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Cognitive control reduces sensitivity to relational aggression among adolescent girls

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Abstract

Relational aggression describes a type of aggression that aims to hurt others through relationships and includes behaviors such as gossip and ostracism. This type of aggression is very common among adolescent girls; and in its more intense forms has been linked with poor psychosocial outcomes, including depression and suicide. In the present study we investigated whether individual differences in sensitivity to relational aggression among adolescent girls predicted recruitment of neural networks associated with executive function and cognitive control. Neural response was measured using functional magnetic resonance imaging (fMRI) during an affect recognition task that included unfamiliar peer faces. We found that relatively fewer reports of being victimized by relational aggression was associated increased recruitment of bilateral dorsolateral prefrontal cortices as well as anterior and posterior cingulate cortices in response to the affect recognition task, as well as with greater competence on behavioral measures of executive function. Our results suggest that girls who are able to recruit specific frontal networks to improve cognitive and executive control are relatively less sensitive to relational aggression.

Introduction

The myriad of changes that occur in adolescence require substantial revision to the systems responsible for understanding one's experience. A shift occurs early in adolescence wherein adolescents become more prosocial than younger children (Fabes et. al., 1999) and friendships become increasingly important (Brown, 2004, Bernt, 1982; Larson & Richards, 1991, Richards, Crowe, Larson, & Swarr, 1998).

A large body of behavioral evidence has underscored the importance of same-sex peer relationships, especially among girls, during this time (Ma & Huebner, 2008; Prinstein, Cheah, Borelli, Simon, Aikins, 2005; Rudolph, 2002). In general, girls have a greater propensity than boys to form close, intimate, self-disclosing friendships (Claes, 1992; Ma & Huebner, 2008). From an evolutionary perspective, greater affiliation among women is advantageous because it ensures group survival. Similarly, from a middle school perspective, a “tend and befriend” pattern (Taylor, 2000) among adolescent girls would seem to be advantageous because tightly-knit friend groups tend to outline and adhere to common norms of behavior, which reduces individual's uncertainty about how to “survive” within the larger school environment (Zwolinski, 2008). The socialization style observed among girls likely reflects the nature of both the biological changes initiated by adolescence, and the socio-cognitive transformations that accompany this maturation.

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In the service of establishing and maintaining these essential social norms, adolescent girls are known to employ a unique form of aggression to enforce social compliance. Relational aggression describes the subtle, indirect forms of hostility that seeks to harm others through manipulation, intention damage or threats of damage to interpersonal relationships (e.g. exclusion, dirty looks, etc.) (Crick & Grotpeter, 1995; see Archer & Coyne, 2005 for a review). This type of aggression is a strategy for attaining a social advantage by manipulating others' social status and alliances (Prinstein & Cillessen, 2003; Puckett, Aikins, & Cillessen, 2008; Tomada & Schneider, 1997). Research has shown that girls are far more likely than boys to engage in relational aggression (Archer, 2004; Bjorkqvist, Osterman & Kaukianinen, 1992). Additionally, girls perceive relationally aggressive behaviors to have greater negative consequences than do boys (Crick & Grotpeter, 1995; Crick & Werner, 1998; Paquette & Underwood, 1999). Adolescent girls report, to a greater extent than boys, that relational aggression is more hurtful and more deleterious to relationships, and more often indicate that they feel worse about themselves after being relationally victimized. (Goldstein & Tisak, 2004; Crick & Bigbee, 1998).

Although the “mean girl” of a group may steal the spotlight, she is the minority. The majority of adolescents are neither the ring-leader nor the pariah of their social scene, but nearly all will experience relational aggression at some point during their adolescence. Among adolescent girls, relational aggression impacts individuals differently. For some, acts of relational aggression are little more than a social nuisance, easily forgotten in an afternoon. For others, these same acts of rejection and/or exclusion give rise to immediate as well as long-term psychosocial problems (Asher & Coie, 1990; Ellis, Crooks, & Wolfe, 2009; Prinstein, Boegers, & Vernberg, 2001; Storch, Bagner, Geffken, & Baumeister, 2004). Previous research has found, for example, that relational victimization may lead to experiences of loneliness and depression as well as problems with self-control (Crick & Grotpeter, 1996). Such difficulties may, in turn, predict future adjustment issues that extend well beyond the years of adolescence (Prinstein et al., 2001). More specifically, Storch and Masia-Warner (2004) found that relationally victimized adolescent girls experienced elevated levels of social anxiety, and, as a result, were denied opportunities for developing prosocial relations with their peers. That is, the victimized girls formed inaccurate views of social relationships due to the ways they had been treated and therefore came to avoid social situations (Storch & Masia-Warner, 2004). In their extreme form, dysfunctional peer relationships have potentially fatal effects. A recent report examined 13,465 adolescents and determined that, “adolescent females who are isolated from the adolescent community or whose relationships are intransitive and likely dissonant are at greater risk for suicidal thoughts than are girls who are embedded in cohesive friendship groups” (Bearman & Moody, 2004, p94).

