sample revealed that positive amygdala–rVLPFC connectivity is concurrently associated with rumination and depressive symptoms and prospectively predicts anxiety symptoms (Davis et al., 2019; Fowler et al., 2017). Thus, this pattern of neural connectivity in adolescence seems to reflect a less effective pattern of emotion regulation that may be an important marker for individual differences in responses to stress and psychopathology.

However, several methodological and conceptual limitations merit further examination. First, research implicates the rVLPFC in multiple aspects of emotion processing, including not only emotion regulation but also emotion valuation and salience (Dolcos et al., 2004; Dolcos & McCarthy, 2006; Kohn et al., 2014). Thus, heightened activation in the rVLPFC may reflect increased emotion reactivity, and positive amygdala–rVLPFC functional connectivity may reflect joint activation of these two regions in response to emotion. This emotion reactivity could interfere with labeling accuracy, as reflected in the observed association with task performance in the present study. However, this explanation is inconsistent with the observed pattern of negative connectivity in daughters of mothers with lower levels of anxious attachment, as one would not expect an inverse association between two emotion reactivity regions in well-adjusted girls. Relatedly, despite evidence suggesting that positive amygdala–PFC functional connectivity may be more or less normative at certain points in development and that this pattern may signal poor emotion regulation, as reflected in stress-reactive rumination (Fowler et al., 2017) and weaker habituation of the amygdala (Hare et al., 2008), research on age-related shifts in connectivity and subsequent outcomes warrants more attention. Moving forward, future tasks should use designs that clearly disentangle emotion reactivity and emotion regulation to confirm the nature of the task-specific connectivity between frontal and subcortical regions.

Second, because our study used an implicit emotion regulation task to elicit individual differences in neural activity, we were unable to capture the experiential and behavioral aspects of emotion regulation (Gross & John, 2003). Prior research supports links between affect labeling and reductions in the experiential aspects of emotion (self-report), reductions in autonomic responses (skin conductance response and heart rate), and importantly, changes in neural response such as decreased amygdala activity (for a review, see Torre & Lieberman, 2018). However, unlike studies in which explicit emotion regulation is induced, affect labeling lacks the intentional goal of reducing the emotional response as well as awareness by the individual that change is occurring. Thus, our implicit emotion regulation task may not serve as a successful regulatory strategy in some individuals. Future research should include self-reports of affect and observations of emotion-related behaviors to test the validity of implicit emotion regulation and to determine the extent of overlap between implicit versus explicit aspects of emotion regulation and their behavioral correlates.

Third, the results were specific to amygdala–rVLPFC connectivity in the context of negative emotions. One possible explanation for the specificity of effects to negative emotions may be the salience of negative emotions relative to positive ones in the amygdala (Morris et al., 1996), which would require more regulatory effort and associated recruitment of the rVLPFC. Alternatively, results may have been specific to amygdala–rVLPFC connectivity in the context of negative emotions due to increased sensitivity of the right hemisphere for processing negative emotion (Dolcos et al., 2004). Although results were not significant when we examined the association between maternal emotional resources and patterns of activation in the left hemisphere in the context of positive emotions, the absence of effects in the context of positive emotions does warrant attention. The implicit emotion regulation task used in this study presents the same number of unique negative (fear, sadness, anger) and positive (happy, calm, surprise) emotions. However, calm is characterized by lower levels of arousal, whereas fear, sadness, anger, happiness, and surprise are all characterized by higher levels of arousal (Tottenham et al., 2009). Thus, the number of high arousing and low arousing emotions differs between positive and negative task blocks. We

cannot determine whether this disparity in arousal accounts for the difference pattern of findings for the right versus left hemisphere and for negative versus positive emotions; thus, future research should replicate these findings using emotions that are matched on level of arousal.

Fourth, consistent with our conceptualization of insecure attachment as an antecedent of emotional awareness, we tested a model in which the measurement of attachment preceded the measurement of emotional awareness. Indeed, prior research supports the idea that insecure attachment predicts lower levels of emotional awareness over time, adjusting for earlier levels of emotional awareness (Monti & Rudolph, 2014). However, there may be a transactional association between insecure attachment and emotional awareness. Thus, it is also possible that low levels of emotional awareness may precede the development of an insecure attachment.

Fifth, in contrast to our pattern of findings, early-life stress (Colich et al., 2017) and maternal deprivation (Gee et al., 2013a) have been associated with negative amygdala–rVLPFC connectivity during implicit emotion regulation. Whereas these prior studies examined youth experience of severe stressors, such as exposure to maltreatment and institutional care, the present community sample of mothers were relatively well-functioning in terms of their average levels of insecure attachment and emotional awareness. As such, it is important for future research to examine whether the results of this study can be replicated in mothers with more significant deficits in emotional resources. Severe and milder forms of adverse caregiving may differentially affect development of neural circuitry; future research should therefore consider these differences. In addition, the patterns of negative amygdala–rVLPFC connectivity linked to severe stressors were observed in a female sample of 11-year-olds (Colich et al., 2017) and a mixed gender sample of 6- to 10-year-olds (Gee et al., 2013a), both younger than our sample of 15-year-olds, suggesting more severe stressors may prompt early maturation of neural systems (stress acceleration hypothesis; see Callaghan & Tottenham, 2016), which may be detrimental for development. Future research should attempt to tease apart whether the developmental timing of negative versus positive amygdala–rVLPFC connectivity helps determine its implications for adaptation. Examination of functional connectivity during emotion regulation at earlier and multiple time points also would help elucidate whether maternal characteristics predict changes in offsprings' neural function over time, and whether the associated changes depend on the timing of exposure to more maladaptive maternal characteristics.

Sixth, the focus of this research was on adolescent females, so it is unclear whether maternal emotional resources would similarly predict amygdala–rVLPFC connectivity in male offspring. Compromised maternal emotional resources may indeed affect girls and boys differently, given that gender differences in parent socialization of emotion are well documented (Brody, 1985/2000; Chaplin, Cole, & Zahn-Waxler, 2005). Specifically, parents differentially respond and attend to different emotions in sons and daughters (Chaplin et al., 2005; Radke-Yarrow & Kochanska, 1990), suggesting the effect of maternal emotional resources on neural processing of emotion may differ by gender. Because ethnic minority groups were underrepresented in the sample, it also will be important for future research to examine whether these results extend to more ethnically diverse samples.

Finally, the motion processing thresholds implemented in this study are less conservative than currently recommended for connectivity analyses. Indeed, recent techniques including framewise displacement and DVARS take into account volume-to-volume changes in motion, along with changes in signal intensity (Power, Barnes, Snyder, Schlagger, & Petersen, 2012). Although many of these techniques are currently used for resting state functional connectivity analyses, it would be beneficial for future research to use more conservative approaches.

CONCLUSIONS

This research provides novel evidence for the role of maternal emotional resources as contributors to adolescent neural processes, an area that has thus far received little attention. Findings revealed that maternal anxious attachment predicted more positive amygdala–rVLPFC connectivity via low levels of maternal emotional awareness. These findings highlight the importance of considering maternal attributes beyond maternal psychopathology as integral to shaping children's emotional development and perhaps a source of risk for disrupted emotional processing.

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