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Associations Between Parent Emotional Arousal and Regulation and Adolescents' Affective Brain Response

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Abstract

Parents' emotional functioning represents a central mechanism in the caregiving environment's influence on adolescent affective brain function. However, a paucity of research has examined links between parental emotional arousal and regulation and adolescents' affective brain function. Thus, the present study examined associations between parents' self-rated negative emotion, parent emotion regulation difficulties, and adolescent brain responsivity to negative and positive emotional stimuli. Participants included 64 12–14 year-old adolescents (31 females) and their female primary caregivers. Adolescents viewed negative, positive, and neutral emotional stimuli during an fMRI scanning session. Region of interest analyses showed that higher parent negative emotion was related to adolescents' greater ACC and vmPFC response to both negatively- and positively-valenced emotional stimuli; whereas, parent negative emotion was related to adolescents' greater amygdala response to negative emotional stimuli only. Furthermore, parent emotion regulation moderated the association between parent negative emotion and adolescents' brain response to negative emotional stimuli, such that parents with high negative emotion and high emotion regulation difficulties had adolescents with the greatest affective brain response. Findings highlight the importance of considering both parent emotional arousal and regulation in understanding the family affective environment and its relation to adolescent emotion-related brain development.

Adolescence is a critical period for the development of social and affective brain systems underlying future emotional competencies (Silvers, Buhle, Ochsner, & Silvers, 2013). Accordingly, youth in this developmental period are highly susceptible to the influence of emotional and social factors, including affective dynamics within the caregiving context (Schriber & Guyer, 2016). As a result, parent emotional arousal and regulation may represent key factors in adolescents' affective brain function. However, limited research has directly examined links between parent emotion and adolescent emotion-related brain function, even though affective neural systems are highly implicated in individual differences in future adjustment (Monk et al., 2008; Stertzer et al., 2005). Understanding

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parent factors linked to adolescent affective brain function is important for informing youth- and family-focused interventions aimed to enhance social and emotional outcomes.

A converging body of behavioral evidence suggests that caregiver and youth emotional functioning are closely linked. For example, evidence shows that high levels of parent negative emotional reactivity are associated with children and adolescents' increased expression of negative affect (Yap, Schwartz, Byrne, Simmons, & Allen, 2010), decreased emotion regulation ability (Eisenberg et al., 2003), and increased adjustment difficulties (Denham et al., 2000). Such associations between caregiver and youth emotional functioning may be explained by a number of potential pathways. First, parents' high negative emotionality may be passed on to children through genetic or gene by environment pathways (Rutter & Silberg, 2002). Second, parents with high levels of negative emotion, such as anger or sadness, may be more likely to utilize harsh or critical parenting strategies, which are linked to greater negative emotionality in youth and impaired psychophysiological regulation (Calkins, Graziano, Berdan, Keane, & Degnan, 2008; Del Vecchio & Rhoads, 2010). Third, parents high in negative emotion may model high expression of negative emotion for youth (Morris et al., 2007). Finally, parents high in negative emotion may be more likely to experience psychopathology, which is associated with impaired emotional outcomes in children and adolescents (Goodman et al., 2011). Across these potential pathways linking parent and child emotion, research suggests that parent and child emotional behaviors may be reciprocally related. That is, in addition to parent influences on child emotion, child factors can influence parent behavior, potentially furthering negative family cycles of emotion (Patterson, 1982).

Interestingly, while studies link increased negative emotion in the family context with youth's compromised emotional development, some evidence also suggests that children exposed to moderate levels of negative emotion may have more opportunities to develop emotion regulation skills and thus may exhibit greater emotional competence (Eisenberg et al., 2003; Greenberg et al., 1999). These discrepant trends characterizing the effects of parent negative emotion may suggest that other factors moderate associations between caregiver and youth emotion. One such potential moderator may be parents' emotion regulation ability. That is, parents who experience and express negative emotion, but who are also able to regulate this emotion may provide an optimal affective environment for youths' emotional development. In contrast, parents who experience and express high negative emotion but who have difficulties regulating this emotion may lead to a negative affective environment in which frequent, poorly modulated negative emotions in the family environment are internalized by youth. Accumulating evidence shows associations between parent emotion regulation and children's emotional and social functioning (Bariola et al., 2011). For example, one study found that parents' emotion regulation difficulties predicted children's internalizing symptoms, which was moderated by children's own emotion dysregulation (Han & Shaffer, 2013). In another study, Bariola and colleagues (2012) found that mothers' emotional suppression was significantly related to that of their child's (Bariola, Hughes, & Gullone, 2012). Hence, it is critical to examine both caregiver negative emotional arousal *and* regulation abilities to understand important emotion-related mechanisms by which the caregiving context is linked to child emotional development.