Given the potentially grave consequences of relational aggression, understanding the behavioral and neurophysiological processes that accompany relative “immunity” to this type of victimization are of great interest. Taken together, the work described above has demonstrated that not all girls are equally injured by relational aggression. As such, elucidating the behavioral and neural correlates of girls who experience less relational aggression may be an important first step in designing programs to help those who are repeatedly victimized. While a number of the studies described above have examined the behavioral correlates and consequences associated with increased sensitivity to relational aggression, none to date has explored the cognitive, and related neurophysiological profiles that may be present in those who report relatively higher or lower experience with relational aggression.

It is well known that along with increasingly complex social proficiencies, new cognitive abilities also emerge during adolescence. These abilities enable significant improvements in information processing that consequently make adolescents more skilled than children with regard to not only interpreting novel experiences, but also understanding behavioral expectations in new situations (Blakemore, 2008). The hallmark of adolescent cognition is a substantial qualitative change in their thinking. Adolescent thought becomes more abstract, logical, and idealistic (see Anderson, Anderson, Jacobs, & Smith, 2008 for a review of cognitive development). Adolescents are more capable of examining their own thoughts, others' thoughts, and what others are thinking about them (Dunn, 1994, Garcia, Hart, & Johnson-Ray, 1997, Piaget, 1954). In addition, adolescents are increasingly able to control their attention so that it is focused on salient information in their environment (Eigsti, Zayas, Mischel, Shoda, Ayduk, Dadlani, Davidson, Aber, & Casey, 2006). A number of recent studies using fMRI have detailed age-related improvements on tasks of cognitive control and executive functions (i.e. impulse control and set shifting). This cognitive control is essential for adolescents' on-going improvements in their ability to suppress inappropriate actions and instead engage in goal-directed behavior (Casey, Galvan, & Hare, 2005; Rubia et. al, 2006; Casey, Getz, & Galvan, 2008). While the findings described above have been couched in the cognitive context, it is also apparent that these changes are closely interwoven with (and perhaps even the basis for some) the complex changes in social behavior that accompany adolescence.

Improvements in cognition and social behavior are believed to closely parallel neural maturation. Perhaps the most consistently reported finding associated with adolescent brain development is the decrease of gray matter throughout the cerebral cortex, most significantly within frontal cortex (see Giedd at al., 1999; Sowell et al., 1999 for reviews). The prefrontal cortex is of primary interest in adolescent development largely because of its well-documented function with regard to cognitive, social and emotional processes in adulthood. The converging evidence of prolonged development and organization of prefrontal cortex throughout childhood and adolescence (Huttenlocher, 1979; Chugani et al., 1987; Diamond, 1988; 1996) suggests an important parallel between brain development and socio-cognitive development.

One striking difference regarding the development of the prefrontal cortex relative to other cortical areas is the continuation of anatomical change well into young adulthood. Continued synaptic pruning (see Huttenlocher, 1979 for a review), as well as increased volume of white matter (Bennett and Baird, 2006) has been reported. There has been further speculation that the ‘use it or lose it’ process of synaptic reorganization and pruning may represent the behavioral, and ultimately, the physiological suppressing of immature behaviors that have become obsolete due the novel demands of adulthood (Casey et al., 2000). More recently, however, interesting developments regarding the exact nature of the changes in white matter during development have provided strong support for the idea of continued development within both the axon and the surrounding myelin (see Paus, 2010 for a review). Not surprisingly, the neurodevelopmental changes that take center stage during adolescence coincide with the emergence of newly entwined cognitive and emotional phenomena. The changes in white matter (both in myelin and axonal caliber) that take place during this time likely reflect the fortification of neural connections that will remain into adulthood (see Paus et al., 2008 for a review).

One specific frontal region in which researchers have observed increases in white matter is the anterior cingulate cortex (Bennett and Baird, 2006), an area known for its prominent role in the mediation and control of emotional, attentional, motivational, social and cognitive behaviors (Vogt et al., 1992). Casey and colleagues (1997) have demonstrated a positive relationship between age and total volume of the anterior cingulated cortex, a relationship the authors attribute to increases in white matter volume (Casey et al., 1997). It is thought that this relationship may reflect improved cortical-cortical and cortical-subcortical coordination. The observed projections from both cortical and subcortical regions to the cingulate in adult subjects are believed to contribute to the coordination and regulation of cognitive and emotional processes. Further, maturation of the dorsal anterior cingulate cortex has been consistently related to self-control and behavioral inhibition (see Isomura and Takada, 2004 for a recent review).

