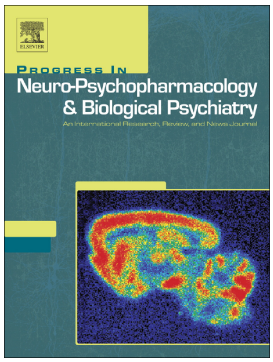

Brain responses in aggression-prone individuals: A systematic review and meta-analysis of functional magnetic resonance imaging (fMRI) studies of anger- and aggression-eliciting tasks

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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

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Abstract

Reactive aggression in response to perceived threat or provocation is part of humans' adaptive behavioral repertoire. However, high levels of aggression can lead to the violation of social and legal norms. Understanding brain function in individuals with high levels of aggression as they process anger- and aggression-eliciting stimuli is critical for refining explanatory models of aggression and thereby improving interventions. Three neurobiological models of reactive aggression – the limbic hyperactivity, prefrontal hypoactivity, and dysregulated limbic-prefrontal connectivity models – have been proposed. However, these models are based on neuroimaging studies involving mainly non-aggressive individuals, leaving it unclear which model best describes brain function in those with a history of aggression.

We conducted a systematic literature search (PubMed and Psycinfo) and Multilevel Kernel Density meta-analysis (MKDA) of nine functional magnetic resonance imaging (fMRI) studies (eight included in the between-group analysis [i.e., aggression vs. control groups], five in the within-group analysis). Studies examined brain responses to tasks putatively eliciting anger and aggression in individuals with a history of aggression alone and relative to controls.

Individuals with a history of aggression exhibited greater activity in the superior temporal gyrus and in regions comprising the cognitive control and default mode networks (right posterior cingulate cortex, precentral gyrus, precuneus, right inferior frontal gyrus) during reactive aggression relative to baseline conditions. Compared to controls, individuals with a history of aggression exhibited increased activity in limbic regions (left hippocampus, left amygdala, left parahippocampal gyrus) and temporal regions (superior, middle, inferior temporal gyrus), and reduced activity in occipital regions (left occipital cortex, left calcarine cortex).

These findings lend support to the limbic hyperactivity model in individuals with a history of aggression, and further indicate altered temporal and occipital activity in anger- and aggression-eliciting conditions involving face and speech processing.

Introduction

Unplanned aggressive behavior that occurs following perceived provocation is referred to as reactive aggression (Anderson & Bushman, 2002). It is distinct from proactive aggression, which is premeditated and instrumentally motivated (Dodge, 1991)(Raine et al., 2006). While reactive aggression is an adaptive human response in specific circumstances, it can also violate societal and legal norms. It accounts for more violent offenses than proactive aggression (Strobel et al., 2011; White et al., 2013) and can have severe repercussions on victims (WHO, 2007).

High levels of reactive aggression can be a sign of emotional or cognitive problems, including a poor ability to regulate negative emotions (Roberton et al., 2012) and poor executive functioning (Giancola, 1995; Ishikawa & Raine, 2003; Séguin, 2009). High levels of reactive aggression can also be a symptom of personality and psychiatric disorders (Lane et al., 2011; Ogilvie et al., 2011) as they are frequently observed in Antisocial and Borderline Personality Disorders (BPD) (Azevedo et al., 2020; Soloff & Chiappetta, 2017), psychopathy (Blair, 2008) and Intermittent Explosive Disorder (IED) (E. F. Coccaro et al., 2007; McCloskey et al., 2016). Research on the factors that might predispose individuals to engage in reactive aggression is thus critical to advance interventions aimed at reducing this problem.

Proposed Neurobiological Mechanisms of Reactive Aggression

Neuroimaging studies of individuals with no documented history of aggression (controls) indicate that aggressive responses to provocation-based tasks are associated with increased activation in the amygdala (Buades-Rotger et al., 2016; Lotze et al., 2007). The amygdala is a limbic region that plays a pivotal role in processing emotionally salient stimuli (Cardinal et al., 2002; Rodrigues et al., 2009). It is highly interconnected with cortical regions such as the orbitofrontal cortex (OFC) and dorsolateral prefrontal cortex (DLPFC) (Schoenbaum et al., 2003). Both the OFC and the DLPFC receive inputs from the amygdala and other medial temporal regions to integrate affective information (Liu et al., 2011), which supports emotion regulation (Banks et al., 2007; Berboth & Morawetz, 2021; Ghashghaei & Barbas, 2002). Thus, the brain areas putatively implicated in reactive aggression belong to a broader neural circuit of cortical and subcortical regions involved in emotion generation and regulation (Kober et al., 2008; Ochsner & Gross, 2014).

Animal studies have indicated that reactive aggression can be mediated by an acute threat response circuit involving projections from the amygdala to the hypothalamus and from the hypothalamus to the periaqueductal gray (PAG; Lin et al., 2011; Nelson & Trainor, 2007). This circuit is also implicated in human reactive aggression in response to threat, frustration, and social provocation (Blair, 2004). Consistently, functional magnetic resonance imaging (fMRI) studies in human controls have shown that activity in the amygdala, hypothalamus, and PAG increases with greater threat proximity (Mobbs et al., 2007, 2009). Additional studies have mimicked social provocation by employing laboratory-based models of reactive aggression, whereby participants could retaliate against punishments from opponents (e.g., removing points during a competitive game; Cherek et al., 1997; Taylor, 1967).

These studies have shown that a similar neural circuitry is involved in the acute threat response and in impulsive retaliation following provocation (Sanfey et al., 2003; Strobel et al., 2011). However, when examining neural responses to emotional provocation in individuals at risk of engaging in reactive aggression (e.g., with chronic irritability), enhanced amygdala activation but not enhanced hypothalamus or PAG activation was observed (Hazlett et al., 2012; Thomas et al., 2013). This distinct pattern of brain activity suggests that those at risk of reactive aggression may process provocation differently from controls, possibly displaying a reduced threat response.

Previous fMRI studies have also found that non-aggressive individuals select higher punishments for their opponents during high relative to low provocation conditions, and that this is positively correlated with enhanced activation in the medial prefrontal cortex (PFC) and anterior cingulate cortex (Krämer et al., 2007, 2011). This enhanced PFC activation may reflect cognitive processing of the provocation as well as a reappraisal of negative emotions (Etkin et al., 2011; Golkar et al., 2012). In contrast, individuals with a history of problematic anger and aggression have been found to show reduced activity in the PFC during reactive aggression following potentially aggression-eliciting tasks (E. F. Coccaro et al., 2007; da Cunha-Bang et al., 2017; McCloskey et al., 2016). Additionally, reactive aggression has been associated with reduced limbic-prefrontal connectivity (Davidson et al., 2000; Siever, 2008). Given its relevance for emotion regulation (Banks et al., 2007; Berboth & Morawetz, 2021; Ghashghaei & Barbas, 2002), reduced limbic-prefrontal connectivity may imply deficits in downregulating negative emotions (E. F. Coccaro et al., 2007; da Cunha-Bang et al., 2017; Siep et al., 2019).