Existing literature using functional MRI indicates that child emotion-related factors, such as temperament and psychopathology, are related to children's and adolescents' neural processing of emotional stimuli (Guyer et al., 2015; Marsh et al., 2008). Yet, few studies have examined associations between parent factors and adolescent affective brain function. Although such research investigating links to brain *function* is limited, a growing body of research has demonstrated relations between parent and family factors (e.g., maltreatment, poverty, parenting style) and youth's brain *structure* (e.g., De Bellis et al., 1999; Luby et al., 2013; Whittle et al., 2011, 2013, 2014). For example, Whittle and colleagues (2014) found that observed positive parenting, characterized by warm/supportive parenting behaviors, was related to adolescents' attenuated volumetric growth in the amygdala and cortical thinning in the anterior cingulate cortex (ACC) and prefrontal cortex. Other work has also identified links between child hippocampal volume and family factors including maternal aggression (Whittle et al., 2011) and caregiver social affiliation (Schneider et al., 2012). Altogether, investigations of brain structure highlight the enduring neurobiological effects of the caregiving environment. However, while understanding the effects of family influences on brain structure is important, greater knowledge of adolescent *functional* brain responsivity is also necessary. In particular, adolescents' functional brain responses to emotion-related stimuli may offer important insights into moment to moment biological processes that underlie children's emotional functioning, which is particularly important to consider during adolescence, a period characterized by emotional and neurobiological plasticity (Crone & Dahl, 2012).

A small number of recent imaging studies have examined links between parent emotion and adolescent affective brain *function*. Tan et al. (2014) investigated relations between maternal observed negative emotion and adolescents' functional brain responses to peer rejection and acceptance during an MRI scan. Authors found that while maternal negative emotion was not related to adolescent brain responses during a peer rejection condition, maternal negative emotion was related to adolescent responses to peer acceptance. Specifically, adolescents with mothers who displayed greater negative emotion showed decreased responsivity in the amygdala, anterior insula, subgenual ACC, and nucleus accumbens, suggesting that maternal negative emotion may be associated with altered affective brain function in rewarding contexts. In another study, Telzer and colleagues (2014) investigated parent and child fMRI brain responses during an affect labeling paradigm and found correlations between parent and child brain responses in regions involved in social and emotion processing, including the amygdala, fusiform gyrus, and ventral lateral prefrontal cortex. Evidence from these initial functional imaging studies suggest that youth's affective brain function may be associated with parent negative emotion, but more work is needed.

Although previous studies have focused on one measure of caregiver emotional functioning (e.g., emotion expression), caregiver negative emotion and emotion regulation may interact in their association with youth's affective brain function. In this vein, the present study investigated the main and interactive associations between caregiver negative emotion, emotion regulation, and adolescents' brain response to negative and positive emotional stimuli using fMRI in three emotion-related regions of interest: amygdala, ACC, and ventral medial prefrontal cortex (vmPFC). Previous studies investigating brain responsivity to negative emotional events highlight the role of subcortical limbic regions, such as the

amygdala, in negative emotion generation or arousal (Hare et al., 2008). Although amygdala responsivity is most commonly linked to negatively- valenced stimuli, recent work also suggests the amygdala is responsive to positively- valenced stimuli (Davey et al., 2011). Researchers have postulated that the amygdala may encode the significance of arousing stimuli, thus responding to stimuli of both negative and positive valence. Likewise the vmPFC and ACC, which we will investigate here, are responsive to emotional stimuli and are consistently activated during emotion regulation paradigms (e.g., fear inhibition, emotional conflict regulation), suggesting these regions are primarily linked to regulation (for a review, see Etkin, Egner, & Kalishch, 2011). Thus, these are three key regions directly related to adolescents' emotion-related brain function, which may be particularly impacted by the emotional quality of the caregiving environment.

In sum, the primary goal of the present study was to investigate associations between parent emotional arousal, emotion regulation, and adolescent affective brain function in response to negative and positive emotional stimuli. These relations were examined cross-sectionally as an important initial step in informing future longitudinal studies capable of furthering our understanding of the direction of effects. Our first aim was to investigate relations between parent negative emotion and adolescent brain response to negatively- and positively- valenced emotional stimuli. For negative stimuli, we hypothesized that high parent negative emotion would be associated with heightened adolescent response in the amygdala (given that this would reflect greater emotional arousal) and attenuated responsivity in ACC and vmPFC (given that these youth might engage regulatory regions to a lesser extent). For positive stimuli, we hypothesized that high parent negative emotion would be linked with lower amygdala response, ACC, and vmPFC response, reflecting attenuated emotional responsivity and regulation to positive emotion. Our second aim was to investigate the moderating role of parent emotion regulation. For negative stimuli, we predicted that adolescents whose parents reported greater negative emotion and emotion regulation difficulties would display the highest level of responsivity in the amygdala and attenuated responsivity in ACC and vmPFC. For positive stimuli, we predicted that adolescents whose parents reported greater negative emotion and emotion regulation difficulties would display the lowest levels of amygdala, ACC, and vmPFC response.

Method

Participants included 64 adolescents (31 females) and their female primary caregivers recruited from the community. Adolescents ranged from 12 – 14 years old ($M = 12.55$, $SD = 0.64$). Caregivers were biological mothers (referred to throughout as parents/caregivers), with the exception of one adoptive mother. The majority of adolescents were European American (73.4%, 6.3% Asian American, 6.3% Latin American, 3.1% African American, 10.9% mixed/other) and most had family household annual incomes above \$100,000 (77.8%; 6.3% between \$75,000–100,000; 11.1% between \$60,000–74,999; 1.6% between \$50,000–59,999; 3.1% < \$50,000; $n = 63$). Ethnicity and income were representative of the community from which families were recruited.