The present study

The present study sought to examine individual differences in response to reported frequency of experience relational aggression (defined herein as sensitivity to relational aggression), using both behavioral and neuroimaging techniques. An individual differences approach to this question is key because we know that there are a variety of ways in which individuals experience adolescence. For some it is a period of increased conflict and stress, while others manage it with relative ease and calm (Morris and Steinberg, 2001). It is also the case that there is great heterogeneity in the way individuals approach peer interactions, and a variety of ways in which they cope with peer related stress; because of these factors it makes sense to look at individual differences within an adolescent sample. By examining factors associated with relatively fewer reported experiences of relational aggression within the framework of individual differences, it may be possible to identify the behavioral or neural strategies that are associated with less sensitivity to relational aggression, and use these as the basis for helping those who are more negatively impacted by relational aggression. Previous studies of adolescent behavior have used MRI to examine the neural basis of individual differences with regard to anxiety (Pine, 2007); intelligence (Shaw, 2007); various aspects of reading (see Schlaggar and McCandliss, 2007 for a review); mathematical ability (Grabner et al., 2007); as well as a number of cognitive processes (see Paus, 2005 for a comprehensive review). We utilized this strategy to explore, in detail, the neural and behavioral profile(s) of girls who reported experiencing relatively fewer incidents of relational aggression.

The findings on peer interactions described above indicate that face-to-face interactions between girls are unique and may be particularly problematic for some. Understanding the processes adolescent girls use to interpret facial cues may elucidate the ways in which social information is processed within the peer context, as well as provide insights regarding girls' sensitivity to relational aggression. The remarkably nuanced nature of adolescent peer interactions necessitates a certain level of hyper-vigilance to social and emotional cues. Evidence in support of this idea has come from studies demonstrating improvements in adolescents' ability to interpret both macro and micro facial expressions (Kolb et al, 1992). Previous studies have shown the suitability and utility of using affect recognition paradigms to collect functional neuroimaging data about adolescents' neurophysiological response to faces (Baird et al, 1999, Thomas et al, 2001, Herba & Phillips, 2004). The current study sought to investigate girls' response to age, sex and racially matched peer faces with the hope of elucidating a behavioral and neurophysiological profile associated with greater sensitivity (measured by frequency of reported experiences) to relational aggression. It was hypothesized that girls who reported being more vulnerable to relational aggression would show relatively decreased activity in frontal regions during a task using age and sex matched peers. It was further hypothesized that girls who reported fewer experiences with relational aggression (i.e. relative immunity) would demonstrate relatively better cognitive control and executive function compared with girls who reported being more frequently victimized by relational aggression.

Methods

Participants

Fourteen adolescent girls (mean age = 14.16 years, age range= 12.8- 15.2 years) participated in the present study. Participants were recruited from a middle school in rural New England. Prior to participation, all participants gave informed assent and parents gave informed consent. Participants received monetary compensation for their participation. All participants were Caucasian.

Participants with a history of organic brain syndrome, head injury, substance abuse, or any Axis I psychiatric disorder were excluded from study. Participants with any family history of psychiatric disorders were also excluded. Family history was based on self-report from participants' parent/guardian(s); participants were also excluded is they had any first-degree relative(s) with an Axis I disorder or if they had any history of seizure disorder.

Behavioral Measures

Participants were asked to complete a self-report survey about their social interactions and executive functioning.

Relational Aggression—Relational aggression was assessed using a measure created in our laboratory. The goal of this scale was to reliably measure the participants experience with relational aggression, to assess the degree to which relational aggression is distinct from overt aggression, and to assess whether relational aggression is related to social-psychological maladjustment. Questions asked participants to mark how often they had been victims of relational aggression (Crick & Grotpeter, 1995). Responses were made on a Likert based scale that ranged from 1 (never) to 5 (always). Items were summed to create an overall score for this scale. A high score on this measure indicated that the individual felt that relational aggressive behaviors had been directed towards them with great frequency. Psychometric characteristics of this scale are being examined for later publication. Items from this scale are listed in Appendix 1A.

Aggression Questionnaire—Buss and Perry's revision (Buss & Perry, 1992) to the classic Hostility Inventory by Durkee and Buss (1957) includes four subscales of aggression factors: Physical Aggression, Verbal Aggression, Anger, and Hostility. For our purposes, we employed the Hostility subscale. The inclusion of this subscale was meant to serve as a reliability check for individual perceptions of relational aggression. Hostility was intended to measure feelings of “ill will or injustice” (p.457, Buss & Perry, 1992) and represented the cognitive component of aggression. Responses were made on a Likert based scale that ranged from 1 (not at all like me) to 5 (extremely like me). Items were summed to create scores for each subscale. High scores on this subscale indicate that the participant has felt increasing amounts of hostile behavior directed toward them. Items from this subscale are listed in Appendix 1B.

BRIEF—The Behavior Rating Inventory of Executive Function (BRIEF)(Gioia et al., 2000) self-report questionnaire was used to measure executive functions in children and adolescents. To date, the BRIEF has been used in over 100 peer reviewed investigations (Strauss et al., 2006) further, the self-report nature of this measure has been shown to correlate strongly with both parent and teacher reports, as well as a number of clinical and performance measures (Guy, et al., 2004). *Executive functions* are defined as a set of processes that guide, direct, and manage cognitive, emotional, and behavioral functioning. The BRIEF contains 86 items, from which two summary scores are derived, Behavioral Regulation (Breg) and Metacognition (Mcog). These two summary scores are then combined to yield a Global Executive Functioning (GEF) score. Responses are given as "Never" (coded as 1), "Sometimes" (coded as 2), and "Often" (coded as 3). Items are summed to create scores for each subscale. Relatively higher scores on these scales reflect increased difficulty with specific aspects of executive control.