Some neuroimaging studies have examined differences in brain function between individuals with and without a history of aggression. One fMRI study of emotional information processing found that participants with IED exhibited greater amygdala activity, diminished OFC activity, and decreased connectivity between these regions compared to controls during angry faces processing, a mild variant of a threatening/provocative task (E. F. Coccaro et al., 2007). Evidence of disrupted amygdala-OFC connectivity during angry faces processing in participants with IED vs. controls has been replicated (McCloskey et al., 2016). In response to provocation, individuals with a history of violent offending (vs. non-aggressive controls) have been found to exhibit greater activity in the amygdala and striatum (da Cunha-Bang et al., 2017), as well as reduced amygdala-PFC and striatal-PFC connectivity (Siep et al., 2019), all of which might reflect poor regulation of emotional responses (Davidson et al., 2000; Siever, 2008).

Based on a qualitative review of prior neuroimaging studies, reactive aggression appears to be associated with amygdala hyperactivity (E. F. Coccaro et al., 2007; da Cunha-Bang et al., 2017; McCloskey et al., 2016), PFC hypoactivity (E. F. Coccaro et al., 2007; Dougherty et al., 2004; Raine et al., 1998), and dysregulated limbic-PFC connectivity (E. F. Coccaro et al., 2007; McCloskey et al., 2016; Siep et al., 2019), with notable differences between those with a history of aggression and controls that require further examination. One systematic review supported the cortico-limbic model of reactive aggression, but did not find strong evidence for amygdala hyperactivity and OFC hypoactivity (Fanning et al., 2017). However, this review only included studies involving non-aggressive individuals. Therefore, it remains unclear what activation patterns would exist in individuals with a history of aggression. Another systematic review reported two meta-analyses: one focused on studies of cognitive tasks in individuals with psychiatric disorders characterized by aggression compared to controls, and one on studies of aggression-eliciting tasks in non-aggressive controls

(Wong et al., 2019). The first found reduced activity in the precuneus, a region involved in cognitive function, in the psychiatric sample (Cavanna & Trimble, 2006b). The second meta-analysis found activation in the right postcentral gyrus during aggression-eliciting tasks, but no activation in regions associated with emotion generation and regulation (e.g., amygdala and PFC), in the control sample. The present systematic review and meta-analysis thus aimed to address the outstanding question of whether brain activity patterns differ between individuals with a history of aggression and controls during putatively aggression-eliciting tasks.

Methods and Materials

To promote transparency and minimize risk of bias, we pre-registered our protocol on PROSPERO on February 2, 2021 (CRD42021211242).

Study Selection

We conducted our systematic review (January 30th - March 18th, 2021) using PubMed (Medline) and APA Psycinfo (Ovid) advanced search builder. The following search criteria and keywords were used: (*"aggression"* or *"aggressive"*) with (*"reactive"* or *"expressive"* or *"hostile"* or *"impulsive"* or *"violent"* or *"explosive" or "anger"* or *"angry"* or *"overt"* or *"emotional"*) paired with (*"fMRI[tw]"* or *"functional magnetic resonance imaging"*), for entries dating January, 1990-March 18th, 2021. We used Covidence (covidence.org) to organize, manage, and detect duplicate citations. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic review (Moher et al., 2009). Two authors (MN, PP) reviewed and screened titles, abstracts, and full texts according to pre-defined selection criteria, and independently coded information on included

sources in a data extraction matrix. Conflicts were resolved through discussion and involving other authors (NJ, MCS). The number of records identified, included, and excluded in the process are depicted in **Figure 1**.

Inclusion/Exclusion Criteria

We included studies that met the following criteria:

1. Peer-reviewed, in English;
2. Reported original data from participants aged ≧16yr. We chose this age threshold as it corresponds to the age of consent to participate in research in Canada (Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans; TCPS 2), where the current study was carried out. Moreover, the conventional 18+ threshold is suboptimal from a brain development standpoint (Johnson et al., 2009), as it does not reflect timing of the brain rewiring process (Arain et al., 2013);
3. Reported whole-brain thresholded results in a standard anatomical space. Studies that used only a region-of-interest approach were excluded;
4. Examined brain activity during aggression-eliciting paradigms, namely, paradigms that have been found to evoke reactive aggression outside the scanner and/or to be a proxy for aggression in the scanner. Studies using resting-state paradigms and/or cognitive paradigms with no anger or aggression-eliciting component were excluded;
5. Involved participants with a history of aggression and a non-aggressive control group. Studies involving only non-aggressive participants were excluded.

We considered as participants with a history of aggression those who met at least one of the following criteria:

1. Have a Diagnostic and Statistical Manual of Mental Disorders (5th ed,; DSM-5; American Psychiatric Association, 2013) or International Classification of Diseases and Related Health Problems (11th ed,; ICD-11; World Health Organization, 2019) psychiatric diagnosis that specifies patterns of behavior disregarding and violating the rights of others (e.g., Antisocial Personality Disorder, IED, Conduct Disorder) with documented history of overtly harming others; and/or
2. Have been charged with, convicted, or incarcerated for aggressive behavior, against persons or property; and/or
3. Scored above a normative threshold on a standardized behavioral assessment of aggression, whether clinician-rated or standardized psychometric measures (e.g., Buss and Perry Aggression Questionnaire; (Buss & Perry, 1992).

Data Synthesis

A quantitative analysis was conducted to compare brain activation during aggression-eliciting paradigms in the at-risk and control groups. This included stratifying brain activation patterns according to condition (aggression-eliciting vs. control) and participant group (aggression vs. controls), and conducting a coordinate based meta-analysis.

Coordinate Based Meta-Analysis: Multi-level Kernel Density Analysis

We conducted a multilevel kernel density analysis (MKDA), which summarizes evidence of activation from the included studies for X (left-right), Y(posterior-anterior), and Z (inferior-superior) peak coordinates in Montreal Neurological Institute (MNI) space (Wager et al., 2009). We chose this method because the alternative, Activation Likelihood Estimation (ALE), treats all peak coordinates across studies as independent units of analysis and, thus, increases the risk of the results being driven by a subset of studies showing the same activation peaks (Kober et al., 2008).

In MKDA, the unit of analysis is the sample size-weighted proportion of studies that report activation differences in a spatial location, which increases generalizability. MKDA summarizes evidence for activation in a local neighborhood around each voxel in a standard brain atlas, and reports coordinates in reference to a statistical contrast map (SCM) of activated brain regions for each study (Wager et al., 2009). Consistency and specificity across studies is analyzed in the neighborhood of each voxel, and consistency is determined by how many SCMs are activated near a voxel (Wager et al., 2007). A 3D histogram of peak locations is constructed and smoothed with a spherical indicator function of radius; this convolution occurs within each SCM and results in the creation of contrast indicator maps (CIMs). Weighted CIMs are thresholded based on the maximum proportion of activated comparison maps under the null hypothesis distribution, where the distribution of contiguous regions of activation in the CIMs are randomly and uniformly distributed throughout the brain (**Figure 2**). Sample size is also considered, as the precision of the estimates from each study is proportional to the square root of the study sample size (Wager et al., 2009). Lastly, 5000 Monte Carlo simulations were performed to compare the observed density map to a null distribution of density maps created by identifying clusters of activated voxels for each SCM and then randomizing cluster centers within gray matter in the standard brain.