Participants were recruited from a larger behavioral study on emotion and risk behaviors in community adolescents. As part of the larger study, families were recruited through mailings

to local households and flyers to middle schools in a suburban area in the mid-Atlantic United States. Inclusion criteria for the larger study included adolescents between 12–14 years, IQ at or above 80, and adequate English proficiency to complete questionnaires. Exclusion criteria for the larger study included a history of psychotic disorders or pervasive developmental disorder. Of the youth in the larger study, eighty-nine adolescents were interested in and eligible to participate in an additional MRI scanning session. MRI inclusion criteria were MRI safety eligibility, not currently pregnant, and no history of congenital brain defect or severe traumatic brain injury. Of those 89 eligible youth, eight adolescents began the fMRI scan but left the scanner before completing the emotion task, nine were excluded due to psychiatric medication use, and eight were excluded due to excessive head motion. Altogether, the final fMRI sample consisted of 64 adolescents. Excluded adolescents did not differ on measures of gender, race, family income, age nor primary study variables including parent negative emotion and parent emotion regulation (p 's > .05).

Procedure

Participants attended three study sessions. In the first two sessions (as part of the larger study), adolescents and their primary caregiver completed questionnaires and interviews assessing social-emotional functioning (e.g., emotion questionnaires) and other lab tasks. In the third session, adolescents completed the fMRI scan, scheduled approximately 2 – 6 weeks from the questionnaire/interview sessions. Functional MRI scans and structural images were acquired on a Siemens 3T Allegra MR scanner outfitted with a quadrature T/R birdcage head coil. During the scan, adolescents completed a structural scan and three functional scans (the emotion task, a reward task, and resting state). Stimuli were presented via a laptop using *Presentation* software and were rear-projected onto a screen and viewed through a mirror mounted to a birdcage head coil. The current study focuses on the emotion task.

fMRI Emotion Task

For the emotion task, adolescents viewed International Affective Picture System images (IAPS; Lang et al., 2008). The IAPS consists of standardized images designed to evoke emotional arousal, which are normed for valence and arousal. Following McRae et al. (2012), IAPS images that were appropriate for adolescents were selected. The IAPS paradigm was a rapid, event-related design that included 27 negative, 27 neutral, and 27 positive IAPS images presented in a pseudo-randomized order across three 6.5-minute runs. Each trial consisted of viewing an image (4 sec), rating the intensity of negative emotion (2 sec) and positive emotion experienced (2 sec) while viewing the image from 1 to 4 using a button box (1 = “weak”; 4 = “strong”), and an inter-stimulus interval jittered between 2s and 12s. Of note, the negative and positive emotion rating prompts were not counterbalanced across trials in order to maintain uniformity across images and runs. Trial order and interstimulus intervals were determined using optseq2 (<http://surfer.nmr.mgh.harvard.edu/optseq>).

Image acquisition

Functional images of the blood oxygen-level dependent (BOLD) response during the emotion task were collected using T2*-weighted gradient-echo echo planar images (EPI) [TR/TE: 2250/30ms; flip = 70°; field of view (FOV): 192mm; matrix size: 64 × 64; 40 axial 3mm thick/1mm gap slices]. For structural imaging, we acquired a T1-weighted MPRAGE anatomical image (TR/TE = 2300/3ms; FOV = 260mm; matrix size = 256 × 256; 160 1mm thick slices).

Behavioral Assessment Measures

Parent negative emotion

Parent reports of their subjective emotion experience were assessed with the Differential Emotions Scale-Revised short form (DES-R, Izard, 1972), which was completed at the second questionnaire session. The present study examined four subscales from the DES—sadness, anger, fear, and anxiety—and summed these scores to calculate a total parent negative emotion score. Each emotion subscale is comprised of five adjectives describing the emotional state. Participants rated on a 5-point scale (1 = *not at all/very slightly*, 5 = *very strongly*) the extent to which each word described the way they felt at the present moment. The DES-R has shown good psychometric properties (Izard, 1972) and demonstrated adequate reliability in the current MRI study sample ($\alpha = 0.79$).

Parent emotion regulation

In the first questionnaire/interview session, parents reported on their own emotion regulation using the 36-item *Difficulties in Emotion Regulation Scale* (DERS; Gratz & Roemer, 2004). The DERS is a widely used self-report of problems in emotion regulation, such as limited access to emotion regulation strategies and problems with goal directed behavior. Participants responded to items on a 5-point Likert scale (1 = *almost never*, 5 = *almost always*), with items such as, “When I’m upset, I have difficulty focusing on other things.” The DERS total scale has shown high reliability and consistency ($\alpha = 0.93$; Gratz & Roemer, 2004) and demonstrated good reliability in the current MRI study sample ($\alpha = 0.83$). Higher scores reflected poorer emotion regulation.