Experimental Task

An event-related affect recognition paradigm was used. Trial onsets were time-locked to the beginning of data acquisition, so that each trial was the length of 1TR (2.5sec). Four categories of facial stimuli were used: 1) male adult faces, 2) female adult faces, 3) male adolescent faces, 4) female adolescent faces. Stimuli were acquired from individuals in another state, and all individuals pictured were unfamiliar to the subject. Each individual contributed five facial expressions (happy, sad, afraid, angry, and neutral) to the stimuli set. All stimuli were head and shoulders views of individuals looking directly into the camera. All digital photographs were standardized for size and intensity. All photographs were validated for affective consistency. Thirty judges from a local high school (blind to the experiment and not participating in the study) were asked to define the facial emotion being expressed. Only photographs with >90% agreement among judges were used.

During each trial, a digital color photograph of a face was presented in the center of the screen for 2500 msec. Participants were asked to attend to the faces and respond if they saw a particular type of facial expression (e.g. fearful, happy etc). The target type of facial expression was randomized across participants. This task was employed as a means to ensure participants maintained visual attention during stimulus presentation.

During each functional run (140TRs, 5:50 minutes total time), 20 faces from each category (80 total) as well as 60 fixation trials were pseudorandomly intermixed. The fixation trials were included to introduce jitter into the time series so that unique estimates of the hemodynamic responses for the trial types of interest could be computed.

Behavioral Apparatus and Imaging Parameters

Visual stimuli were presented using an Apple G3 laptop computer running PsyScope 1.2.5 software (Cohen, et al., 1993). Stimuli were projected to participants with an Epson (model ELP-7000) LCD projector onto a screen positioned at the head end of the bore and viewed through a mirror mounted on the head coil. Participants' behavioral responses were recorded using hand-held, fiber-optic buttons interfaced with a PsyScope button box (New Micros, Dallas, TX).

All images were acquired using a 1.5 Tesla scanner (General Electric Medical Systems Signa CV/Nvi LX8.4, Waukesha, WI) with a standard head coil. Anatomical images were acquired using a high-resolution 3-D spoiled gradient recovery sequence (SPGR; 128 sagittal slices, TR = 7.7sec, TE = 3 msec, flip angle = 15°, voxel size = 1 × 1 × 1.2 mm). Functional images were collected in runs using a gradient spin-echo, echo-planar sequence sensitive to BOLD contrast (T2*) (TR = 3sec, TE = 40 msec, flip angle = 90°, 3.75 × 3.75 mm in-plane resolution). During each functional run, 140 volumes of axial images (25 slices, 4.5 mm slice thickness, 1 mm skip between slices) were acquired.

fMRI Data Analysis

For each functional run, data were preprocessed to remove sources of noise and artifact. Using SPM99 (Wellcome Department of Cognitive Neurology), data were then realigned within and across runs to correct for head movement, and co-registered with each participant's anatomical data.

Functional data were then transformed into a standard anatomical space (3-mm isotropic voxels) based on the ICBM 152 brain template (Montreal Neurological Institute) which approximates Talairach and Tournoux (Talairach & Tournoux, 1988) atlas space. Normalized data were then spatially smoothed (6 mm full-width-at-half-maximum [FWHM]) using a Gaussian kernel. Analyses took place at two levels: first, within subject activity was examined using a fixed-effects model; second, a random effects model was used to explore the data across subjects.

Statistical analyses were performed on individual subjects using a general linear model incorporating task effects modeled with a canonical hemodynamic response function and its temporal derivative, as well as mean, linear, and quadratic trends for each of the two runs. This model was used to compute parameter estimates (b) and t-contrast images for comparison of each facial condition to a baseline condition (fixation cross) (male adult faces, female adult faces, male peers, female peers) at each voxel.

To identify regions for which the level of activation across participants was specifically related to the perception of relational aggression, a simple regression analysis was performed on the average images for the female peer condition relative to baseline (fixation cross). Individual contrast images were submitted to a second-level, random-effects regression analysis to create mean t-images. Based on our research question, selected regions demonstrated relative increases in activation consistent with relative decreases in reports of relational aggression across individuals. An automated peak-search algorithm identified the location of peak activations based on voxel-wise t values (threshold $p < .0025$, $t=3.43$, extent 10 voxels, uncorrected for multiple comparisons).

