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Regular Article

Cortical volume alterations in the limbic network in adolescents with high reactive aggression

Johannah Bashford-Largo[1,2], R. James R. Blair[3], Karina S. Blair[1], Matthew Dobbertin[1,4], Jaimie Elowsky[5], Ahria Dominguez[6], Melissa Hatch[7] and Sahil Bajaj[8]

[1]Child and Family Translational Research Center, Boys Town National Research Hospital, Boys Town, NE, USA, [2]Center for Brain, Biology and Behavior, University of Nebraska-Lincoln, Lincoln, NE, USA, [3]Child and Adolescent Mental Health Centre, Mental Health Services, Capital Region of Denmark, Copenhagen, Denmark, [4]Child and Adolescent Psychiatric Inpatient Center, Boys Town National Research Hospital, Boys Town, NE, USA, [5]Clinical Psychology Department, University of Nebraska-Lincoln, Lincoln, NE, USA, [6]Clinical Health, Emotion, and Neuroscience (CHEN) Laboratory, Department of Neurological Sciences, College of Medicine, University of Nebraska Medical Center, Omaha, NE, USA, [7]Mind and Brain Health Laboratories (MBHL), Department of Neurological Sciences, College of Medicine, University of Nebraska Medical Center, Omaha, NE, USA and [8]Department of Cancer Systems Imaging, MD Anderson Center, University of Texas, Houston, TX, USA

Abstract

Previous studies show aggression-related structural alterations in frontal and limbic brain regions. Most studies have focused on overall aggression, instead of its subtypes, and on specific regions instead of networks. This study aims to identify both brain networks and regions that are associated with reactive and proactive subtypes of aggression. Structural MRI data were collected from 340 adolescents (125 F/215 M) with a mean age of 16.29 ($SD = 1.20$). Aggression symptomology was indexed via the Reactive Proactive Aggression Questionnaire (RPQ). Freesurfer was used to estimate Cortical Volume (CV) from seven networks and regions within specific networks associated with aggression. Two multivariate analyses of covariance (MANCOVAs) were conducted on groups for low versus higher reactive and proactive RPQ scores. Our reactive aggression MANCOVA showed a main effect in CV [$F(14,321) = 1.935$, $p = 0.022$,$\eta p^2 = 0.078$] across all the 7-Networks. Unpacking this main effect revealed significant volumetric differences in the right Limbic Network (LN) ($p = 0.029$) and the Temporal Pole ($p = 0.011$), where adolescents in the higher reactive aggression group showed higher cortical volumes. Such findings are consistent with region/voxel-specific analyses that have associated atypical structure within the LN and reactive aggression. Moreover, the temporal pole is highly interconnected with regions important in the regulation and initiation of reactive aggression.

Keywords: adolescence; aggression; limbic; MRI; network; reactive

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Introduction

High levels of aggression can have significant costs to society and are one of the leading causes for youth seeking referrals to mental health (Magalotti et al., 2019). While aggression is not atypical during childhood development, maladaptive levels of aggression (i.e., overly frequent and intense) can lead to impaired social relationships, incarceration, and even death (Hendricks & Liu, 2012). An increased risk for aggression is transdiagnostic with a variety of psychiatric diagnoses, including major depressive disorder (MDD), attention-deficit/hyperactivity disorder (ADHD), conduct disorder (CD), and oppositional defiant disorder (ODD) (Buchmann et al., 2014; Liu & Cole, 2021; Saylor & Amann, 2016). Given the poor prognosis for aggressive individuals, there is a considerable need to determine reliable trait variables that might aid in clinical decision-making.

Corresponding author: J. Bashford-Largo; Email: johannah.bashford-largo@boystown.org

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Substantial neuroimaging work has pointed to an association between an increased risk for aggression and structural and functional disruptions within regions of the fronto-limbic-striatal systems (Blair, 2016; Ducharme et al., 2011; Sukhodolsky et al., 2021). However, it is important to note that acts of aggression are not homogenous and have different subtypes and etiologies. A commonly made distinction is drawn between reactive and proactive aggression. Reactive aggression is unplanned and made in response to threat or social provocation, whereas the less common proactive aggression is goal-oriented and is seen as more callous (Blair, 2018; Blair et al., 2021; Crick & Dodge, 1996).

There are a lack of studies distinguishing between these two subtypes of aggression, though there are indications that they can be differentiated at the neural level (Cima & Raine, 2009; Naaijen et al., 2020). Most neuroimaging studies focus on frontal regions involved in response control and reinforcement-based decision-making as well as limbic structures, such as the amygdala and hippocampus. Overall, high aggression, especially reactive aggression, is associated with a decrease in activity in the ventral medial prefrontal cortex (vmPFC) and an increase in activity in the amygdala (Blair et al., 2021; Choe et al., 2015; Coccaro et al., 2007; Lee et al., 2008; Sukhodolsky et al., 2021). Structural and functional

connectivity between the amygdala and vmPFC and/or orbitofrontal cortex (OFC) has also been considered to be important in regulating aggression (Sukhodolsky et al., 2021; White et al., 2016). However, one DTI study in a healthy sample showed no structural differences within OFC-amygdala connectivity between participants with high and low physical aggressiveness (Beyer et al., 2014).

There are few neuroimaging studies that have examined the differences in reactive and proactive aggression. Functional studies tend to agree on a few key findings regarding the two subtypes. The response to threat involves increased function within the amygdala, hypothalamus, and periaqueductal gray (Coker-Appiah et al., 2013; Haller, 2018). These regions are shown to be associated with reactive aggression, which is mediated by a threat response circuit involving these regions and the vmPFC (Blair, 2016). Proactive aggression has been shown to be associated with not only the amygdala but also regions implicated in goal setting and reward, such as the dorsolateral PFC and striatum (Belfry & Kolla, 2021; Blair, 2016).

Of the very few structural studies that have looked at the subtypes, there have been mixed results. There have been reports that increased anterior cingulate cortex volume (Farah et al, 2018) but decreased thickness (Romero-Martínez et al., 2022; Yang et al., 2017) is selectively associated with proactive aggression. One study using youth with conduct disorder saw significant decreases in gyrification in the bilateral superior parietal cortex within individuals with high proactive aggression scores (Jiang et al., 2022). Alternatively, though, there is at least one report that both proactive and reactive aggression were associated with increased right OFC volume and thickness of the left paracentral areas (Yang et al., 2017). Amygdala volumes have been reported to negatively correlate with proactive aggression (Naaijen et al., 2020) but positively with reactive aggression (Farah et al., 2018). Reactive aggression has also been reported to negatively correlate with insula volume (Naaijen et al., 2020).

Few studies have specifically looked at networks implicated in aggression severity. Studies have seen that alterations in connectivity within and/or between the default-mode network (DMN) and other networks/regions were predictive of aggression (Dailey et al., 2018; Ibrahim et al., 2022; Weathersby et al., 2019). Other studies have seen disruptions in activity and connectivity within the DMN in individuals who are prone to aggression (Broulidakis et al., 2016; Dalwani et al., 2014; Sun et al., 2022; Tang et al., 2013; Zhou et al., 2016). Another network commonly seen in aggression literature is the limbic network (LN), where structural and connectivity alterations relative to typical developing participants have been reported in individuals presenting with higher aggression (Ducharme et al., 2011; Yang et al., 2017). The LN is comprised of the OFC and temporal pole (Yeo et al., 2011) and involved in important frontal-limbic connections commonly seen in those with aggression (Gan et al., 2016).