Software, Data, and Code Availability.

We performed analyses in MATLAB v.R2021a using the MKDA toolbox developed by Tor Wager (https://github.com/canlab/CanlabCore). Our code is publicly available on the Open Science Framework (http://osf.io/CG94W). To identify activated brain regions associated with the generated MNI coordinates, we used Neurosynth (https://neurosynth.org/locations/).

Results

Participants

Our systematic literature review included 9 studies involving 230 individuals with a history of aggression and 235 controls. Tables 1–3 report information on demographic and clinical characteristics (**Tables 1** & **2**), offense histories, and antisocial behavior assessments (**Table 3**).

The aggression and control groups were matched for demographic characteristics. Participants with a history of aggression were aged 17-44yr, controls were 17-47yr. All studies included adults only, except for one involving participants <18 years of age (Klapwijk et al., 2016; *M*=17, *SD*=1.2). All participants completed secondary education, except for the one study involving older adolescents (Klapwijk et al., 2016). Three studies involved both females and males (E. Coccaro et al., 2007; Herpertz et al., 2017; Mccloskey et al., 2016), five involved males only (Klapwijk et al., 2016; Lee et al., 2009; Schienle et al., 2017; Seok & Cheong, 2020; Tonnaer et al., 2017) and one was comprised of females only (Krauch et al., 2018). Half reported ethnicity, with ~70% of participants being Caucasian (E. Coccaro et al., 2007; Mccloskey et al., 2016; Schienle et al., 2017; Tonnaer et al., 2017). One study included only Asian participants (Lee et al., 2009).

Seven out of nine studies involved participants with a history of aggression and a psychiatric disorder, including BPD (Herpertz et al., 2017; Krauch et al., 2018), IED (E. Coccaro et al., 2007; Mccloskey et al., 2016; Seok & Cheong, 2020), Conduct Disorder (Klapwijk et al., 2016), or multiple disorders (Tonnaer et al., 2017). Seven studies reported information on comorbid conditions, which included personality disorders, affective disorders, and substance disorders (E. Coccaro et al., 2007; Herpertz et al.,

2017; Klapwijk et al., 2016; Krauch et al., 2018; Mccloskey et al., 2016; Schienle et al., 2017; Tonnaer et al., 2017). Three studies reported that some participants were receiving psychotropic medication (antidepressants, most commonly; (E. Coccaro et al., 2007; Krauch et al., 2018; Tonnaer et al., 2017).

Four studies reported that participants had criminal offense histories, including attempted manslaughter or murder, assault, or domestic violence (Klapwijk et al., 2016; Lee et al., 2009; Schienle et al., 2017; Tonnaer et al., 2017). An assessment of antisocial behaviors was conducted in each of the included studies, by means of the Lifetime History of Aggression (E. F. Coccaro et al., 1997), Buss and Perry Aggression Questionnaire (Buss & Perry, 1992), Reactive-Proactive Aggression Questionnaire (Raine et al., 2006), Anger Rumination Scale (Sukhodolsky et al., 2001), or State-Trait Anger Expression Inventory (Spielberger, 2010). The aggression groups scored higher than normative values on all these measures, and significantly higher than their respective control groups.

Tasks

fMRI tasks aimed at eliciting aggression included script-driven-imagery tasks (Herpertz et al., 2017; Krauch et al., 2018; Tonnaer et al., 2017), a personal-space intrusion task (Schienle et al., 2017), an anger-eliciting task (Klapwijk et al., 2016), and viewing emotional images (E. Coccaro et al., 2007; Lee et al., 2009; Mccloskey et al., 2016) and videos (Seok & Cheong, 2020). During script-driven-imagery tasks, participants listened to audiotapes and were asked to imagine the scenes as vividly as possible to provoke an intense emotional response. We compared conditions that likely elicited aggression (e.g., “anger induction”, “anger engagement”) to neutral conditions. In the personal-space intrusion task, participants viewed static or “approaching” neutral faces, where pictures were enlarged to the point where only the mouth and eyes were visible, creating the impression of an invasion of

personal space (Schienle et al., 2017). We compared the approaching condition to the static face condition. In the anger-eliciting task, participants read the responses of a fictional opponent following an unfair distribution of tokens (Klapwijk et al., 2016). We compared angry responses (potentially aggression-eliciting) to happy responses (baseline). In the implicit emotion processing task, participants viewed faces expressing emotions and had to identify their gender (E. F. Coccaro et al., 2007). We compared the angry face viewing condition (potentially aggression-eliciting) to rest (blank screen; no neutral face condition available). In the explicit emotion processing task, participants had to identify the emotional valence of neutral, positive, or negative faces; we compared angry vs. neutral faces. During the passive viewing of images tasks, participants viewed neutral, positive, and aggressive pictures, the latter involving violent pictures with female victims or images depicting general aggressive threats (e.g., person pointing a gun). The task involving passive viewing of video clips included anger-related and neutral clips; for these, we contrasted the anger-/aggression-related and neutral conditions.

Multi-Level Kernel Density Analysis (MKDA) Results

Information was available from five studies for the within-group analysis (Herpertz et al., 2017; Klapwijk et al., 2016; Krauch et al., 2018; Mccloskey et al., 2016; Schienle et al., 2017) and from eight studies for the between-group analysis (E. Coccaro et al., 2007; Herpertz et al., 2017; Klapwijk et al., 2016; Krauch et al., 2018; Lee et al., 2009; Mccloskey et al., 2016; Seok & Cheong, 2020; Tonnaer et al., 2017). We considered significant voxels those >95th percentile value under the null hypothesis (threshold derived from Monte Carlo simulations) (Kober & Wager, 2010). This generated the final regions of activated contrast indicator maps. Herpertz et al. (2017) had the largest sample size (N=112) and thus the greatest influence on the analysis.

Figure 3 depicts the final map of significant results generated after the weighted average of the contrast indicator maps was compared and thresholded with the maximum proportion of activated comparison maps under the null hypothesis distribution. Peak brain activations are denoted (**Tables 5** & **6)**.

Between-group MKDA indicated sets of regions that were more strongly activated in the aggression vs. control group, comprising a total of 2134 voxels (**Table 5**). These included the left hippocampus, left amygdala, left parahippocampal gyrus, right superior temporal sulcus, right inferior temporal gyrus and middle temporal gyrus. The clusters are shown in **Figure 3A** with coordinates (-30, -12, -26) representing the first set of clusters. Between-group MKDA also indicated regions that were more strongly activated in the controls vs. aggression group, comprising a total of 727 voxels (**Table 6**). These regions included the left occipital cortex, left medial occipital cortex, left lingual gyrus of the occipital lobe, left calcarine cortex and left V2. The clusters are shown in **Figure 3B**, with coordinates (-22, -73, 4) representing the first set of clusters.