For each participant, hemodynamic response functions (10 frames long) for each trial type were then estimated across each ROI using a finite impulse response formulation of the general linear model. The parameter estimates for this model (calculated using the least-squares solution to the general linear model) are estimates for the temporally evolving response magnitude at each of the 10 points in peristimulus time, selectively averaged across all occurrences of that peristimulus time interval. This approach has recently been implemented by Poldrack and colleagues as an add-on toolbox to the SPM analysis software (SPM ROI Toolbox, http://spmtoolbox.sourceforge.net). This method resulted in a single value for each region, per individual, to be used in ROI analyses.

Results

Behavioral Results

All participants performed at ceiling on the affect recognition task, correctly identifying their target expression on nearly every trial. Importantly, this result provided behavioral confirmation that all participants were engaged in the task of evaluating the facial expressions.

As predicted, the hostility portion of the aggression scale was found to correlate closely with our measure of relational aggression ($r=.86$, $p<.001$). This finding is highly consistent with previous data ($N=461$, $r=.50$, $p<.0001$. Baird, unpublished data) and adds validity to the precision of the relational aggression measure. Regarding the measures of executive function, Metacognition was correlated with Relational Aggression ($r=.65$, $p=.01$) and Hostility ($r=.82$ $p<.001$). Behavioral Regulation was also correlated with Relational Aggression ($r=.54$, $p=.05$) and Hostility ($r=.80$, $p<.001$). Finally Global Executive Function was correlated with Relational Aggression ($r=.64$, $p<.01$) and Hostility ($r=.86$, $p<.001$). Taken together, these correlations suggest that girls who report having relatively more difficulty on executive function tasks, as well as psychosocial measures (hostility, behavioral regulation) also report experiencing more relational aggression.

Age effects were also examined by correlating age with both the behavioral measures and the signal from the regions of interest. No significant relationships were revealed; this is likely due to the small (2.5 yrs) range in the age of our participants, as well as our relatively small sample size (n=14).

fMRI Results

Comparison of female peer faces to baseline—To identify brain regions that were responsive to the faces of female peers, trials consisting of female peer faces were compared to a fixation cross which was used as baseline. This analysis was performed based on the well-established pattern of neural response to faces. Because our primary analyses were based on regression, we chose to do this comparison as a reliability check, to ensure that the data were “typical” of those observed when individuals view faces (see Kanwisher, 2000 for a review).

Female peer faces produced statistically significant activity relative to baseline in a number of regions. The largest regions of increased activity in response to female peer faces were seen in the bilateral fusiform gyrus. Additional regions of increases activity also included, supplementary motor area, the dorsolateral prefrontal cortex (middle frontal gyrus), and the frontal pole (superior frontal gyrus) (see Table 1).

Correlations between behavioral measures and neural activity—Driven by our a priori hypotheses, we carried out a behavioral correlation between the female peer face vs fixation conditional and response to relational aggression exclusively. Following this, we extracted all regions of statistical significance and checked to see if the additional behavioral measures correlated with activity in these same regions. A number of correlations emerged from this exploration (described below). Using the regions of interest determined by the relational aggression/female peer face correlation, we also examined activity in these regions during the additional facial categories (male peer, female adult, male adult each relative to fixation). No significant correlations were found between activity in these regions and behavioral measures (relational aggression, hostility and executive functioning) during any of the alternative face conditions (please see table 2). Therefore, the findings reported below refer exclusively to relationships between behavioral measures and neural activity during the presentation of female peer faces.

Relational Aggression—Results revealed that relatively lower scores on the relational aggression measure predicted increased signal intensities in response to female peer faces (vs. Fixation) in the posterior cingulate (BA 31; x, y, z: 11, -43, 38; r=-.87, p<.001), anterior cingulate (BA 24; x, y, z: 1, 34, 32; r=-.82, p<.001), right middle frontal gyrus (BA 9/46; x, y, z; -35, 34, 32; r=-.81, p=.001), and left middle frontal gyrus (BA 9/46; x, y, z: 46, 22, 30; r=-.73, p=.003)(see Figure 1, Table 2). The signal intensities from these regions were then correlated with the other behavioral measures.

Hostility—Results revealed that relatively lower scores on the hostility measure predicted increased signal intensities in response to female peer faces (vs. fixation) in the posterior cingulate (BA 31; x, y, z: 11, -43, 38; r=-.82, p<.001), right middle frontal gyrus (BA 9/46; x, y, z; -35, 34, 32; r=-.60, p=.02), and left middle frontal gyrus (BA 9/46; x, y, z: 46, 22, 30; r=-.56, p=.04). These results were not surprising, given that these measures of hostility were found to correlate highly with our measure of relational aggression.

Executive Function—Results revealed that activity in the right middle frontal gyrus (BA 9/46; x, y, z; -35, 34, 32) in response to female peer faces (vs. fixation) was correlated with scores on the Metacognition subscale (r=-.60, *p*=.02), Global Executive Function (r=-.60, p=.02) and trended with regard to Behavioral regulation (r=-.50, *p*=.07). Additionally, activity in the posterior cingulate in response to female peer faces (BA 31; x, y, z: 11, -43, 38) was correlated with scores on the Metacognition subscale (r=-.53, *p*=.05). These results were not surprising, given that these measures of executive function were found to correlate highly with our measure of relational aggression.