This present study will look at the differences in cortical volume (CV) between high and low aggression groups (both reactive and proactive aggression groups) within seven different networks: Visual Network, Somatomotor Network; Dorsal Attention Network, Ventral Attention Network, Limbic Network, Frontoparietal Network, and Default-Mode Network.

Previous literature has shown alterations in regions within the DMN and LN in individuals at increased risk for aggression (De Brito et al., 2009; Ducharme et al., 2011; Yang et al., 2017). Because of these previous findings, we adopted an exploratory approach and hypothesized that proactive and reactive aggression would be associated with alterations in CV within these regions in these networks (specifically orbitofrontal cortices and superior temporal gyri).

Methods

Participants

Participants were recruited from a residential care facility in the Midwest and from the surrounding community. Participants recruited from the residential facility had been referred for behavioral and mental health problems, whereas participants from the community were recruited through flyers or social media. Structural MRI data were collected from 340 adolescents (125 F/215 M) with a mean age of 16.29 ($SD = 1.20$, 14–18 years), and IQ of 103.91 ($SD = 10.73$).

Exclusion criteria included braces, claustrophobia, active substance dependence, pervasive developmental disorder, Tourette's syndrome, lifetime history of psychosis, neurological disorder, head trauma, non-English speaking, and presence of active safety concerns. Clinical characterization was done through psychiatric interviews by licensed and board-certified child and adolescent psychiatrists with the participants and their parents to adhere closely to common clinical practice. All participants and their parents provided written informed assent/consent prior to enrollment. The study protocol was approved by the Institutional Review Board at Boys Town National Research Hospital (BTNRH).

Demographics characteristics

Group differences in sex, age, IQ, intracranial volume (ICV) (Barnes et al., 2010), and RPQ scores were examined via chi square and independent sample t-tests. These variables were used as covariates in the following analyses.

Data collection

Neuroanatomical data

High resolution structural MRI (T1-weighted) data were collected using a 3-Tesla Siemens MRI scanner located at BTNRH. Whole-brain anatomical data for each participant were acquired using a 3D magnetization-prepared rapid acquisition gradient echo sequence, which consisted of 176 axial slices (slice thickness = 1 mm, voxel resolution = $0.9 \times 0.9 \times 1$ mm3, repetition time = 2200ms; echo time = 2.48 ms; matrix size = 256×208; field of view (FOV) = 230 mm, and flip angle = 8o).

General intelligence (IQ)

The Wechsler Abbreviated Scale of Intelligence II (WASI-II) (Wechsler, 2011) was used to estimate IQ in the domains of perceptual reasoning, verbal comprehension, and Full-Scale IQ (FSIQ). FSIQ scores have high reliability ($\alpha = 0.98$) and strong correlations ($r = 0.92$) with scores on the full Wechsler Adult Intelligence Scale-III (Wechsler, 1997, 1999) and were used in the current context.

Reactive-proactive aggression questionnaire

The Reactive-Proactive Aggression Questionnaire (RPQ; Raine et al., 2006) is a 23-item questionnaire which has shown to be a validated measure of both proactive aggression (11 items; $\alpha = 0.87$) and reactive (12 items; $\alpha = 0.83$) aggression in youth (Cima et al., 2013).

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Table 1. Demographics of sample

Demographics	High Reactive Aggression $N = 178$	Low Reactive Aggression $N = 162$	Significance ($\chi 2$/t-value)	High Proactive Aggression $N = 208$	Low Proactive Aggression $N = 132$	Significance ($\chi 2$/t-value)
Sex	66 F/112 M	59 F/103 M	0.02^{ns}	73 F/135 M	52 F/80 M	0.64^{ns}
Age (SD)	16.26 (1.13)	16.31 (1.27)	0.30^{ns}	16.22 (1.12)	16.39 (1.30)	1.23^{ns}
IQ (SD)	102.20 (9.15)	105.79 (11.98)	3.08**	102.79 (9.98)	105.68 (11.64)	2.36*
ICV ($x10^6$) in mm^3 (SD)	1.50 (1.57)	1.53 (1.56)	1.45^{ns}	1.51 (1.50)	1.52 (1.66)	0.81*
Total (SD)	14.73 (6.80)	4.37 (2.36)	−19.29***	13.08 (7.40)	4.49 (2.88)	−15.04***
Reactive (SD)	11.12 (3.49)	3.59 (1.85)	−25.14***	9.46 (4.63)	4.49 (2.88)	−12.21***
Proactive (SD)	3.61 (4.12)	0.67 (1.17)	−9.13***	3.61 (3.74)	0.00 (0.0)	−13.94***
MDD (%)	33 (18.5)	12 (7.4)	–	31 (14.9)	14 (10.6)	–
SAD (%)	47 (26.4)	30 (18.5)	–	49 (23.6)	28 (21.2)	–
GAD (%)	56 (31.5)	30 (18.5)	–	58 (27.9)	28 (21.2)	–
PTSD (%)	27 (15.2)	11 (6.8)	–	30 (14.4)	8 (6.1)	–
CD (%)	102 (57.3)	43 (26.5)	–	111 (53.4)	34 (25.8)	–
ODD (%)	111 (62.4)	64 (39.5)	–	119 (57.2)	50 (37.9)	–
ADHD (%)	111 (62.4)	58 (35.8)	–	121 (58.2)	54 (40.9)	–
Antipsychotics (%)	13(7.30)	7 (4.30)	–	16 (7.7)	4 (3.0)	–
SSRIs (%)	29 (16.30)	23 (14.2)	–	39 (18.8)	13 (9.8)	–
Stimulants (%)	31 (17.4)	21 (13.0)	–	35 (16.8)	17 (12.9)	–

Key to table. ns: Non-Significant; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; SD = Standard Deviation; IQ = Intelligent Quotient; ICV = Intercranial Volume; MDD = Major Depressive Disorder; SAD = Social Anxiety Disorder; GAD = Generalized Anxiety Disorder; PTSD = Post Traumatic Stress Disorder; CD = Conduct Disorder; ODD = Oppositional Defiant Disorder; ADHD = Attention Deficit Hyperactivity Disorder; SSRIs=Selective Serotonin Reuptake Inhibitors. There was a 43.5% overlap between the two high aggression groupings.

Image preprocessing

The "recon-all" pipeline from the FreeSurfer toolbox (Version 6.0; https:// surfer.nmr.mgh.harvard.edu) was used to process the anatomical brain images (Dale et al., 1999; Fischl et al., 1999) and for estimating CV measures. Structural image processing included head motion-correction, brain extraction, automated transformation to the standard MNI template space, volumetric segmentation into cortical and sub-cortical matter, intensity correction, and parcellation of the cerebral cortex into gyral and sulcal matter (Desikan et al., 2006). See (Dale et al., 1999; Fischl, 2004; Fischl et al., 1999) for full details. Steps to ensure preprocessing accuracy included a careful visual inspection of raw structural images, skull-stripped brain volumes, and pial surfaces via FreeSurfer (Version 6.0; https:// surfer.nmr.mgh.harvard.edu).