Data Analysis Plan

fMRI data preprocessing—fMRI data was analyzed with FSL 5.0 (FMRIB’s Software Library; Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012). Data were motion corrected, slice-timing corrected, and were B0 unwarped. Runs with extreme motion outliers—motion greater than 3mm in any direction for one TR or motion greater than 1.5 mm for 80% of TRs—were excluded. Data were smoothed with a 6mm FWHM Gaussian kernel, and a highpass temporal filter of 1/96 Hz was applied to remove frequency drifts in MR signal. Data were co-registered to each adolescent’s MPRAGE image and then to the Montreal Neurological Institute (MNI) template. For the first level analyses, FILM (FMRIB’s Improved Linear Model) was used, and regressors for the onset and duration of events of interest were convolved with a double gamma hemodynamic response function to create explanatory variables. Motion correction parameters were included as nuisance

regressors. For remaining runs with motion greater than 1.5 mm (< 3 mm) for one TR in any direction, FSL's motion outlier function was run, and additional motion confounds were included in first-level analyses. Following prewhitening, multiple regression was performed to estimate effects of the task. BOLD responses to negative, positive, and neutral images were examined, and the contrasts between conditions (negative $>$ neutral, positive $>$ neutral) were examined.

Primary data analyses—Region of interest (ROI) analyses of a priori regions were conducted using the Automated Anatomical Atlas (AAL, Tzourio-Mazoyer et al., 2002), including bilateral amygdala, ACC, and vmPFC. Mean contrast of parameter estimate (COPE) values from the first-level analysis of negative, positive, and neutral trials were extracted from ROIs. Negative $>$ neutral and positive $>$ neutral contrast scores were calculated. Linear regressions testing the main effects of parent negative emotion and emotion regulation difficulties and the parent negative emotion $\times$ emotion regulation interaction on each ROI were performed. Main effects were entered first, followed by interaction effects (Aiken & West, 1991), in order to examine the change in percentage of variance explained (R^2). Following recommendations by Cohen (1998), an R^2 value of 0.01 was considered a small effect size, 0.09 was considered medium, and 0.25 was considered large (Cohen, 1998). For all primary analyses, the predictor and moderator were mean-centered, and gender was covaried. False discovery rate procedures were used to adjust interaction coefficient p -values for multiple comparisons using an alpha-level of .05 (Benjamini & Yekutieli, 2001). If FDR-corrected interaction p -values were statistically significant ($p < .05$) or trend-level ($p < .10$), interactions were probed by examining simple slopes at -1 and $+1$ standard deviation of the moderator using Hayes' PROCESS macro in SPSS 18.0 (Hayes, 2013). In addition to hypothesis-driven ROI analyses, exploratory whole-brain analyses were conducted to investigate associations between adolescent whole-brain response to the negative $>$ neutral and positive $>$ neutral conditions and parent emotion variables (parent negative emotion, and parent negative emotion $\times$ emotion regulation interaction). Whole-brain analyses were conducted using FSL's FLAME mixed effects model and were corrected for multiple comparisons using a voxel-based threshold of $z > 2.8$ and cluster-based correction of $p < 0.05$.

Results

Preliminary Data Analysis

Primary study variables were examined for outliers (values greater than 3 standard deviations above the mean). Three regions had one outlier in the negative condition (right ACC, left vmPFC, and right vmPFC), and four regions had one outlier in the positive condition (left amygdala, right amygdala, left ACC, and right ACC). Parent negative emotion and parent emotion regulation scores each had one outlier. Following procedures in prior fMRI studies (e.g., Price et al., 2014), outliers were set to 3 standard deviations above the variable mean.

Covariates—Associations between primary study variables—adolescent BOLD response, parent negative emotion, parent emotion regulation—and potential covariates were

examined. Demographic variables, including adolescent age, gender, and race, were considered as potential covariates. Parent emotion regulation was related to adolescent gender ($t = -2.17$, $p < .05$), with parents of boys reporting higher levels of emotion regulation difficulties. Thus, adolescent gender was included in all primary regression analyses. No other significant associations emerged between potential demographic covariates and primary study variables.

Adolescent fMRI task emotion ratings—Mean negative and positive ratings of negative, neutral, and positive images were examined. Adolescents' mean negative emotion ratings were greater for negative images ($M = 3.39$, $SD = 0.47$) than for neutral images ($M = 1.50$, $SD = 0.45$; $t = 28.59$, $p < .001$) and positive images ($M = 1.32$, $SD = 0.36$; $t = 28.66$, $p < .001$). Mean positive emotion ratings were greater for positive images ($M = 2.98$, $SD = 0.46$) than for negative images ($M = 1.18$, $SD = 0.26$; $t = 28.93$, $p < .001$) and neutral images ($M = 2.06$, $SD = 0.53$; $t = 18.81$, $p < .001$). Higher ratings for negative images were associated with greater ACC response to the negative-neutral contrast (L: $r = -0.25$, $p = .06$; R: $r = -0.24$, $p = .06$) at levels approaching significance, but no associations emerged for amygdala and vmPFC. Higher positive ratings for positive images were related to lower right ACC response in the positive > neutral contrast and were marginally related to lower left ACC response (L: $r = -0.24$, $p = .06$; R: $r = -0.27$, $p < .05$). Again, no associations emerged for amygdala or vmPFC. Neither negative emotion nor positive ratings were significantly correlated with parent negative emotion or emotion regulation difficulties.