Additional Brain Regions—Given the role of the amygdala in the processing of facial expressions (see Davis and Whalen, 2001 for a review), we investigated activity in this region using anatomically defined regions of interest (Baird et al., 1999). For each participant, mean activation was determined for each stimuli condition, based on a 8 mm^3 sphere placed centrally in both the left (-19,0,-19) and right (19,0,-19) amygdala. Amygdala activity was not significantly greater in response to female peer faces (vs fixation) and was not correlated with any of the behavioral measures. This was somewhat surprising to us, and we suggest that a larger sample size may have produced more activity in this region, known for its low change in BOLD signal due to its blood supply, and partial volume effects.

Discussion

The current study utilized a facial processing paradigm designed to emulate interpersonal encounters that might occur during a typical day in the life of a middle school student. To this end we used four categories of faces (adult female, adult male, adolescent female, adolescent male) displaying different emotions. We wanted, however, to focus our investigation on how emerging cognitive, emotional, and behavioral processing abilities interacted with neural networks in adolescent girls. Because it is impossible to measure an adolescent's brain activity during an average day, as well as control for the variability in adolescent girls' friendships, we used functional neuroimaging techniques (fMRI) to assess neuronal activation in response to photographs of novel peer faces that were age and sex-matched to our participants.

The importance of affiliation between girls during adolescence has been repeatedly affirmed by both evolutionary and socio-cultural findings (see Taylor, 2000 for a review). Based on the empirical and theoretical data that have described the importance of social self-perceptions during the teenage years (Jacobs, et. al, 2004), it is not surprising that teenagers place great importance on their friendships. Adolescents turn to peer groups for emotional support and perceive group approval as an indication of social acceptability (Brown, 1993). In order to navigate the choppy waters of adolescence, one must be highly attuned to, and able to learn from, one's peers. As the creators and keepers of group memberships and social norms, age and sex matched peers become increasingly salient targets to female adolescents.

We sought to better understand, in terms of both brain and behavior, what accounts for individual differences in adolescent girls' sensitivity to relational aggression (RA). To investigate this question, we performed regression analyses using sensitivity to relational aggression as a predictor of neural activity during an affect recognition task that used age and sex matched targets. We did not observe discernable areas of relatively increased activity as participants reported increasing sensitivity to relational aggression (i.e. they reported high levels of relational aggression within relationships). By contrast, we discovered a constellation of cortical areas whose increasing activity was closely associated with decreasing sensitivity to relational aggression. We identified a constellation of cortical regions including anterior and posterior cingulate, as well as bilateral dorsolateral prefrontal cortex (DLPFC) whose activity correlated significantly with individual sensitivity to

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relational aggression. We had hypothesized that there would be a neurophysiological pattern associated with vulnerability to relational aggression. Our findings supported this idea, albeit in a slightly unexpected manner. Our results described above clearly indicate a pattern of frontal response associates with decreased sensitivity (as defined by reported frequency), or perhaps, increased immunity, to relational aggression.

Previous findings have described a constellation of prefrontal regions involved in social and emotional regulation (Banyas, 1999) as well as cognitive control (Bishop, Duncan, Brett, & Lawrence, 2004). In addition to being critical for executive functions such as problem solving, working memory, planning and organization, and response inhibition, areas of the prefrontal cortex (e.g. dorsolateral prefrontal cortex (DLPFC) as well as anterior and posterior cingulate cortices) have been implicated in studies of cognitive reappraisal that require participants to consciously use cognition to “reframe” unpleasant thoughts or experiences (Ochsner et al., 2002).

Active maintenance of working memory and cognitive inhibition are the hallmarks of DLPFC function. For example, “appropriate” behaviors are often the result of information and strategies that are held in mind and attended to, despite presence of conflicting “natural inclinations” (Diamond et al., 2002). Not surprisingly, this region has been repeatedly implicated in the cognitive modulation of emotional response (see Miller and Cohen, 2001 for a review), a process essential for coping with relational aggression. The DLPFC is also known to work closely with the anterior cingulate cortex (ACC) on tasks requiring ongoing monitoring and potential adjustment of cognitive control processes. While the DLPFC is known for representing and maintaining task demands, the ACC serves to monitor and evaluate ongoing behavior in order to detect and correct discrepancies and errors (MacDonald et al., 2000; Cohen et al., 2000).

The posterior cingulate cortex (PCC) has been described as an area that focuses shifts in visual-spatial attention, and is often responsible for “resetting” or redirecting attention. Previous results have suggested that the PCC inhibits the parietal cortices to avoid distractions and simultaneously activates the medial prefrontal cortex to redirect attention so the individual can internally generate mental strategies (Small et al., 2003). Specifically, PCC is important in shifting attention to prepare for an expected target when a preceding clue has predicted what's to come (Small et al., 2003). Within the context of the present findings, this suggests that girls who are able to recruit activity from their PCC in response to peer faces may be better able to regulate their attention, and in turn better plan their interactions with peers. Consistent with the observed pattern of neural activation, our participants who showed greater immunity to RA also reported having fewer problems with metacognition, behavioral regulation and executive function more generally which validated our hypothesis that girls who showed reduced sensitivity to relational aggression would show better frontal regulation and executive functioning.