Data analysis

Behavioral analysis

A correlation between reactive and proactive aggression scores was conducted to look at a possible association between these subtypes of aggression.

Network volume analysis

FreeSurfer was used to parcellate the whole brain into seven networks using Yeo's atlas (Yeo et al., 2011) (N1: Visual Network; N2: Somatomotor Network; N3: Dorsal Attention Network; N4: Ventral Attention Network; N5: Limbic Network; N6: Frontoparietal Network; and N7: Default-Mode Network). A network cortical volume analysis was conducted (sex, age, IQ, and intracranial volume [ICV] were used as covariates) using network-wise CV data to look at potential differences between high and low aggression groupings. Two multivariate analyses of covariance (MANCOVAs) were conducted on the seven bilateral networks (14 total) for each subscale RPQ score group (i.e., one examining groups with higher vs. lower reactive aggression and a second examining groups differing in proactive aggression levels).

Region-based analysis

Our steps for region-based analysis are as follows: 1. Identify any significant networks (as described above). 2. If any significant networks were discovered using the above analysis, we then extracted regions from the networks. 3. We then looked at associations of CV of the extracted regions and aggression groups by performing a MANCOVA– again with sex, age, IQ, and ICV as covariates.

Follow-up analyses

Potential confounds: impact of other major psychopathologies and prescribed medications

Several of our participants were diagnosed with different psychiatric disorders including Major Depressive Disorder ($N = 45$), Social Anxiety Disorder ($N = 77$), Generalized Anxiety Disorder ($N = 86$), Post-Traumatic Stress Disorder ($N = 38$), Conduct Disorder ($N = 145$), Oppositional Defiant Disorder ($N = 169$), and Attention-Deficit/Hyperactivity Disorder ($N = 175$). In addition, several of our youth were on psychiatric medications ($N = 124$) during the time of the study, including SSRIs, stimulants, and antipsychotics. Table 1

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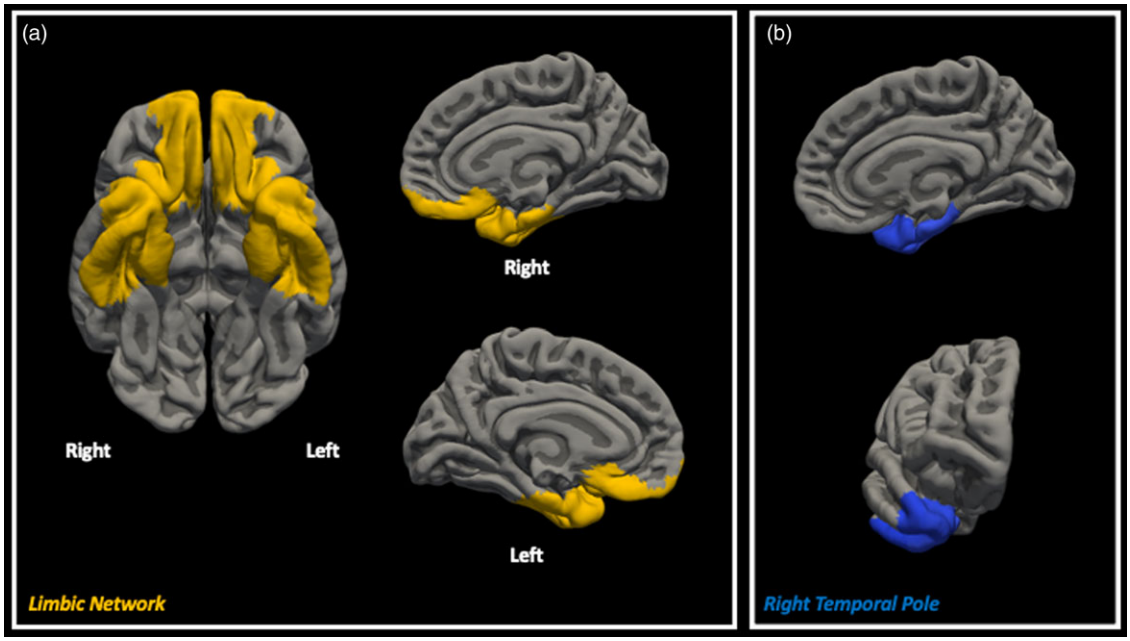

Figure 1. Limbic network and temporal pole locations: location of the limbic network (via Yeo's 7 network parcellation) and temporal pole (via clustering).

shows demographic characteristics of both comorbidities and medications. Given the potential confounds, the MANCOVA described above (individual networks) was repeated, first, with the inclusion of psychiatric diagnoses and, second, with the inclusion of prescribed medications as covariates.

Potential confounds

In order to control for the effects of proactive aggression when looking at reactive aggression and vice versa, a follow-up MANCOVA with the other aggression subtype as a covariate will be run if either of the groups showed significant network cortical volume differences. Another follow-up MANCOVA will be run after removing participants that had high scores in both reactive and proactive aggression as well.

Results

Bivariate analysis

Reactive aggression scores and proactive aggression scores from the RPQ were significantly correlated across the entire sample ($r = 0.63$, $p < 0.001$).

Demographics characteristics

Table 1 shows the total number of participants in each group. There was some overlap ($n = 148$, 43.5%) between groups (meaning these youth had high scores in both reactive and proactive aggression). There were no significant differences in sex ($\chi^2(1) = 0.016$, $p = 0.90$; $\chi^2(1) = 0.642$, $p = 0.42$) or age ($t(338) = 0.302$, $p = 0.76$; t $(248.52) = 1.23$, $p = 0.22$) between high/low reactive and high/low proactive aggression groups respectively. ICV was not significantly different between high/low reactive aggression groups, [$t(338) = 1.452$, $p = 0.15$], but was significantly different between high/low proactive aggression groups, [$t(338) = 0.81$, $p = 0.04$], where those with low proactive aggression had higher ICV. There were significant differences in IQ between high and low reactive [$t(300.378) = 3.081$, $p = 0.002$] and high and low proactive [$t(247.64) = 2.36$, $p = 0.019$] aggression groups, where lower aggression groups had higher IQ scores.

Group differences in CV

Our MANCOVAs showed a significant main effect across the 7 networks in CV for reactive aggression [$F(14,321) = 1.935$, $p = 0.022$, ηp2 = 0.078; Wilk's lambda = 0.922] but no significant effects for the MANCOVA on proactive aggression [$F(14,321) = 0.666$, $p = 0.807$, $\eta p^2 = 0.028$; Wilk's lambda = 0.972]. This particularly reflected group differences driven by the right Limbic Network [$F(1,334) = 4.802$, $p = 0.029$, $\eta p^2 = 0.014$], where adolescents in the higher reactive aggression group showed higher cortical volumes (Figures 1 and 2).

Follow-up exploratory analysis of the MANCOVA main effect

Our ROI-specific MANCOVA for the right Limbic Network showed significant group differences in ROI volume [$F(2,333) = 3.471$, $p = 0.032$,$\eta p^2 = 0.020$; Wilk's lambda = 0.980]. Specifically, we saw significant difference in CV of the Temporal Pole [$F(1,334) = 6.466$, $p = 0.011$, $\eta p^2 = 0.019$], where adolescents in the higher reactive aggression group showed higher cortical volumes (Figure 3).