Aim 1: Associations with Parent Negative Emotion

Analyses shown in Table 1 and 2 provide regression results for each ROI controlling for child gender for the negative > neutral contrast and positive > neutral contrast, respectively.

Negative > neutral ROI analysis—We hypothesized that high parent negative emotion would be associated with heightened adolescent amygdala response and attenuated ACC and vmPFC response. Results of linear regressions revealed that higher parent negative emotion was related to higher levels of left amygdala, bilateral ACC, and bilateral vmPFC (see Table 1).

Positive > neutral ROI analysis—For positive stimuli, we hypothesized that high parent negative emotion would be associated with lower amygdala response, ACC, and vmPFC response. Results of linear regression analyses indicated that higher parent negative emotion was related to higher levels of bilateral ACC and bilateral vmPFC; however, no significant associations emerged for amygdala (see Table 2).

Exploratory whole-brain analysis—To explore additional brain regions correlated with parent negative emotion, whole-brain analyses were conducted correlating the negative > neutral contrast and positive > neutral contrasts with parent negative emotion. Table 3 includes MNI coordinates for cluster peaks of regions increasing with parent negative emotion. Bilateral dorsal medial PFC, right frontopolar PFC, right inferior frontal gyrus, right cerebellum, and left middle temporal gyrus showed greater BOLD response to the negative > neutral condition as parent negative emotion increased ($z = 2.8$, $p < .05$, cluster

corrected). For the positive > neutral contrast, bilateral dorsal medial PFC, bilateral frontopolar PFC, left cerebellum, right caudate, left middle temporal gyrus, and right inferior frontal gyrus showed greater BOLD response to the positive > neutral condition as parent negative emotion increased ($z = 2.8$, $p < .05$, cluster corrected).

Aim 2: Moderation by Parent Emotion Regulation

Negative > neutral ROI analysis—We hypothesized that the combination of high parent negative emotion and emotion regulation difficulties would be associated with higher levels of adolescent amygdala response to negative emotional stimuli. Consistent with hypotheses, linear regressions showed a significant parent negative emotion X emotion regulation interaction for bilateral amygdala (see Table 1). Interaction effects accounted for 12–13% of the variance explained beyond that accounted for by the main effects, representing a medium effect size. For both left and right amygdala, simple slopes for parents with high emotion regulation difficulties (+1 SD) were significantly different than zero, (L: $B = 1.59$, $SE = 0.45$, $p < .001$; R: $B = 0.99$, $SE = 0.42$, $p < .05$). Findings suggest that for parents with high emotion regulation difficulties, high negative emotion was associated with adolescents' greater amygdala responsivity to negative stimuli. Simple slopes for parents with low emotion regulation difficulties (−1 SD) were nonsignificant. Notably, adolescents with parents with low emotion regulation difficulties showed moderately high levels of amygdala response, regardless of parent's level of negative emotion (see Figure 1).

We hypothesized that the combination of high parent negative emotion and emotion regulation difficulties would be associated with *lower* levels of adolescent vmPFC response to negative emotional stimuli. Linear regressions showed a significant parent negative emotion X emotion regulation interaction for left and right vmPFC. Interaction effects accounted for 8–9% of the variance explained beyond that accounted for by the main effects, representing a small effect size. Contrary to hypotheses, the simple slope for parents with high emotion regulation difficulties (+1 SD) showed a positive association between parent negative emotion and vmPFC response, (L: $B = 2.84$, $SE = 0.56$, $p < .001$; R: $B = 1.71$, $SE = 0.38$, $p < .001$). In other words, for parents with high emotion regulation difficulties, high negative emotion was associated with *greater* adolescent vmPFC response. Again, simple slopes for parents with low emotion regulation difficulties (−1 SD) were nonsignificant (see Figure 1).

Similar to hypotheses for vmPFC responsivity, we hypothesized that high parent negative emotion in combination with high parent emotion regulation difficulties would be associated with *lower* levels of adolescent ACC response to negative emotional stimuli. Linear regressions showed that emotion regulation did not significantly moderate the relationship between higher negative emotion and adolescent right ACC response; however, the interaction effect for left ACC approached statistical significance (L: $p = .071$; R: $p = .24$). Similar to findings involving vmPFC, follow up analyses of simple slopes for left ACC indicated that parents with high emotion regulation difficulties (+1 SD) showed a positive association between parent negative emotion and left ACC response (L: $B = 2.62$, $SE = 0.61$, $p < .001$). That is, for parents with high emotion regulation difficulties, high negative emotion was associated with adolescents' *greater* ACC response. Once more, simple slopes

for parents with low emotion regulation difficulties (-1 SD) were nonsignificant, indicating that there were no differences across levels of negative emotion for those parents (see Figure 1).

Positive > neutral ROI analysis—We hypothesized that adolescents with parents high in negative emotion combined with high parent emotion regulation difficulties would show dampened amygdala, ACC, and vmPFC response to positive stimuli. However, contrary to hypotheses, no significant interaction effects emerged across ROIs.

Exploratory whole-brain analyses—To identify additional regions moderated by parent emotion regulation, whole-brain analyses were conducted correlating the negative > neutral contrast and positive > neutral contrasts with parent negative emotion and the parent negative emotion X emotion regulation interaction. No significant clusters emerged for these contrasts.