While the present results are highly consistent with a number of studies that have demonstrated a similar frontal network in response to tasks requiring cognitive control, it is critical to underscore that our participants were adolescents. It is well established that the frontal systems described above are still maturing in the average adolescent (see Giedd, 2008; Casey et al., 2000 for reviews). Improvements in cognitive control largely result from synergistic maturation in working memory capacity, selective attention, error detection, and inhibition, all of which have been shown to improve with maturational changes in the structure and function of the prefrontal cortex (see Giedd at al., 2008; Sowell et al., 1999 for reviews). Given that the age range of our participants was fairly narrow, this suggests that individual variation in the maturation of these networks may play an important role in the emergence of executive functions, and as a result, give these girls an advantage in complex social and emotional interactions. Additional research is needed to determine what gives rise to the differential maturation of frontal networks among adolescent girls; however it is reasonable to speculate that life experience, genetic contributions and pubertal onset may all be significant factors.

In summary, it is thought that the constellation of active neural regions observed within girls who are more immune to relational aggression subserve a cognitive network that helps girls orient to socially salient stimuli, to interpret stimuli, and to overtly/cognitively strategize to formulate a plan (D'Esposito, Postle and Rypma, 2000). This cognitive network serves two primary functions; first to draw attention to socially salient targets (this bias is the cornerstone for adolescent affiliative behavior), and second to organize and direct cognition in order to regulate emotion and behavior.

Taken together, our findings suggest that the ability to recruit this frontal network characterizes girls who may be immune, or at least less sensitive to, relational aggression. Further, the data suggest that this network is likely modulated by overt, effortful cognition, as indicated by converging evidence from both our neurophysiologic and behavioral data. The present results support the idea that some adolescents may be using learned strategies to modulate their sensitivity to relational aggression. Participants who reported being less frequently victimized by relational aggression showed more robust recruitment of brain regions associated with cognitive control during a peer affect recognition task; and further indicated that they were better able to regulate their behavior, had more mature metacognition and behavioral regulation as well as fewer problems with executive functions generally, relative to their peers in the present study. It was also found that increased activity within this network of frontal regions was closely related to more advanced/mature looking executive function as measured by meta-cognitive and global executive abilities. Finally, it is important to note that girls with relatively better scores on meta-cognition, and global executive functioning also reported experiencing fewer incidents relational aggression, suggesting that the ability to mobilize cognitive resources in the face of peer interactions, as measured by both behavior and frontal function, reduces one's risk of being ostracized and/or victimized by relational aggression.

The type of social-psychological distress and anxiety associated with being a victim of relational aggression can make it difficult to concentrate on schoolwork and to function in activities of everyday living, and in its worst form can be lethal. The present findings are critical to understanding what may make specific girls more or less vulnerable to relational aggression, and further suggest that there may be a cognitive means by which to ameliorate social interactions for girls who are particularly impacted by relational aggression.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix 1A. Relational Aggression Scale Items

1. Has a friend ever told you that they will stop liking you unless you do what they say?
2. Has a friend ever stopped talking to you or ignored you, because they did not like something you did?
3. Has a friend ever used body language to make you feel bad or embarrassed (i.e. dirty looks, turning their back, laughing at you)?
4. Has a friend ever tried to keep you from being in their group of friends?
5. Has a friend ever spread rumors about you that were not true?
6. Has a friend ever told others a secret that you told them in private (for example, something you told them not to tell anyone)?

Appendix 1B. Hostility Scale Items (Buss and Perry, 1992)

1. I am sometimes eaten up with jealousy
2. At times I feel I have gotten a raw deal out of life
3. I wonder why sometimes I feel so bitter about things
4. I know that "friends" talk about me behind my back
5. I am suspicious of overly friendly strangers
6. I sometimes feel that people are laughing at me behind my back
7. When people are especially nice, I wonder what they want
8. Other people always seem to get the breaks