Follow-up to reactive aggression analysis

Diagnoses

Our follow-up MANCOVA analysis with the addition of seven psychiatric diagnoses (see Table 1 for full list) continued to show a significant equation that mirrored the results of the main analysis [$F(14,314) = 2.145$, $p = 0.010$, $\eta p^2 = 0.087$], still showing strongest significant differences in the right Limbic Network [$F(1,327) = 7.116$, $p = 0.008$, $\eta p^2 = 0.021$].

Medication

Our follow-up MANCOVA analysis with the addition of the three medications (Antipsychotics, stimulants, and SSRIs) continued to

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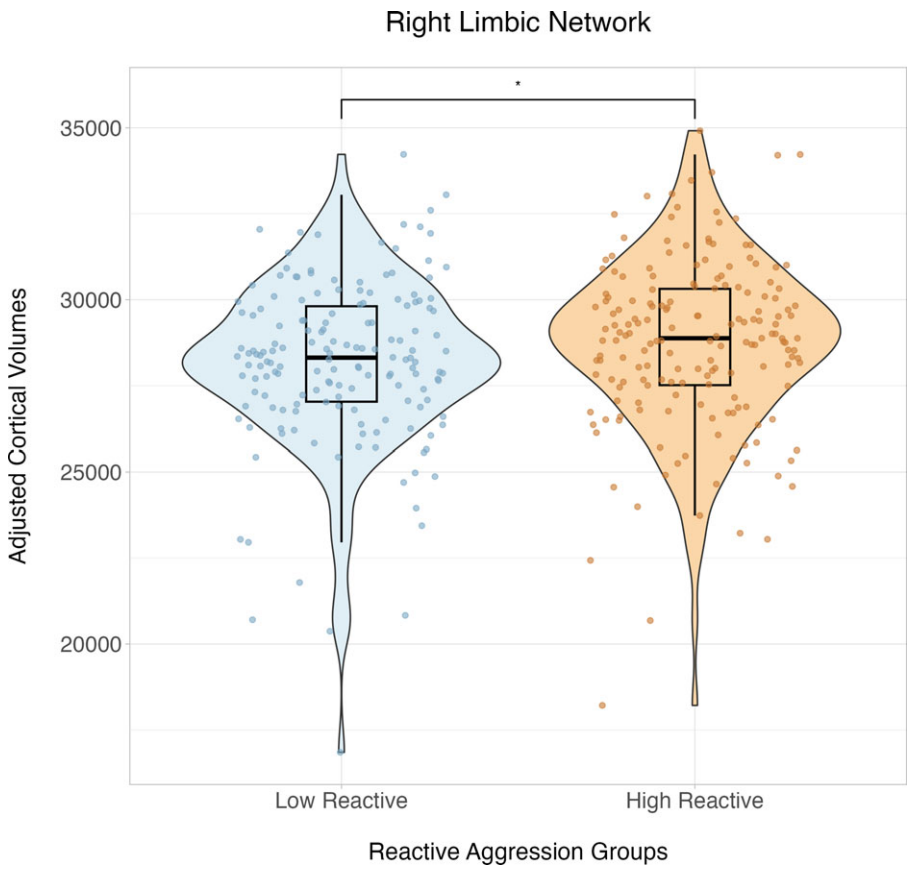

Figure 2. Limbic network: identified cortical network, limbic network (a), and identified region of significance, temporal pole (b). Cortical volume of the right limbic network was significantly different between those with high and low reactive aggression (high reactive aggression > low reactive aggression). * = $p < 0.05$.

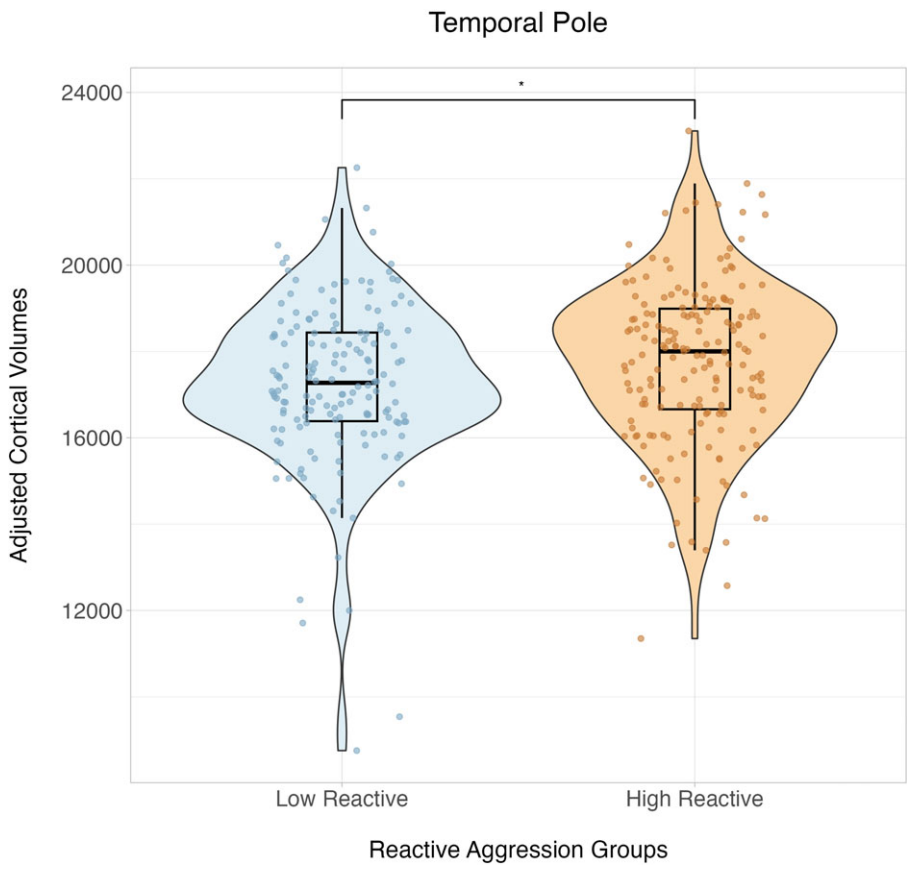

Figure 3. Temporal pole. Within the right limbic network, cortical volume of the temporal pole was also significantly different between those with high and low reactive aggression (high reactive aggression > low reactive aggression) * = $p < 0.05$.

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show a significant equation that mirrored the results of the main analysis [$F(14,318) = 2.023$, $p = 0.016$, $\eta p^2 = 0.082$], again showing strongest significant differences in the right Limbic Network [$F(1,331) = 5.126$, $p = 0.024$, $\eta p^2 = 0.015$].

Subtype

Our follow-up MANCOVA analysis with the addition of proactive aggression as a covariate in our regression analysis, continued to show a significant equation that mirrored the results of the main analysis [$F(14, 320) = 1.805$, $p = 0.037$, $\eta p^2 = 0.073$], again showing strongest significant differences in the right Limbic Network [$F(1,333) = 5.557$, $p = 0.019$, $\eta p^2 = 0.016$]. When adding reactive aggression as a covariate to our MANCOVA looking at proactive aggression, we still saw a non-significant result ($p = 0.879$).