Discussion

Although evidence suggests caregiver and offspring emotional functioning are closely related (Bariola et al., 2011), no study to date has examined relations between parent emotional arousal and regulation and adolescent affective neural processing. The present study investigated associations between parents' emotional arousal and regulation and their adolescent's brain response during an fMRI emotional processing task. Results indicated that higher parent negative emotion was related to adolescents' greater ACC and vmPFC response to both negatively- and positively-valenced emotional stimuli; whereas, parent negative emotion was related to adolescents' greater amygdala response to negative emotional stimuli only. Further, parent emotion regulation moderated the relationship between parent negative emotion and youth's brain response to negative—but not positive—emotional stimuli. Specifically, high levels of parent negative emotion were associated with adolescents' greater bilateral amygdala and vmPFC response to negative emotional stimuli when parents also had difficulties regulating emotions. Altogether, the present cross-sectional study represents a first step in linking parent emotional functioning with adolescent affective neural processing and highlights the need for future longitudinal studies to investigate the temporal links between parent and child emotion-related neurobiology.

Parent Negative Emotion and Adolescent Brain Response

Behavioral studies show links between negative parent behaviors and increased emotional reactivity in youth (e.g., Yap et al., 2010). Consistent with this literature, findings indicated that adolescents with parents high in negative emotion showed higher amygdala response in the negative versus neutral image condition. The amygdala is a region involved in the processing of emotion, learning, and triggering of physiological stress responses, and thus is sensitive to affectively salient stimuli (Rodrigues, LeDoux, & Sapolsky, 2009). Adolescents' amygdala responsivity to negative emotional stimuli may reflect a dispositional emotional reactivity that may be shared genetically and/or transmitted environmentally from parent and child. For example, negative emotion in parents may spill over into parenting interactions, or parents may model these negative emotional responses. These parenting emotion-related

behaviors may be linked to greater emotion-related reactivity at the neurobiological level. At the same time, given reciprocal interactions between parents and adolescents, adolescent negative emotional reactivity may also be associated with increases in parent negative emotional arousal over time.

In regards to processing of positive stimuli, findings revealed no statistically significant relation between parent negative emotion and adolescent amygdala response to positive stimuli. This finding suggests that parent negative emotion may not be directly associated with youth's limbic processing of positive stimuli relative to neutral stimuli. However, parent negative emotion was not significantly related to *less* amygdala response to positive stimuli as reported in another study (i.e., Tan et al, 2014). Of note, Tan and colleagues utilized a different context for measuring parenting, a maternal support task, and a different fMRI task design.

With respect to medial prefrontal and cortical regions, we hypothesized that adolescents with parents high in negative emotion would exhibit lower ACC and vmPFC response to both positive and negative stimuli, suggestive of decreased monitoring and regulation of emotional states. Contrary to hypotheses, parent negative emotion was related to *increased* ACC and vmPFC response to both negative and positive emotional stimuli. In addition to ACC and vmPFC involvement, exploratory whole-brain analyses also showed heightened activation in other frontal regions to negative and positive emotional stimuli—including dorsal medial PFC, frontopolar PFC, and inferior frontal gyrus—as parent negative emotion increased. Together, results from both ROI and whole-brain analyses suggest prefrontal and cortical responses linked to parent negative emotion may reflect an overall increase in neurobiological processing to emotionally *arousing* stimuli regardless of valence. Of particular interest, the vmPFC is thought to be involved in the monitoring of affective cues, including the processing of contextual meaning of stimuli (Roy, Shohamy, & Wager, 2012). This monitoring may subsequently trigger the suppression or enhancement of affective responses in subcortical limbic regions (Myers-Schulz & Koenigs, 2012). Our findings suggest that youth whose parents have high negative emotion may monitor and evaluate emotionally arousing stimuli of both positive and negative valence in medial frontal regions.

Additionally, findings may imply that adolescents exposed to caregiving environments in which parents experience high levels of negative emotion may be more likely to engage regulatory regions, such as the vmPFC, to regulate heightened emotional responses. Youth with highly negative caregivers may automatically engage more regulatory resources to modulate emotional experiences. These youth may also have more opportunities to engage in emotion regulation in daily life and thus may do so relatively automatically. However, repeated or chronic exposure to negative emotional events via the caregiving environment may also be associated with the over-involvement or exhaustion of regulatory resources.

Finally, exploratory whole-brain analyses identified additional regions linked to parent negative emotion, including regions involved in emotional experience (i.e., cerebellum) as well as areas involved in reward (i.e., caudate), visual (i.e., middle temporal gyrus), and social processing (i.e., inferior frontal gyrus). Of particular interest, the inferior frontal gyrus may be involved in emotional recognition and contagion, such that this region may play an

intriguing role in parent-child emotional transmission (Shamay-Tsoory, 2011). Accordingly, future studies should explore these regions in relation to parent and child emotional functioning.