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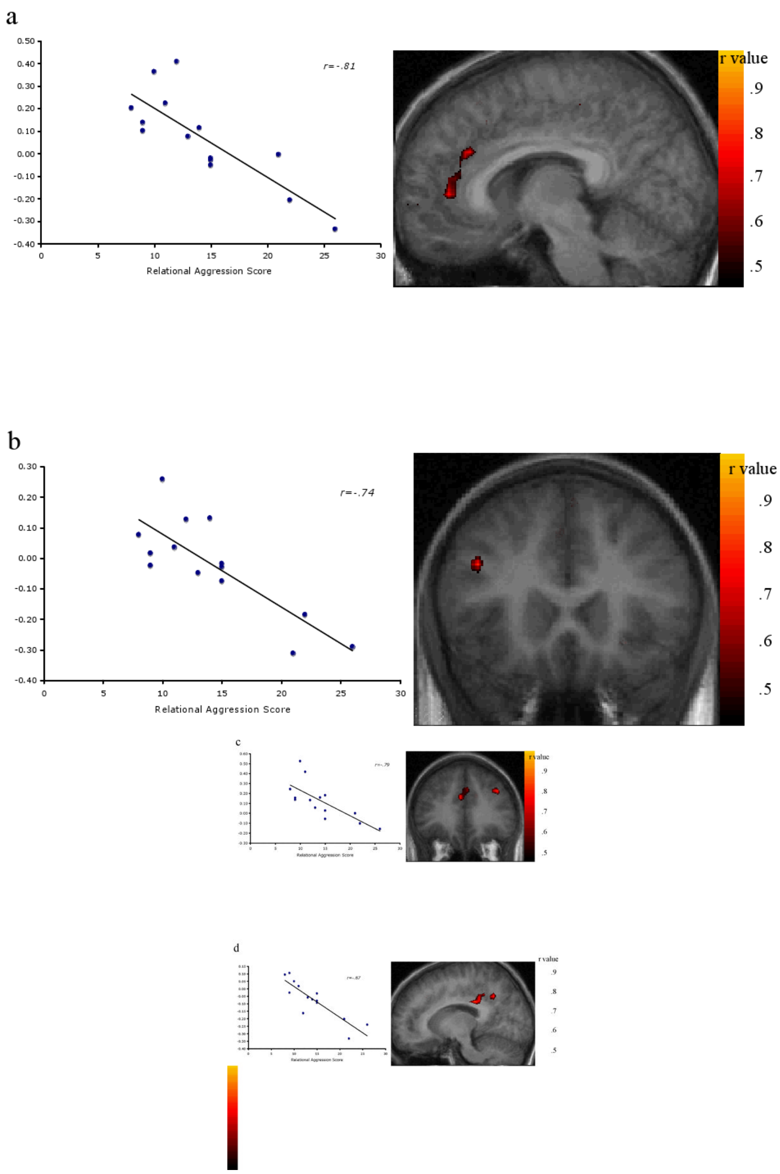

Figure 1.

Scatterplots (left) and statistical activation maps (right) of significant correlations between experiences of relational aggression and neural activity. (**a**) anterior cingulate (1, 34, 32); (**b**) right middle frontal gyrus of DLPFC (46,22,30); (**c**) left middle frontal gyrus of DLPFC (-35,34,32); (**d**) right posterior cingulate (11, -43, 38)

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Table 1

Regions showing greater activity to female peers relative to baseline

		MNI coordinates (mm)				
Region Label	**Brodmann Area**	***x***	***y***	***z***	**Region size (mm3)**	***t*-value**
Fusiform Gyrus	37	-33	-78	-15	10557	5.86
	37	33	-84	-14	1674	5.82
R Middle Frontal Gyrus	45/46	43	15	21	405	6.60
L Superior Frontal Gyrus	6	-1	19	59	1080	7.73
	9	-10	60	32	324	5.57

Statistical threshold: $p < .0025$, extent 10 voxels

Table 2

Regions showing significant correlation with behavioral measures

Region Label	Brodmann Area	MNI coordinates (mm) *x*	*y*	*z*	Region size (mm3)	FPF *r*-value	MPF *r*-value	FAF *r*-value	MAF *r*-value
A. Relational Aggression									
Anterior Cingulate	24/32	1	34	32	3483	-0.82***	-0.24	-0.41	-0.26
R Middle Frontal Gyrus	9/46	46	22	30	324	-0.81***	-0.18	-0.39	-0.16
L Middle Frontal Gyrus	9/46	-35	34	32	1026	-0.79**	-0.33	-0.30	0.08
R Posterior Cingulate	31	11	-43	38	1584	-0.87***	-0.26	0.01	-0.40
B. Hostility									
R Middle Frontal Gyrus	9/46	46	22	30	324	-0.59*	-0.25	-0.41	0.06
L Middle Frontal Gyrus	9/46	-35	34	32	1026	-0.56*	-0.11	-0.39	0.23
R Posterior Cingulate	31	11	-43	38	1584	-0.82***	-0.41	-0.29	-0.53
C. Metacognition									
R Middle Frontal Gyrus	9/46	46	22	30	324	-0.81**	-0.35	-0.27	0.06
R Posterior Cingulate	31	11	-43	38	1584	-0.53*	-0.37	-0.13	-0.44
D. Global Executive Functioning									
R Middle Frontal Gyrus	9/46	46	22	30	324	-0.59*	-0.38	-0.28	0.24

Statistical threshold: $p < .0025$, extent 10 voxels

* p<.05,

** p<.01,

*** p<.001

note: all faces are being viewed by female adolescent participants. FPF=female peer faces, MPF=male peer faces, FAF=female adult faces, MAF=male adult faces