Removal of participants in both high score groups

Our next follow-up MANCOVA was the same as the main analysis (7 Network), however, with the removal of individuals that had both high reactive aggression scores and high proactive aggression scores (43.5% who had both). The removal of these participants made our results no longer significant within the reactive aggression groupings [$F(14, 173) = 1.423$, $p = 0.147$, $\eta p^2 = 0.103$].

Discussion

The goal of this study was to examine differences in cortical volumes (CV) in brain networks within high and low aggression groups (both reactive and proactive aggression). We found that CV of the right Limbic Network (LN) was significantly greater in those with higher vs. lower reactive aggression scores. In addition, region-specific analysis showed that within the right LN, CV of the temporal pole was significantly increased in the higher reactive aggression score group. Contrary to our hypothesis, we did not see any significant differences in CV within networks in proactive aggression groups.

Previous work has typically taken a region/voxel-focused approach to analysis and not focused on network-level structural alterations in individuals prone to higher levels of aggression (Chester et al., 2017; Jiang et al., 2022; Naaijen et al., 2020). However, and consistent with the current findings, there are several previous results which indicate atypical LN function/structure relating to increased aggression risk. Indeed, accounts of reactive aggression have stressed the importance of dysfunction in components of this system for some time (Bertsch et al., 2020; Blair, 2004). Individuals at increased risk of reactive aggression frequently show poor emotion regulation (Nikolic et al., 2022). Notably, the role of OFC in emotion regulation has long been recognized (Blair, 2004; Christiansen et al., 2019; Zheng et al., 2018). Empirical work has associated atypical connectivity between the amygdala/temporal cortex and OFC with an increased risk for aggression, particularly reactive aggression (Sukhodolsky et al., 2021; White et al., 2016). These regions have also been implicated in mediating reactive aggression (Coccaro et al., 2007; Gan et al., 2016). Moreover, atypical structure of OFC and amygdala volumes have been associated with an increased risk of reactive aggression (Farah et al., 2018; Yang et al., 2017), and lesions within the LN can lead to increased impulsivity and aggression (Berlin et al., 2004; Kuniishi et al., 2016; Potegal, 2012; Shiba et al., 2015).

It should be noted that within the LN, it was particularly atypical temporal pole structure that was associated with increased risk for reactive aggression. The temporal pole is a dominant hub in the processing of semantic and socioemotional information (Guo et al., 2022; Pehrs et al., 2017) and is considerably interconnected with other regions very important in the regulation and initiation of reactive aggression: the amygdala (Li et al., 2016), as well as OFC (Novitskaya et al., 2020; Olson et al., 2007). It could be speculated that larger volumes are associated with strong emotional reactions and disruptions in the perception of provocations, leading to outbursts or disrupted emotional processing. Previous work has tended to report reductions in thickness and volume in the temporal pole (rather than the increased volume seen here) in groups of aggressive individuals (Cope et al., 2014; Ermer et al., 2012; Gregory et al., 2012; Ly et al., 2012). However, most of that work has been conducted in individuals with psychopathy which was not a predominant feature of the sample with higher reactive aggression studied here. It is notable that one previous finding, in a slightly more similar study, also observed increased temporal pole volumes in those exhibiting higher reactive aggression (Breitschuh et al., 2018).

In contrast to predictions, there was no association of CV within the DMN and either reactive or proactive aggression. Previous work has reported alterations in connectivity within and/or between the DMN and other networks/regions were predictive of aggression (Dailey et al., 2018; Ibrahim et al., 2022; Weathersby et al., 2019), disruptions in activity and connectivity within the DMN in individuals who are prone to aggression (Broulidakis et al., 2016; Dalwani et al., 2014; Sun et al., 2022; Tang et al., 2013; Zhou et al., 2016) and structural alterations within the DMN in individuals at increased risk for aggression (De Brito et al., 2009; Ducharme et al., 2011; Yang et al., 2017). The reason for the absence of comparable findings in the current cohort are unclear but it is possible that it represents a Type II error.

Also, in contrast to predictions, we found no networks showing atypical structure in the group of participants showing higher levels of proactive aggression. Relatively little previous work has focused on individuals showing higher levels of proactive aggression as opposed to focusing on samples who are at increased for proactive aggression (but also reactive aggression), such as individuals with psychopathy (Blair, 2010; Garofalo et al., 2021; Hofhansel et al., 2020). It has been argued that proactive aggression is a chosen behavior reflecting the individual's decision-making (Blair, 2019). This may result in socially undesirable choices because of the economic realities of the individual or because the individual's representations of potential costs (e.g., the distress of others) is disrupted (Blair, 2019). As such, it is possible that structural differences may be less commonly seen in those at increased risk for proactive rather than reactive aggression.

Despite the strengths of our study, including large sample size and diverse range of clinical symptomatology, there were some caveats. First, 72% of the adolescents in our sample had at least one psychiatric diagnosis, and it could be argued that we are seeing results from specific disorders instead of aggression severity. Our follow-up analysis with diagnoses as covariates showed results approximate to the main analysis, with the LN still showing highest significance. Second, multiple adolescents were on medications including SSRIs, stimulants, and antipsychotics. Our follow-up analysis with the inclusion of the medications as covariates also revealed LN showing significant differences between the two groups. Third, our reactive aggression group was not matched in IQ scores; those in the lower reactive aggression group had higher IQ scores than those with higher reactive aggression. However, we did use IQ as a covariate in our analysis (in addition to age, sex, and ICV). As such, it is unlikely that our findings can be considered to

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reflect group differences in IQ. Fourth, multiple participants were in both the high proactive aggression group as well as the high reactive aggression group. A post hoc analysis was ran removing individuals in both groups, which made our results no longer significant (see Table 1 for breakdown of groups). Fifth, the group-based analysis approach chosen here due to test-retest reliability concerns runs the risk of data loss by dichotomizing the variable of interest (Dawson & Weiss, 2012) Our goal would be to extend the current study in future work where the test-retest reliability of core measures is known and satisfactory.

In conclusion, our study revealed that CV of the right LN, particularly the temporal pole region within the LN, was significantly greater in those with higher reactive aggression scores. These findings broaden our knowledge of the neurobiology of reactive aggression and can inform future imaging work.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954579424000750.

Data availability statement. The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to IRB restrictions.

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Competing interests. None.