Moderation by Parent Emotion Regulation

Region of interest analyses indicated that parent emotion regulation abilities moderated the relationship between parent negative emotion and adolescent neural response to negative stimuli. However, parent emotion regulation abilities did not moderate this relationship with respect to positive stimuli. Perhaps, parents may model or socialize emotion regulation, particularly for negative emotion.

With respect to limbic response to negative stimuli, adolescents from caregiving contexts in which parents experienced both high levels of negative emotion arousal and emotion regulation difficulties showed higher levels of amygdala response to negative emotional stimuli. This finding suggests that poor parent emotion regulation abilities may exacerbate parent-offspring transmission of negative emotionality. Additionally, considering literature highlighting the mutual effects of parent-child negative emotion, highly negative youth may lead parents to feel more negative emotion, especially in the absence of strong emotion regulation abilities. Interestingly, when parents reported low levels of emotion regulation difficulties, parent negative emotion was not significantly related to adolescent amygdala response. However, adolescents of parents with low emotion regulation difficulties (regardless of low or high negative emotion) showed high mean levels of amygdala responsivity (see Figure 1), similar to or even higher than mean levels of adolescents with parents high in negative emotion and dysregulation. This pattern was unexpected, and it is unclear why adolescents with regulated parents would show high levels of amygdala response. Perhaps these adolescents are infrequently exposed to high levels of negative emotion in the family context; thus, these youth showed greater reactivity to novel, negatively-charged stimuli. As this is the first study examining links between parents' emotion regulation and adolescents' neural function, future research is needed in order to replicate this finding.

As above, adolescents with parents high in negative emotion showed higher ACC and vmPFC engagement to negative stimuli. This relationship was significantly strengthened when parents also had difficulties regulating emotions for adolescent bilateral vmPFC and at a level approaching significance for left ACC. Interestingly, when parents reported low levels of emotion regulation difficulties, the level of parent negative emotion was not related to adolescent ACC or vmPFC brain response, and the ACC/vmPFC response in youth with parents with low emotion regulation difficulties was low. These findings suggest that the association between dispositional negative emotion in parents and negative emotional processing is lessened when parents are able to effectively regulate this negative emotion. However, when negative emotion is dysregulated and presumably expressed in the caregiving context, the coupling of parent negative emotion and dysregulation is linked to increased medial prefrontal engagement to negative emotional stimuli, particularly in the vmPFC.

Limitations and Future Directions

The present study has several limitations that should be addressed in future research. First, the cross-sectional design of the present study limits our ability to draw conclusions regarding reciprocal influences of parent and adolescent emotional functioning. For example, adolescents who are emotionally reactive may influence their caregiver's ability to regulate strong emotions or may influence their caregiver's level of emotional arousal. Accordingly, future studies using longitudinal designs are necessary for understanding the direction of effects. Secondly, although we highlight the importance of caregiving in the current study, many other environmental factors may affect adolescent affective brain activation and should be explored further, such as family socioeconomic status (Kim et al., 2013) and neighborhood quality (McBride Murry, Berkel, Gaylord-Harden, Copeland-Linder, & Nation, 2011). Additionally, although we chose to examine theoretically-driven a priori ROIs, these regions did not emerge as significant in the exploratory whole-brain analysis. Of note, we did find similar, somewhat overlapping patterns of activation, particularly in prefrontal regions that have also been implicated in aspects of emotional processing such as emotion regulation (e.g., dlPFC; Golkar et al., 2012). Future research should explore other cortical regions that may be involved in adolescent affective processing.

Furthermore, the present study's sample consisted of primarily European-American middle to high-income families from the community, which may hinder the generalizability of findings to more diverse or clinical groups of adolescents. Although the current study predominantly focuses on the role of mothers on adolescent brain function, the findings must be tempered by the fact that the study employed community-based adolescents who likely experience lower levels of negative affect and psychosocial stressors compared to clinical samples of youth. Additionally, the present study investigated mothers' emotional functioning; however, future studies should examine paternal associations with adolescent emotional development to assess the generalizability of the findings across caregivers. Finally, this study utilized a state level assessment of parent negative emotion, which may limit the generalizability of our findings to other contexts. Future work would benefit from the addition of trait level affective measures as well as the assessment of parent negative emotion across varying contexts.

Despite these limitations, the present study offers unique insight into the interactive nature of caregiver negative emotion and emotion regulation and its relation to adolescent affective brain processing. We found that higher caregiver negative emotional arousal was linked to greater neural responsivity to emotional stimuli, and that parents' emotion dysregulation may strengthen these associations for negatively-valenced information. Given these findings, future studies examining how adolescent brain function relates to youth emotional and social competencies are needed, as brain function may represent one mechanism through which parent emotion impacts child psychosocial functioning. Still, findings from the present study represent a first step in identifying important connections between parent emotion and child emotion-related brain function, which may have implications for parent or family focused intervention efforts. Our results suggest that interventions may focus on improving parent's emotional arousal and emotion regulation in order to affect youth's emotional development, even at the neurobiological level.

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Figure 1. Parent negative emotion X emotion regulation difficulties predicting adolescent amygdala, ACC, vmPFC response. ER = emotion regulation; SD = standard deviation.