We further conducted within-group MKDA in the two groups separately. In the aggression group, multiple regions activated more in the aggression-inducing vs. control conditions, comprising a total of 2513 voxels (Supplement **Table 1**). These regions included the right/left superior temporal gyrus, right inferior frontal gyrus, right middle frontal gyrus, right precentral gyrus, occipital pole, SMA, posterior cingulate cortex (PCC) and precuneus. The clusters are shown in **Supplement Figure 1A**, with coordinates (56, -18 -1) representing the first cluster. In the control group, a few regions activated more in the aggression-eliciting conditions relative to the control conditions, comprising a total of 989 voxels (Supplement Table 2). These regions included the right/left superior

temporal sulcus, left cuneus, left calcarine, right premotor cortex, and left inferior occipital gyrus. The clusters are shown in Supplement Figure 1B, with coordinates (49, -30, -1) representing the first cluster.

Discussion

Neural Responses to Elicited Aggression in Individuals with a History of Aggression Relative to Controls

Our between-group MKDA analysis included eight studies (E. Coccaro et al., 2007; Herpertz et al., 2017; Klapwijk et al., 2016; Krauch et al., 2018; Lee et al., 2009; Mccloskey et al., 2016; Seok & Cheong, 2020; Tonnaer et al., 2017) and revealed greater left limbic activation (left amygdala, left hippocampus, left parahippocampal gyrus), greater temporal activation (superior, middle, and inferior temporal gyrus), and decreased left occipital activation (left occipital cortex and left calcarine cortex) during aggression-eliciting conditions (vs. baseline) in the aggression group relative to the control group.

Expanding the Amygdala Hyperactivity Model of Reactive Aggression

The finding of increased limbic activation in individuals with a history of aggression relative to controls provides support for and extends the amygdala hyperactivity model of reactive aggression (Davidson et al., 2000; Siever, 2008). This is in contrast with a previous meta-analysis (Wong et al., 2019), which did not find abnormalities in limbic activation in individuals with high trait aggression. This discrepancy might be due to the nature of the tasks examined. Instead of cognitive tasks, in the current study, we selected tasks focused on emotion generation and regulation in response to perceived provocation or anger elicitation, which might explain greater limbic involvement.

Our results further expand on the amygdala hyperactivity model of reactive aggression by suggesting that other limbic areas that have received less attention, namely the hippocampus and parahippocampal gyrus, are also implicated. The hippocampus is embedded in the temporal lobe, on the posterior part of the limbic lobe (Anand & Dhikav, 2012) and is mainly involved in episodic memory (Buzsáki & Moser, 2013; Squire, 1992), but also in emotion regulation and emotional memory processing (Brühl et al., 2014; Ruiz et al., 2014). Structural abnormalities in the hippocampus, such as exaggerated asymmetry, have been associated with impulsive and disinhibited behaviors (Raine et al., 2004). Disruption of the PFC-hippocampal circuitry has been linked with affect dysregulation and impulsive disinhibited behavior (Gregg & Siegel, 2001; LeDoux, 1996; Raine et al., 2004). Therefore, the hippocampus may play a role in modulating aggressive responses (LeDoux, 1996). Our findings support this possibility and motivate further work examining the role of the hippocampus in reactive aggression. For instance, enhanced hippocampus and parahippocampal gyrus activation in individuals with a history of aggression during provocation might reflect enhanced recall of associative memories related to aggression (Takahashi et al., 2002). Future studies could address this possibility by examining differences between individuals with a history of reactive aggression and controls in mnemonic performance while processing aggression-eliciting stimuli.

Our results further hint at the importance of amygdala-hippocampal coupling. These regions display bi-directional functional relationships during encoding of emotional events (Richardson et al., 2004) and contribute to forming semantic representations of emotionally-valanced stimuli (Canli et al., 2000; Mégevand et al., 2017). The hippocampus forms episodic representations of the emotional significance of events, which influence amygdala responses when emotional stimuli are next encountered (Phelps, 2004).

Our findings also suggested left hemispheric lateralization in individuals with a history of aggression. The left amygdala appears to be involved in specific and sustained stimulus evaluation, whereas the right amygdala is preferentially engaged in the automatic detection of emotional stimuli (Gläscher & Adolphs, 2003; Wright et al., 2001). Thus, it is possible that individuals with high levels of aggression engage in a more detailed analysis of the aggression-eliciting stimuli. Abnormalities in left amygdala-hippocampal coupling have been associated with deficits in the perception of social cues, including facial expressions (Schulze et al., 2016). In particular, a meta-analysis found increased left amygdala and left hippocampus activation during the processing of negative emotional stimuli in those with BPD (Schulze et al., 2016). Since most participants with a history of aggression in our meta-analysis had psychiatric disorders, the enhanced amygdala-hippocampus co-activation might also be a distinctive feature of reactive aggression in the context of psychiatric conditions, but this warrants further study.

No Support for the Limbic-Prefrontal Model of Reactive Aggression

Our results did not provide direct support for the PFC hypoactivity model of reactive aggression (E. Coccaro et al., 2007; Davidson et al., 2000; Mccloskey et al., 2016). However, we did not assess functional connectivity, and thus did not test models that focus on interactions between amygdala and PFC regions in the control of aggressive responses. Limbic-PFC models conceptualize reactive aggression as a failure in top-down control systems (i.e., PFC) to inhibit aggressive reactions largely generated in the limbic system (Siever, 2008). Consistent with this, prior studies observed amygdala hyperactivity and PFC hypoactivity in violent offenders (da Cunha-Bang et al., 2017, 2018), and decreased attenuation of amygdala reactivity by the PFC in aggressive individuals with BPD (Mancke et al., 2015; Schulze et al., 2016). Since our aggression group displayed abnormal occipital activation (as discussed below),

one possibility is that PFC areas influenced amygdala activity indirectly, through modulation of other regions directly connected to it, namely perceptual areas in the occipital cortex (Ochsner et al., 2002). Indeed, regions like the DLPFC, implicated in the reappraisal of negative emotion through attenuation of amygdala responses (Hariri et al., 2000; Pessoa et al., 2002), have sparse direct connections to the amygdala (McDonald, 1998). Future functional connectivity studies are needed to elucidate this possibility.

Although prefrontal activation was not observed in our between-group analyses, our within-group analysis found enhanced activation in the right inferior frontal gyrus (IFG), the right posterior cingulate cortex (PCC) and the precuneus in individuals with a history of aggression, but not in controls. The right inferior frontal gyrus (IFG) is part of the PFC and is an essential component of response inhibition (Aron et al., 2004; Logan et al., 1997; Suda et al., 2020). Since aggression has been linked to response inhibition deficits (Hoaken et al., 2003; Pawliczek et al., 2013), enhanced right IFG activity in individuals with a history of aggression might reflect an effort to inhibit aggressive responses, which is particularly relevant as participants had to presumably refrain from exhibiting aggressive behaviors in the scanner. Further, previous studies involving non-aggressive individuals have shown that enhancing right IFG activity through brain stimulation improves inhibition in a stop signal task (Jacobson et al., 2011). Future research could explore whether stimulating this area also enhances response inhibition in individuals with high levels of aggression

The PCC and precuneus are part of the default mode network (DMN; Gusnard & Raichle, 2001; Utevsky et al., 2014) and represent some of the most metabolically active brain regions at-rest and during cognitive tasks (Gur et al., 2009; Pfefferbaum et al., 2011). The PCC integrates information across cortical networks (Hagmann et al., 2008), supporting behavioral regulation in changing environments (Leech et al., 2012; Pearson et al., 2011). The precuneus is a regulatory region strongly interconnected with the fronto-

parietal network (FPN; Cavanna & Trimble, 2006), and its disrupted activation has been observed in high trait aggressive individuals (Wong et al., 2019). Activation of the PCC and precuneus in individuals with a history of aggression during the processing of anger-inducing stimuli may thus reflect ineffective DMN suppression, or an increased effort to suppress behavioral responses to provocation. However, it should be noted that no between group differences were found in the IFG, PCC, and precuneus.