References

Barnes, J., Ridgway, G. R., Bartlett, J., Henley, S. M. D., Lehmann, M., Hobbs, N., Clarkson, M. J., MacManus, D. G., Ourselin, S., & Fox, N. C. (2010). Head size, age and gender adjustment in MRI studies: A necessary nuisance? *NeuroImage*, *53*(4), 1244–1255. https://doi.org/10.1016/j.neuroimage.2010.06.025

Belfry, K. D., & Kolla, N. J. (2021). Cold-blooded and on purpose: A review of the biology of proactive aggression. *Brain Sciences*, *11*(11), 1412. https://doi.org/10.3390/brainsci11111412

Berlin, H. A., Rolls, E. T., & Kischka, U. (2004). Impulsivity, time perception, emotion and reinforcement sensitivity in patients with orbitofrontal cortex lesions. *Brain: A Journal of Neurology*, *127*(Pt 5), 1108–1126. https://doi.org/10.1093/brain/awh135

Bertsch, K., Florange, J., & Herpertz, S. C. (2020). Understanding brain mechanisms of reactive aggression. *Current Psychiatry Reports*, *22*(12), 81. https://doi.org/10.1007/s11920-020-01208-6

Beyer, F., Münte, T. F., Wiechert, J., Heldmann, M., Krämer, U. M., & Siegel, A. (2014). Trait aggressiveness is not related to structural connectivity between orbitofrontal cortex and amygdala. *PLOS ONE*, *9*(6), e101105. https://doi.org/10.1371/journal.pone.0101105

Blair, R. J. R. (2004). The roles of orbital frontal cortex in the modulation of antisocial behavior. *Brain and Cognition*, *55*(1), 198–208. https://doi.org/10.1016/S0278-2626(03)00276-8

Blair, R. J. R. (2010). Neuroimaging of psychopathy and antisocial behavior: A targeted review. *Current Psychiatry Reports*, *12*(1), 76–82. https://doi.org/10.1007/s11920-009-0086-x

Blair, R. J. R. (2018). Traits of empathy and anger: Implications for psychopathy and other disorders associated with aggression. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *373*(1744), 20170155. https://doi.org/10.1098/rstb.2017.0155

Blair, R. J., Zhang, R u, Bashford-Largo, J., Bajaj, S., Mathur, A., Ringle, J., Schwartz, A., Elowsky, J., Dobbertin, M., Blair, K. S., & Tyler, P. M. (2021). Reduced neural responsiveness to looming stimuli is associated with increased aggression. *Social Cognitive and Affective Neuroscience*, *nsab058*(10), 1091–1099. https://doi.org/10.1093/scan/nsab058

Blair, R. J. R. (2016). The neurobiology of impulsive aggression. *Journal of Child and Adolescent Psychopharmacology*, *26*(1), 4–9. https://doi.org/10.1089/cap.2015.0088

Blair, R. J. R. (2019). Dysfunctional neurocognition in individuals with clinically significant psychopathic traits. *Dialogues in Clinical Neuroscience*, *21*(3), 291–299. https://doi.org/10.31887/DCNS.2019.21.3/rblair

Breitschuh, S., Schöne, M., Tozzi, L., Kaufmann, Jörn, Strumpf, H., Fenker, D., Frodl, T., Bogerts, B., & Schiltz, K. (2018). Aggressiveness of martial artists correlates with reduced temporal pole grey matter concentration. *Psychiatry Research. Neuroimaging*, *281*, 24–30. https://doi.org/10.1016/j.pscychresns.2018.08.001

Broulidakis, M. J., Fairchild, G., Sully, K., Blumensath, T., Darekar, A., & Sonuga-Barke, E. J. S. (2016). Reduced default mode connectivity in adolescents with conduct disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *55*(9), 800–808.e1. https://doi.org/10.1016/j.jaac.2016.05.021

Buchmann, A., Hohmann, S., Brandeis, D., Banaschewski, T., & Poustka, L. (2014). Aggression in children and adolescents. *Current Topics in Behavioral Neurosciences*, *17*, 421–442. https://doi.org/10.1007/7854_2013_261

Chester, D. S., Lynam, D. R., Milich, R., & DeWall, C. N. (2017). Physical aggressiveness and gray matter deficits in ventromedial prefrontal cortex. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *97*, 17–22. https://doi.org/10.1016/j.cortex.2017.09.024

Choe, D. E., Shaw, D. S., & Forbes, E. E. (2015). Maladaptive social information processing in childhood predicts young men's atypical amygdala reactivity to threat. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *56*(5), 549–557. https://doi.org/10.1111/jcpp.12316

Christiansen, H., Hirsch, O., Albrecht, B., & Chavanon, M.-L. (2019). Attention-deficit/Hyperactivity disorder (ADHD) and emotion regulation over the life span. *Current Psychiatry Reports*, *21*(3), 17. https://doi.org/10.1007/s11920-019-1003-6

Cima, M., & Raine, A. (2009). Distinct characteristics of psychopathy relate to different subtypes of aggression. *Personality and Individual Differences*, *47*(8), 835–840. https://doi.org/10.1016/j.paid.2009.06.031

Cima, M., Raine, A., Meesters, C., & Popma, A. (2013). Validation of the dutch reactive proactive questionnaire (RPQ): Differential correlates of reactive and proactive aggression from childhood to adulthood: Reactive and proactive aggression. *Aggressive Behavior*, *39*(2), 99–113. https://doi.org/10.1002/ab.21458

Coccaro, E. F., McCloskey, M. S., Fitzgerald, D. A., & Phan, K. L. (2007). Amygdala and orbitofrontal reactivity to social threat in individuals with impulsive aggression. *Biological Psychiatry*, *62*(2), 168–178. https://doi.org/10.1016/j.biopsych.2006.08.024

Coker-Appiah, D. S., White, S. F., Clanton, R., Yang, J., Martin, A., & Blair, R. J. R. (2013). Looming animate and inanimate threats: The response of the amygdala and periaqueductal gray. *Social Neuroscience*, *8*(6), 621–630. https://doi.org/10.1080/17470919.2013.839480

Cope, L. M., Ermer, E., Nyalakanti, P. K., Calhoun, V. D., & Kiehl, K. A. (2014). Paralimbic gray matter reductions in incarcerated adolescent females with psychopathic traits. *Journal of Abnormal Child Psychology*, *42*(4), 659–668. https://doi.org/10.1007/s10802-013-9810-4

Crick, N. R., & Dodge, K. A. (1996). Social information-processing mechanisms in reactive and proactive aggression. *Child Development*, *67*(3), 993. https://doi.org/10.2307/1131875

Dailey, N. S., Smith, R., Vanuk, J. R., Raikes, A. C., & Killgore, W. D. S. (2018). Resting-state functional connectivity as a biomarker of aggression in mild traumatic brain injury. *NeuroReport*, *29*(16), 1413–1417. https://doi.org/10.1097/WNR.0000000000001127

Dale, A. M., Fischl, B., & Sereno, M. I. (1999). Cortical surface-based analysis. *I. Segmentation and Surface Reconstruction. NeuroImage*, *9*(2), 179–194. https://doi.org/10.1006/nimg.1998.0395

Dalwani, M. S., Tregellas, J. R., Andrews-Hanna, J. R., Mikulich-Gilbertson, S. K., Raymond, K. M., Banich, M. T., Crowley, T. J., & Sakai, J. T. (2014). Default mode network activity in male adolescents with conduct and substance use disorder. *Drug and Alcohol Dependence*, *134*, 242–250. https://doi.org/10.1016/j.drugalcdep.2013.10.009

Dawson, N. V., & Weiss, R. (2012). Dichotomizing continuous variables in statistical analysis: A practice to avoid. *Medical Decision Making*, *32*(2), 225–226. https://doi.org/10.1177/0272989X12437605