Table 1
Region of Interest Regression Analyses Predicting Adolescent Neural Response to Negative Emotion Stimuli

	B	SE	Uncorrected p-value	Corrected p-value	R ²
Left Amygdala					
Step 1					.10
Parent negative emotion	1.17 *	.46			
Parent ER difficulties	-0.14	0.12			
Child gender	1.02	2.92			
Step 2					
Negative emotion X ER	0.08 **	0.03	.003	.007	.13 **
Right Amygdala					
Step 1					.06
Parent negative emotion	0.63	0.42			
Parent ER difficulties	-0.16	0.11			
Child gender	-0.79	2.70			
Step 2					
Negative emotion X ER	.07 **	0.02	.005	.012	.12 **
Left ACC					
Step 1					.24 **
Parent negative emotion	2.23 **	0.60			
Parent ER difficulties	0.14	0.16			
Child gender	-4.37	3.78			
Step 2					
Negative emotion X ER	.08 *	0.03	.029	.071	.06 *
Right ACC					
Step 1					.23 **
Parent negative emotion	1.55 **	0.44			
Parent ER difficulties	0.10	0.11			
Child gender	-3.70	2.73			
Step 2					

	B	SE	Uncorrected p-value	Corrected p-value	R ²
Negative emotion X ER	0.04 [†]	0.03	.098	.240	.04 [†]
Left vmPFC					
Step 1					
Parent negative emotion	2.39 ^{**}	0.56			.27 ^{**}
Parent ER difficulties	0.08	0.15			
Child gender	0.93	3.53			
Step 2					
Negative emotion X ER	0.09 ^{**}	0.03	.006	.015	.09 ^{**}
Right vmPFC					
Step 1					
Parent negative emotion	1.43 ^{**}	0.38			.21 ^{**}
Parent ER difficulties	0.00	0.10			
Child gender	0.77	2.39			
Step 2					
Negative emotion X ER	0.06 [*]	0.02	.011	.027	.08 [*]

[†] $p < .10$,
^{*} $p < .05$,
^{**} $p < .01$

Note. For child gender, female was coded as 0. vmPFC = ventral medial prefrontal cortex; ACC = anterior cingulate cortex; ER = emotion regulation.

Table 2

Region of Interest Regression Analyses Predicting Adolescent Neural Response to Positive Emotion Stimuli

	B	SE	Uncorrected p-value	Corrected p-value	R²
Left Amygdala					
Step 1					.01
Parent negative emotion	0.31	0.38			
Parent ER difficulties	0.00	0.10			
Child gender	0.28	2.36			
Step 2					
Negative emotion X ER	-0.02	0.02	.33	.81	.02
Right Amygdala					
Step 1					.02
Parent negative emotion	0.29	0.33			
Parent ER difficulties	-0.55	0.09			
Child gender	0.12	2.06			
Step 2					
Negative emotion X ER	-0.01	0.02	.50	1.0	.01
Left ACC					
Step 1					.20**
Parent negative emotion	1.70**	0.48			
Parent ER difficulties	0.04	0.12			
Child gender	-1.08	3.00			
Step 2					
Negative emotion X ER	0.03	0.03	.37	.91	.01
Right ACC					
Step 1					.29**
Parent negative emotion	1.63**	0.36			
Parent ER difficulties	0.01	0.09			
Child gender	-3.20	2.24			
Step 2					
Negative emotion X ER	0.02	0.02	.43	1.0	.01

	B	SE	Uncorrected p-value	Corrected p-value	R ²
Left vmPFC					
Step 1					.26**
Parent negative emotion	1.83**	0.45			
Parent ER difficulties	0.07	0.12			
Child gender	-2.63	2.82			
Step 2					
Negative emotion X ER	0.05	0.03	.06	.15	.05
Right vmPFC					
Step 1					.20**
Parent negative emotion	1.94**	0.55			
Parent ER difficulties	-0.10	0.14			
Child gender	-4.56	3.42			
Step 2					
Negative emotion X ER	0.03	0.03	.34	.83	.01

* $p < .05$,

** $p < .01$

Note: For child gender, female was coded as 0. vmPFC = ventral medial prefrontal cortex, ACC = anterior cingulate cortex; ER = emotion regulation.

Table 3
Whole-brain Cluster Peaks of Regions Increasing with Parent Negative Emotion

Region	$Z_{\max}$	N voxels	Peak MNI Coordinates		
			X	Y	Z
<i>Negative > Neutral</i>					
Right dorsal medial PFC	4.36	2445	0	68	22
Right frontopolar PFC	4.29	479	34	50	-14
Right inferior frontal gyrus	4.32	358	60	16	10
Right cerebellum	4.16	275	32	-76	-34
Left middle temporal gyrus	4.26	257	-64	-40	0
<i>Positive > Neutral</i>					
Right dorsal medial PFC	5.03	5101	18	42	44
Right frontopolar PFC	4.60	877	34	62	0
Left cerebellum	5.05	863	-36	-82	-36
Right caudate	3.96	294	14	8	8
Left middle temporal gyrus	3.75	274	-66	-40	-2
Right inferior frontal gyrus	3.94	251	58	18	10

Note. Coordinates represent peak voxels in each region at $z > 2.8$ with a corrected cluster significance threshold of $p < .05$. PFC = prefrontal cortex.