Novel Findings: Role of Temporal and Occipital Regions in Reactive Aggression

Our finding of greater activation in the superior temporal gyrus, right inferior temporal gyrus and middle temporal gyrus in individuals with a history of aggression relative to controls is novel. The temporal lobe is involved in speech, sound, and visual affect processing (Furl et al., 2010; Goghari et al., 2011; Haxby et al., 2000). In particular, the superior temporal gyrus is involved in social cognition (Bigler et al., 2007) through its role in processing auditory information (e.g., spoken words; Zevin, 2009) and visual information (e.g., eye and body movements; Allison et al., 2000; Haxby et al., 2000). The superior temporal gyrus is also one of the main sites of high-level sensory information convergence (Bruce et al., 1981). Since half of the studies involved viewing faces or videos, and half involved listening to anger-eliciting scripts or audiotapes, activation of these regions in both groups seems intuitive. At least two factors might explain group differences. First, social information processing may be compromised in those with high levels of aggression (E. F. Coccaro, Fanning, et al., 2016) who frequently display a hostile attribution bias (Bailey & Ostrov, 2008; Crick, 1995). Therefore, greater superior temporal gyrus activation in this group might reflect sensitivity to anger-provoking social cues (Jones, 2012; Lee et al., 2009; Morland et al., 2012). Second, given evidence of direct projections from the superior temporal gyrus to the hippocampal entorhinal cortex (Amaral et al., 1983), this result may also reflect differences in the acquisition of new

emotionally salient memories (Suzuki & Amaral, 2004; van Strien et al., 2009). Although functional neuroimaging studies have not found evidence of temporal lobe dysfunction associated with reactive aggression, there is evidence suggesting that individuals with temporal lobe epilepsy engage in recurrent episodes of interictal affective aggression (Falconer, 1973). Anatomical MRI studies on patients with temporal lobe epilepsy and IED found left temporal lesions and amygdala atrophy in subgroups of aggressive patients (van Elst et al., 2000).

To our knowledge, decreased activation in the left occipital cortex in individuals with a history of aggression relative to controls has not been previously noted. As such, this too is a novel finding of the current work. The occipital lobe is the visual processing area of the brain; it is implicated in object and face recognition, visuospatial processing, and visual memory formation (Rehman & Al Khalili, 2021). Prior research indicated that the amygdala facilitates perception and attention to emotionally salient stimuli through projections to the visual stream (Tamietto & de Gelder, 2010) and by modulating activation in higher sensory processing areas (Wendt et al., 2011). Our results suggest that the mechanism by which the amygdala facilitates perception of aggression-eliciting stimuli through its modulation of visual streams might be dysregulated in individuals with a history of aggression, and connectivity analyses are required to directly assess this.

Limitations

Our meta-analysis is limited by the possibility of publication bias (and, thus, false positive results; Mlinarić et al., 2017; Sedgwick, 2015) and by the small number of studies. Studies were characterized by small samples (potentially under-powered) and substantial variation in analyses parameters (Schuit et al., 2015). MKDA adjusts for some of these biases by ensuring that larger and

more rigorous studies exert the highest effects. Meta-analytic methods including small-sample adjustments, profile likelihood, or hierarchical Bayesian models (Cornell et al., 2014) are recommended. Although the average sample size of the studies included in our meta-analysis was higher than what is typically observed in the fMRI literature (51 vs. 13 participants; Button et al., 2013), we did not have sufficient power to examine potential moderators such as task type, psychiatric comorbidities, medication status, and fMRI methodology. Furthermore, participants were mostly male (58%) white (70%) young adults (*Mdn* = 32 years old), which challenges generalizability to other groups.

The included studies were heterogenous in how they defined the aggression groups. Four studies involved violent offenders with Antisocial Personality Disorder (Schienle et al., 2017; Tonnaer et al., 2017), Conduct Disorder (Klapwijk et al., 2016), or no psychiatric diagnoses (Lee et al., 2009), and five studies involved participants with IED or BPD, both characterized by reactive aggression (E. Coccaro et al., 2007; Herpertz et al., 2017; Krauch et al., 2018; Mccloskey et al., 2016; Seok & Cheong, 2020). All participants displayed high levels of aggression at psychometric assessments (Buss & Perry, 1992; E. F. Coccaro et al., 1997). We cannot be certain that all participants had a history of engaging exclusively in reactive aggression following a provocation, versus proactive aggression or both. For example, antisocial personality traits predict higher levels of both forms of aggression (Lobbestael et al., 2013). It would therefore be beneficial if studies reported specific accounts of participants' aggression history.

The included studies were also heterogeneous in terms of participants' diagnoses, substance use history, and medication status. Individuals with IED have been shown to display significantly lower gray matter volume than healthy and psychiatric controls (i.e., with no aggressive behaviour) in the amygdala, OFC, ventral medial prefrontal cortex, anterior cingulate cortex, and insula (E. F.

Coccaro, Fitzgerald, et al., 2016). Lower gray matter volume in these regions may be a characteristic of impulsively aggressive individuals and may account for dysregulated socio-emotional processing in response to potentially aggression-eliciting stimuli. Studies on structural brain abnormalities in BPD have also found gray matter volume reduction in the amygdala (Minzenberg et al., 2008; Rüsch et al., 2003), DLPFC, hippocampus, and OFC (de Araujo Filho et al., 2014; O'Neill et al., 2013). Moreover, five of the included studies involved participants with a history of alcohol and substance use (E. Coccaro et al., 2007; Herpertz et al., 2017; Krauch et al., 2018; Mccloskey et al., 2016; Tonnaer et al., 2017) and three involved a small number of participants taking antidepressants (E. Coccaro et al., 2007; Krauch et al., 2018; Tonnaer et al., 2017). Morphometric studies in individuals with alcohol and cocaine use disorders showed reduced grey matter volume in some of the regions found to differ between individuals with a history of aggression and controls in the current study, namely amygdala and superior temporal gyrus (Demirakca et al., 2011; Sim et al., 2007), which suggests that substance use may have influenced our results.