De Brito, S. A., Mechelli, A., Wilke, M., Laurens, K. R., Jones, A. P., Barker, G. J., Hodgins, S., & Viding, E. (2009). Size matters: Increased grey matter in boys with conduct problems and callous-unemotional traits. *Brain*, *132*(4), 843–852. https://doi.org/10.1093/brain/awp011

Desikan, R. S., Ségonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., Buckner, R. L., Dale, A. M., Maguire, R. P., Hyman, B. T., Albert, M. S., & Killiany, R. J. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *NeuroImage*, *31*(3), 968–980. https://doi.org/10.1016/j.neuroimage.2006.01.021

Ducharme, S., Hudziak, J. J., Botteron, K. N., Ganjavi, H., Lepage, C., Collins, D. L., Albaugh, M. D., Evans, A. C., & Karama, S. (2011). Right anterior cingulate cortical thickness and bilateral striatal volume correlate with CBCL aggressive behavior scores in healthy children. *Biological Psychiatry*, *70*(3), 283–290. https://doi.org/10.1016/j.biopsych.2011.03.015

Ermer, E., Cope, L. M., Nyalakanti, P. K., Calhoun, V. D., & Kiehl, K. A. (2012). Aberrant paralimbic gray matter in criminal psychopathy. *Journal of Abnormal Psychology*, *121*(3), 649–658. https://doi.org/10.1037/a0026371

Farah, T., Ling, S., Raine, A., Yang, Y., & Schug, R. (2018). Alexithymia and reactive aggression: The role of the amygdala. *Psychiatry Research: Neuroimaging*, *281*, 85–91. https://doi.org/10.1016/j.pscychresns.2018.09.003

Fischl, B. (2004). Automatically parcellating the human cerebral cortex. *Cerebral Cortex*, *14*(1), 11–22. https://doi.org/10.1093/cercor/bhg087

Fischl, B, Sereno, MI, & Dale , AM (1999). Cortical surface-based analysis. II: Inflation, flattening, and a surface-based coordinate system. *Neuroimage*, *9*, 195–207. https://doi.org/10.1006/nimg.1998.0396

Gan, G., Preston-Campbell, R. N., Moeller, S. J., Steinberg, J. L., Lane, S. D., Maloney, T., Parvaz, M. A., Goldstein, R. Z., & Alia-Klein, N. (2016). Reward vs. Retaliation-the role of the mesocorticolimbic salience network in human reactive aggression. *Frontiers in Behavioral Neuroscience*, *10*, 179. https://doi.org/10.3389/fnbeh.2016.00179

Garofalo, C., Neumann, C. S., & Velotti, P. (2021). Psychopathy and aggression: The role of emotion dysregulation. *Journal of Interpersonal Violence*, *36*(23-24), NP12640–NP12664. https://doi.org/10.1177/0886260519900946

Gregory, S., ffytche, D., Simmons, A., Kumari, V., Howard, M., Hodgins, S., & Blackwood, N. (2012). The antisocial brain: Psychopathy matters. *Archives of General Psychiatry*, *69*(9), 962–972. https://doi.org/10.1001/archgenpsychiatry.2012.222

Guo, P., Hu, S., Jiang, X., Zheng, H., Mo, D., Cao, X., Zhu, J., & Zhong, H. (2022). Associations of neurocognition and social cognition with brain structure and function in early-onset schizophrenia. *Frontiers in Psychiatry*, *13*, 798105.

Haller, J. (2018). The role of central and medial amygdala in normal and abnormal aggression: A review of classical approaches. *Neuroscience and Biobehavioral Reviews*, *85*, 34–43. https://doi.org/10.1016/j.neubiorev.2017.09.017

Hendricks, K., & Liu, J. (2012). Childbearing depression and childhood aggression: Literature review. *MCN: The American Journal of Maternal/Child Nursing*, *37*(4), 253–261. https://doi.org/10.1097/NMC.0b013e3182482c5e

Hofhansel, L., Weidler, C., Votinov, M., Clemens, B., Raine, A., & Habel, U. (2020). Morphology of the criminal brain: Gray matter reductions are linked to antisocial behavior in offenders. *Brain Structure & Function*, *225*(7), 2017–2028. https://doi.org/10.1007/s00429-020-02106-6

IBM Corp. (2017). *IBM SPSS Statistics for Windows*. IBM Corp.

Ibrahim, K., Noble, S., He, G., Lacadie, C., Crowley, M. J., McCarthy, G., Scheinost, D., & Sukhodolsky, D. G. (2022). Large-scale functional brain networks of maladaptive childhood aggression identified by connectome-based predictive modeling. *Molecular Psychiatry*, *27*(2), 985–999. https://doi.org/10.1038/s41380-021-01317-5

Jiang, Y., Gao, Y., Dong, D., Sun, X., Situ, W., & Yao, S. (2022). Brain anatomy in boys with conduct disorder: Differences among aggression subtypes. *Child Psychiatry & Human Development*, *55*(1), 3–13. https://doi.org/10.1007/s10578-022-01360-5

Kuniishi, H., Ichisaka, S., Matsuda, S., Futora, E., Harada, R., & Hata, Y. (2016). Chronic inactivation of the orbitofrontal cortex increases anxiety-like behavior and impulsive aggression, but decreases depression-like behavior in rats. *Frontiers in Behavioral Neuroscience*, *10*, 250. https://doi.org/10.3389/fnbeh.2016.00250

Lee, T. M. C., Chan, S. C., & Raine, A. (2008). Strong limbic and weak frontal activation to aggressive stimuli in spouse abusers. *Molecular Psychiatry*, *13*(7), 655–656. https://doi.org/10.1038/mp.2008.46

Li, W., Cui, H., Zhu, Z., Kong, L., Guo, Q., Zhu, Y., Hu, Q., Zhang, L., Li, H., Li, Q., Jiang, J., Meyers, J., Li, J., Wang, J., Yang, Z., & Li, C. (2016). Aberrant functional connectivity between the amygdala and the temporal pole in drug-free generalized anxiety disorder. *Frontiers in Human Neuroscience*, *10*, 549. https://doi.org/10.3389/fnhum.2016.00549

Liu, Q., & Cole, D. A. (2021). Aggressive outbursts among adults with major depressive disorder: Results from the collaborative psychiatric epidemiological surveys. *Journal of Psychiatric Research*, *135*, 325–331. https://doi.org/10.1016/j.jpsychires.2021.01.040

Ly, M., Motzkin, J. C., Philippi, C. L., Kirk, G. R., Newman, J. P., Kiehl, K. A., & Koenigs, M. (2012). Cortical thinning in psychopathy. *American Journal of Psychiatry*, *169*(7), 743–749. https://doi.org/10.1176/appi.ajp.2012.11111627

Magalotti, S. R., Neudecker, M., Zaraa, S. G., & McVoy, M. K. (2019). Understanding chronic aggression and its treatment in children and adolescents. *Current Psychiatry Reports*, *21*(12), 123. https://doi.org/10.1007/s11920-019-1105-1

Naaijen, J., Mulder, L. M., Ilbegi, S., de Bruijn, S., Kleine-Deters, R., Dietrich, A., Hoekstra, P. J., Marsman, J.-B. C., Aggensteiner, P. M., Holz, N. E., Boettinger, B., Baumeister, S., Banaschewski, T., Saam, M. C., M E Schulze, U., Santosh, P. J., Sagar-Ouriaghli, I., Mastroianni, M., Castro Fornieles, J., Bargallo, N., Rosa, M., Arango, C., Penzol, M. J., Werhahn, J. E., Walitza, S., Brandeis, D., Glennon, J. C., Franke, B., Zwiers, M. P., & Buitelaar, J. K. (2020). Specific cortical and subcortical alterations for reactive and proactive aggression in children and adolescents with disruptive behavior. *NeuroImage: Clinical*, *27*, 102344. https://doi.org/10.1016/j.nicl.2020.102344

Nikolic, M., Pezzoli, P., Jaworska, N., & Seto, M. C. (2022). *Brain responses in aggression-prone individuals: A systematic review and meta-analysis of functional magnetic resonance imaging (fMRI) studies of anger- and aggression-eliciting tasks* (pp. 2022.01.11.475895), bioRxiv.