Across all studies, individuals with a history of aggression scored significantly higher than controls in antisocial behaviour assessments. One previous study found different structural brain features in individuals with life-long/persistent antisocial behaviour compared to individuals with adolescence-limited antisocial behaviour and non-antisocial behaviour (Carlisi et al., 2021). Specifically, the persistent group exhibited lower gray-matter volumes in subcortical regions such as the amygdala, hippocampus, brain stem, cerebellum and thalamus. As such, potential brain structure abnormalities associated with persistent antisocial behavior may also partly underlie our findings. However, given that IED, BPD, substance use disorders, and life-long antisocial behaviour share similar morphometric abnormalities, particularly in the amygdala, we do not expect the heterogeneity to fundamentally affect brain responses.

Additionally, we cannot assume that reduced grey matter in a specific region directly relates to altered functioning in this region (Mars et al., 2018; Poldrack, 2010).

A key limitation of the examined literature is that paradigms currently used in fMRI research to study reactive aggression target proxies of reactive aggression, rather than reactive aggression *per se;* as such, they likely lack external validity and experimental realism (Tedeschi & Quigley, 1996). Novel protocols should thus be developed to more effectively study the neural basis of reactive aggression. For example, more realistic tasks could combine virtual reality (VR) and fMRI (Beck et al., 2007; Reggente et al., 2018). Exploring the use of VR to elicit aggression will require specific safety protocols to minimize ethical and safety concerns (Lavoie et al., 2021). Alternative devices that are less sensitive to motion, such as electroencephalogram (EEG) or functional near-infrared spectroscopy (fNIRS) could also be used (Duan et al., 2020; Wriswede et al., 2011).

Conclusions

These findings lend support to the limbic hyperactivity model of reactive aggression and further implicate differential temporal and occipital activity in anger- and aggression-eliciting situations that involve face, visual, and speech processing. Future studies can advance our understanding of reactive aggression by examining potential participant- and task-related moderators, functional connectivity, and specific hypotheses derived from our findings.

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Authors' contributions

Conceptualization (PP, MN, MCS, NJ); Funding acquisition (PP); Data curation (MN, PP); Methodology (MN, PP, NJ); Supervision (PP, MCS, NJ); Formal Analysis and Visualization (MN, PP); Writing, original draft (MN, PP); Writing, review & editing (PP, MN, NJ, MCS).

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Scripts available at osf.io/CG94W. BioRxiv Preprint doi: https://doi.org/10.1101/2022.01.11.475895. Authors have no conflicts of interest to disclose.

Ethics Satement

The work described in the original articles included in this meta-analysis has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The manuscript is in line with the Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals and aims for the

inclusion of representative human populations (sex, age, and ethnicity) as per those recommendations. The terms sex and gender have been used correctly.

Author Statement

Conceptualization (PP, MN, MCS, NJ); Funding acquisition (PP); Data curation (MN, PP); Methodology (MN, PP, NJ); Supervision (PP, MCS, NJ); Formal Analysis and Visualization (MN, PP); Writing, original draft (MN, PP); Writing, review & editing (PP, MN, NJ, MCS).

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Supplementary data

Supplementary material

References

Allison, null, Puce, null, & McCarthy, null. (2000). Social perception from visual cues: Role of the STS region. *Trends in Cognitive Sciences*, *4*(7), 267–278. https://doi.org/10.1016/s1364-6613(00)01501-1

Amaral, D. G., Insausti, R., & Cowan, W. M. (1983). Evidence for a direct projection from the superior temporal gyrus to the entorhinal cortex in the monkey. *Brain Research*, *275*(2), 263–277. https://doi.org/10.1016/0006-8993(83)90987-3

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Anand, K. S., & Dhikav, V. (2012). Hippocampus in health and disease: An overview. *Annals of Indian Academy of Neurology*, *15*(4), 239–246. https://doi.org/10.4103/0972-2327.104323

Anderson, C. A., & Bushman, B. J. (2002). Human Aggression. *Annual Review of Psychology*, *53*(1), 27–51. https://doi.org/10.1146/annurev.psych.53.100901.135231

Arain, M., Haque, M., Johal, L., Mathur, P., Nel, W., Rais, A., Sandhu, R., & Sharma, S. (2013). Maturation of the adolescent brain. *Neuropsychiatric Disease and Treatment*, *9*, 449–461. https://doi.org/10.2147/NDT.S39776

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, *8*(4), 170–177. https://doi.org/10.1016/j.tics.2004.02.010

Azevedo, J., Vieira-Coelho, M., Castelo-Branco, M., Coelho, R., & Figueiredo-Braga, M. (2020). Impulsive and premeditated aggression in male offenders with antisocial personality disorder. *PloS One*, *15*(3), e0229876. https://doi.org/10.1371/journal.pone.0229876

Bailey, C. A., & Ostrov, J. M. (2008). Differentiating Forms and Functions of Aggression in Emerging Adults: Associations with Hostile Attribution Biases and Normative Beliefs. *Journal of Youth and Adolescence*, *37*(6), 713–722. https://doi.org/10.1007/s10964-007-9211-5

Banks, S. J., Eddy, K. T., Angstadt, M., Nathan, P. J., & Phan, K. L. (2007). Amygdala-frontal connectivity during emotion regulation. *Social Cognitive and Affective Neuroscience*, *2*(4), 303–312. https://doi.org/10.1093/scan/nsm029

Beck, L., Wolter, M., Mungard, N., Kohnen, T., & Sturm, W. (2007). *Combining Virtual Reality and Functional Magnetic Resonance Imaging (fMRI): Problems and Solutions*. 14.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). Manual for the Beck depression Inventory-II.San Antonio, TX: Psychological Corporation

Berboth, S., & Morawetz, C. (2021). Amygdala-prefrontal connectivity during emotion regulation: A meta-analysis of psychophysiological interactions. *Neuropsychologia*, *153*, 107767. https://doi.org/10.1016/j.neuropsychologia.2021.107767

Bigler, E., Mortensen, S., Neeley, E., Ozonoff, S., Krasny, L., Johnson, M., Lu, J., Provencal, S., McMahon, W., & Lainhart, J. (2007). Superior Temporal Gyrus, Language Function, and Autism. *Developmental Neuropsychology*, *31*, 217–238. https://doi.org/10.1080/87565640701190841

Bijleveld, E., Custers, R., Van der Stigchel, S., Aarts, H., Pas, P., & Vink, M. (2014). Distinct neural responses to conscious versus unconscious monetary reward cues. *Human Brain Mapping*, *35*(11), 5578–5586. https://doi.org/10.1002/hbm.22571

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. (2008). The amygdala and ventromedial prefrontal cortex: Functional contributions and dysfunction in psychopathy. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1503), 2557–2565. https://doi.org/10.1098/rstb.2008.0027

Bruce, C., Desimone, R., & Gross, C. G. (1981). Visual properties of neurons in a polysensory area in superior temporal sulcus of the macaque. *Journal of Neurophysiology*, *46*(2), 369–384. https://doi.org/10.1152/jn.1981.46.2.369

Button, K. S., Ioannidis, J., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S., & Munafò, M. R. (2013). Power failure: why small sample size undermines the reliability of neuroscience. Nature reviews neuroscience, 14(5), 365-376.

Brühl, A. B., Scherpiet, S., Sulzer, J., Stämpfli, P., Seifritz, E., & Herwig, U. (2014). Real-time neurofeedback using functional MRI could improve down-regulation of amygdala activity during emotional stimulation: A proof-of-concept study. *Brain Topography*, *27*(1), 138–148. https://doi.org/10.1007/s10548-013-0331-9

Buades-Rotger, M., Engelke, C., Beyer, F., Keevil, B. G., Brabant, C., & Krämer, U. M. (2016). Endogenous testosterone is associated with lower amygdala reactivity to angry faces and reduced aggressive behavior in healthy young women. *Scientific Reports*, *6*, 38538. https://doi.org/10.1038/srep38538

Buss, A. H., & Perry, M. (1992). The aggression questionnaire. *Journal of Personality and Social Psychology*, *63*(3), 452–459. https://doi.org/10.1037//0022-3514.63.3.452

Buzsáki, G., & Moser, E. I. (2013). Memory, navigation and theta rhythm in the hippocampal-entorhinal system. *Nature Neuroscience*, *16*(2), 130–138. https://doi.org/10.1038/nn.3304

Canli, T., Zhao, Z., Brewer, J., Gabrieli, J. D., & Cahill, L. (2000). Event-related activation in the human amygdala associates with later memory for individual emotional experience. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *20*(19), RC99.

Cardinal, R. N., Parkinson, J. A., Hall, J., & Everitt, B. J. (2002). Emotion and motivation: The role of the amygdala, ventral striatum, and prefrontal cortex. *Neuroscience and Biobehavioral Reviews*, *26*(3), 321–352. https://doi.org/10.1016/s0149-7634(02)00007-6

Carlisi, C. O., Moffitt, T. E., Knodt, A. R., Harrington, H., Langevin, S., Ireland, D., Melzer, T. R., Poulton, R., Ramrakha, S., Caspi, A., Hariri, A. R., & Viding, E. (2021). Association of subcortical gray-matter volumes with life-course-persistent antisocial behavior in a population-representative longitudinal birth cohort. *Development and Psychopathology*, 1–11. https://doi.org/10.1017/S0954579421000377

Cavanna, A. E., & Trimble, M. R. (2006a). The precuneus: A review of its functional anatomy and behavioural correlates. *Brain: A Journal of Neurology*, *129*(Pt 3), 564–583. https://doi.org/10.1093/brain/awl004

Cavanna, A. E., & Trimble, M. R. (2006b). The precuneus: A review of its functional anatomy and behavioural correlates. *Brain*, *129*(3), 564–583. https://doi.org/10.1093/brain/awl004

Chechko, N., Kellermann, T., Zvyagintsev, M., Augustin, M., Schneider, F., & Habel, U. (2012). Brain Circuitries Involved in Semantic Interference by Demands of Emotional and Non-Emotional Distractors. *PLOS ONE*, *7*(5), e38155. https://doi.org/10.1371/journal.pone.0038155

Cherek, D. R., Moeller, F. G., Schnapp, W., & Dougherty, D. M. (1997). Studies of violent and nonviolent male parolees: I. Laboratory and psychometric measurements of aggression. *Biological Psychiatry*, *41*(5), 514–522. https://doi.org/10.1016/s0006-3223(96)00059-5

Clark, C. A. C., Liu, Y., Wright, N. L. A., Bedrick, A., & Edgin, J. O. (2017). Functional neural bases of numerosity judgments in healthy adults born preterm. *Brain and Cognition*, *118*, 90–99. https://doi.org/10.1016/j.bandc.2017.07.011

Coccaro, E. F., Berman, M. E., & Kavoussi, R. J. (1997). Assessment of life-history of aggression: Development and psychometric characteristics. *Psychiatry Research*, *73*(3), 147–157. https://doi.org/10.1016/S0165-1781(97)00119-4

Coccaro, E. F., Fanning, J. R., Keedy, S. K., & Lee, R. J. (2016). Social cognition in Intermittent Explosive Disorder and aggression. *Journal of Psychiatric Research*, *83*, 140–150. https://doi.org/10.1016/j.jpsychires.2016.07.010

Coccaro, E. F., Fitzgerald, D. A., Lee, R., McCloskey, M., & Phan, K. L. (2016). Frontolimbic Morphometric Abnormalities in Intermittent Explosive Disorder and Aggression. *Biological Psychiatry. Cognitive Neuroscience and Neuroimaging*, *1*(1), 32–38. https://doi.org/10.1016/j.bpsc.2015.09.006

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

Coccaro, E., Mccloskey, M., Fitzgerald, D., & Phan, K. L. (2007). Amygdala and Orbitofrontal Reactivity to Social Threat in Individuals with Impulsive Aggression. *Biological Psychiatry*, *62*, 168–178. https://doi.org/10.1016/j.biopsych.2006.08.024

Cornell, J. E., Mulrow, C. D., Localio, R., Stack, C. B., Meibohm, A. R., Guallar, E., & Goodman, S. N. (2014). Random-effects meta-analysis of inconsistent effects: A time for change. *Annals of Internal Medicine*, *160*(4), 267–270. https://doi.org/10.7326/M13-2886

Corradi-Dell'Acqua, C., Hofstetter, C., & Vuilleumier, P. (2014). Cognitive and affective theory of mind share the same local patterns of activity in posterior temporal but not medial prefrontal cortex. *Social Cognitive and Affective Neuroscience*, *9*(8), 1175–1184. https://doi.org/10.1093/scan/nst097

Crescentini, C., Mengotti, P., Grecucci, A., & Rumiati, R. I. (2011). The effect of observed biological and non biological movements on action imitation: An fMRI study. *Brain Research*, *1420*, 80–92. https://doi.org/10.1016/j.brainres.2011.08.077

Crick, N. R. (1995). Relational aggression: The role of intent attributions, feelings of distress, and provocation type. *Development and Psychopathology*, *7*(2), 313–322. https://doi.org/10.1017/S0954579400006520

da Cunha-Bang, S., Fisher, P. M., Hjordt, L. V., Perfalk, E., Beliveau, V., Holst, K., & Knudsen, G. M. (2018). Men with high serotonin 1B receptor binding respond to provocations with heightened amygdala reactivity. *NeuroImage*, *166*, 79–85. https://doi.org/10.1016/j.neuroimage.2017.10.032

da Cunha-Bang, S., Fisher, P. M., Hjordt, L. V., Perfalk, E., Persson Skibsted, A., Bock, C., Ohlhues Baandrup, A., Deen, M., Thomsen, C., Sestoft, D. M., & Knudsen, G. M. (2017). Violent offenders respond to provocations with high amygdala and striatal reactivity. *Social Cognitive and Affective Neuroscience*, *12*(5), 802–810. https://doi.org/10.1093/scan/nsx006