Novitskaya, Y., Dümpelmann, M., Vlachos, A., Reinacher, P. C., & Schulze-Bonhage, A. (2020). In vivo-assessment of the human temporal network: Evidence for asymmetrical effective connectivity. *NeuroImage*, *214*, 116769. https://doi.org/10.1016/j.neuroimage.2020.116769

Olson, I. R., Plotzker, A., & Ezzyat, Y. (2007). The enigmatic temporal pole: A review of findings on social and emotional processing. *Brain*, *130*(7), 1718–1731. https://doi.org/10.1093/brain/awm052

Pehrs, C., Zaki, J., Schlochtermeier, L. H., Jacobs, A. M., Kuchinke, L., & Koelsch, S. (2017). The temporal pole top-down modulates the ventral visual stream during social cognition. *Cerebral Cortex*, *27*(1), 777–792. https://doi.org/10.1093/cercor/bhv226

Potegal, M. (2012). Temporal and frontal lobe initiation and regulation of the top-down escalation of anger and aggression. *Behavioural Brain Research*, *231*(2), 386–395. https://doi.org/10.1016/j.bbr.2011.10.049

Raine, A., Dodge, K., Loeber, R., Gatzke-Kopp, L., Lynam, D., Reynolds, C., Stouthamer-Loeber, M., & Liu, J. (2006). The reactive-proactive aggression questionnaire: Differential correlates of reactive and proactive aggression in adolescent boys. *Aggressive Behavior*, *32*(2), 159–171. https://doi.org/10.1002/ab.20115

Romero-Martínez, Á., Sarrate-Costa, C., & Moya-Albiol, L. (2022). Reactive vs proactive aggression: A differential psychobiological profile? Conclusions derived from a systematic review. *Neuroscience & Biobehavioral Reviews*, *136*, 104626. https://doi.org/10.1016/j.neubiorev.2022.104626

Saylor, K. E., & Amann, B. H. (2016). Impulsive aggression as a comorbidity of attention-deficit/Hyperactivity disorder in children and adolescents. *Journal of Child and Adolescent Psychopharmacology*, *26*(1), 19–25. https://doi.org/10.1089/cap.2015.0126

Shiba, Y., Kim, C., Santangelo, A. M., & Roberts, A. C. (2015). Lesions of either anterior orbitofrontal cortex or ventrolateral prefrontal cortex in marmoset monkeys heighten innate fear and attenuate active coping behaviors to predator threat. *Frontiers in Systems Neuroscience*, *8*, 250. https://doi.org/10.3389/fnsys.2014.00250

Sukhodolsky, D. G., Ibrahim, K., Kalvin, C. B., Jordan, R. P., Eilbott, J., & Hampson, M. (2021). Increased amygdala and decreased frontolimbic resting-state functional connectivity in children with aggressive behavior. *Social Cognitive and Affective Neuroscience*, *17*(7), 634–644. https://doi.org/10.1093/scan/nsab128

Sun, Q., Zhang, Y., Zhou, J., & Wang, X. (2022). Altered resting-state functional connectivity in the default mode network in male juvenile violent offenders. *Brain Imaging and Behavior*, *16*(2), 608–616. https://doi.org/10.1007/s11682-021-00535-3

Tang, J., Liao, Y., Song, M., Gao, J.-H., Zhou, B., Tan, C., Liu, T., Tang, Y., Chen, J., Chen, X., & Zhan, W. (2013). Aberrant default mode functional connectivity in early onset schizophrenia. *PloS One*, *8*(7), e71061. https://doi.org/10.1371/journal.pone.0071061

Weathersby, F. L., King, J. B., Fox, J. C., Loret, A., & Anderson, J. S. (2019). Functional connectivity of emotional well-being: Overconnectivity between default and attentional networks is associated with attitudes of anger and aggression. *Psychiatry Research: Neuroimaging*, *291*, 52–62. https://doi.org/10.1016/j.pscychresns.2019.08.001

Wechsler, D. (1997). *Wechsler adult intelligence scale®—third edition (WAIS®-III)*,. Pearson Assessment Inc.

Wechsler, D. (1999). *Manual for the Wechsler abbreviated scale of intelligence*. The Psychological Corporation.

Wechsler, D. (2011). *Wechsler abbreviated scale of intelligence-second edition (WASI-II)*. NCS Pearson.

White, S. F., VanTieghem, M., Brislin, S. J., Sypher, I., Sinclair, S., Pine, D. S., Hwang, S., & Blair, R. J. R. (2016). Neural correlates of the propensity for retaliatory behavior in youths with disruptive behavior disorders. *The American Journal of Psychiatry*, *173*(3), 282–290. https://doi.org/10.1176/appi.ajp.2015.15020250

Yang, Y., Joshi, S. H., Jahanshad, N., Thompson, P. M., & Baker, L. A. (2017). Neural correlates of proactive and reactive aggression in adolescent twins: Neural correlates of adolescent aggression. *Aggressive Behavior*, *43*(3), 230–240. https://doi.org/10.1002/ab.21683

Thomas Yeo, B. T., Krienen, F. M., Sepulcre, J., Sabuncu, M. R., Lashkari, D., Hollinshead, M., Roffman, J. L., Smoller, J. W., Zöllei, L., Polimeni, J. R., Fischl, B., Liu, H., & Buckner, R. L. (2011). The organization of the human cerebral cortex estimated by intrinsic functional connectivity. *Journal of Neurophysiology*, *106*(3), 1125–1165. https://doi.org/10.1152/jn.00338.2011

Zheng, K.-Z., Wang, H.-N., Liu, J., Xi, Y.-B., Li, L., Zhang, X., Li, J.-M.,Yin, H., Tan, Q.-R., Lu, H.-B., & Li, B.-J. (2018). Incapacity to control emotion in major depression may arise from disrupted white matter integrity and OFC-amygdala inhibition. *CNS Neuroscience & Therapeutics*, *24*(11), 1053–1062. https://doi.org/10.1111/cns.12800

Zhou, J., Yao, N., Fairchild, G., Cao, X., Zhang, Y., Xiang, Y.-T., Zhang, L., & Wang, X. (2016). Disrupted default mode network connectivity in male adolescents with conduct disorder. *Brain Imaging and Behavior*, *10*(4), 995–1003. https://doi.org/10.1007/s11682-015-9465-6