Davidson, R. J., Putnam, K. M., & Larson, C. L. (2000). Dysfunction in the neural circuitry of emotion regulation—A possible prelude to violence. *Science (New York, N.Y.)*, *289*(5479), 591–594. https://doi.org/10.1126/science.289.5479.591

de Araujo Filho, G. M., Abdallah, C., Sato, J. R., de Araujo, T. B., Lisondo, C. M., de Faria, Á. A., Lin, K., Silva, I., Bressan, R. A., da Silva, J. F. R., Coplan, J., & Jackowski, A. P. (2014). Morphometric hemispheric asymmetry of orbitofrontal cortex in women with borderline personality disorder: A multi-parameter approach. *Psychiatry Research*, *223*(2), 61–66. https://doi.org/10.1016/j.pscychresns.2014.05.001

Demirakca, T., Ende, G., Kämmerer, N., Welzel-Marquez, H., Hermann, D., Heinz, A., & Mann, K. (2011). Effects of alcoholism and continued abstinence on brain volumes in both genders. *Alcoholism, Clinical and Experimental Research*, *35*(9), 1678–1685. https://doi.org/10.1111/j.1530-0277.2011.01514.x

Denke, C., Rotte, M., Heinze, H.-J., & Schaefer, M. (2016). Lying and the Subsequent Desire for Toothpaste: Activity in the Somatosensory Cortex Predicts Embodiment of the Moral-Purity Metaphor. *Cerebral Cortex*, *26*(2), 477–484. https://doi.org/10.1093/cercor/bhu170

Derogatis, L. R., & Unger, R. (2010). Symptom Checklist-90-Revised. Corsini Encyclopedia of Psychology (pp. 1–2). American Cancer Society.

Dodge, K. A. (1991). The structure and function of reactive and proactive aggression. In *The development and treatment of childhood aggression* (pp. 201–218). Lawrence Erlbaum Associates, Inc.

Dougherty, D. D., Rauch, S. L., Deckersbach, T., Marci, C., Loh, R., Shin, L. M., Alpert, N. M., Fischman, A. J., & Fava, M. (2004). Ventromedial prefrontal cortex and amygdala dysfunction during an anger induction positron emission tomography study in patients with major depressive disorder with anger attacks. *Archives of General Psychiatry*, *61*(8), 795–804. https://doi.org/10.1001/archpsyc.61.8.795

Duan, L., Feng, Q., & Xu, P. (2020). Using Functional Near-Infrared Spectroscopy to Assess Brain Activation Evoked by Guilt and Shame. *Frontiers in Human Neuroscience*, *14*. https://www.frontiersin.org/article/10.3389/fnhum.2020.00197

Dulas, M. R., & Duarte, A. (2011). The effects of aging on material-independent and material-dependent neural correlates of contextual binding. *NeuroImage*, *57*(3), 1192–1204. https://doi.org/10.1016/j.neuroimage.2011.05.036

Etkin, A., Egner, T., & Kalisch, R. (2011). Emotional processing in anterior cingulate and medial prefrontal cortex. *Trends in Cognitive Sciences*, *15*(2), 85–93. https://doi.org/10.1016/j.tics.2010.11.004

Falconer, M. A. (1973). Reversibility by Temporal-Lobe Resection of the Behavioral Abnormalities of Temporal-Lobe Epilepsy. *New England Journal of Medicine*, *289*(9), 451–455. https://doi.org/10.1056/NEJM197308302890904

Fang, J., Egorova, N., Rong, P., Liu, J., Hong, Y., Fan, Y., Wang, X., Wang, H., Yu, Y., Ma, Y., Xu, C., Li, S., Zhao, J., Luo, M., Zhu, B., & Kong, J. (2016). Early cortical biomarkers of longitudinal transcutaneous vagus nerve stimulation treatment success in depression. *NeuroImage : Clinical*, *14*, 105–111. https://doi.org/10.1016/j.nicl.2016.12.016

Fanning, J. R., Keedy, S., Berman, M. E., Lee, R., & Coccaro, E. F. (2017). Neural Correlates of Aggressive Behavior in Real Time: A Review of fMRI Studies of Laboratory Reactive Aggression. *Current Behavioral Neuroscience Reports*, *4*(2), 138–150. https://doi.org/10.1007/s40473-017-0115-8

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. W. (1995). The Structured Clinical Interview for DSM-III-R Personality Disorders (SCID-II). Part I: Description. *Journal of Personality Disorders*, *9*(2), 83–91. https://doi.org/10.1521/pedi.1995.9.2.83

First, M. B., Gibbon, M., Spitzer, R. L. Williams, J. B. W., & Benjamin, L. S. (1997).

Structured clinical interview for DSM-IV axis II personality disorders, (SCID-II). Washington, DC: American Psychiatric Association.

First, M. B., France, A., & Pincus, H. A. (2004). DSM-IV-TR guidebook (pp. xi, 501).

American Psychiatric Publishing, Inc.

Furl, N., van Rijsbergen, N. J., Kiebel, S. J., Friston, K. J., Treves, A., & Dolan, R. J. (2010). Modulation of perception and brain activity by predictable trajectories of facial expressions. *Cerebral Cortex (New York, N.Y.: 1991)*, *20*(3), 694–703. https://doi.org/10.1093/cercor/bhp140

Geng, J. J., & Mangun, G. R. (2011). Right temporoparietal junction activation by a salient contextual cue facilitates target discrimination. *NeuroImage*, *54*(1), 594–601. https://doi.org/10.1016/j.neuroimage.2010.08.025

Ghashghaei, H. T., & Barbas, H. (2002). Pathways for emotion: Interactions of prefrontal and anterior temporal pathways in the amygdala of the rhesus monkey. *Neuroscience*, *115*(4), 1261–1279. https://doi.org/10.1016/s0306-4522(02)00446-3

Giancola, P. R. (1995). Evidence for dorsolateral and orbital prefrontal cortical involvement in the expression of aggressive behavior. *Aggressive Behavior*, *21*(6), 431–450. https://doi.org/10.1002/1098-2337(1995)21:6<431::AID-AB2480210604>3.0.CO;2-Q

Gläscher, J., & Adolphs, R. (2003). Processing of the Arousal of Subliminal and Supraliminal Emotional Stimuli by the Human Amygdala. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *23*, 10274–10282. https://doi.org/10.1523/JNEUROSCI.23-32-10274.2003

Goghari, V. M., MacDonald, A. W., & Sponheim, S. R. (2011). Temporal Lobe Structures and Facial Emotion Recognition in Schizophrenia Patients and Nonpsychotic Relatives. *Schizophrenia Bulletin*, *37*(6), 1281–1294. https://doi.org/10.1093/schbul/sbq046

Golkar, A., Lonsdorf, T., Olsson, A., Lindstrom, K., Berrebi, J., Fransson, P., Schalling, M., Ingvar, M., & Ohman, A. (2012). Distinct Contributions of the Dorsolateral Prefrontal and Orbitofrontal Cortex during Emotion Regulation. *PloS One*, *7*, e48107. https://doi.org/10.1371/journal.pone.0048107

Gregg, T. R., & Siegel, A. (2001). Brain structures and neurotransmitters regulating aggression in cats: Implications for human aggression. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *25*(1), 91–140. https://doi.org/10.1016/s0278-5846(00)00150-0

Gur, R. C., Ragland, J. D., Reivich, M., Greenberg, J. H., Alavi, A., & Gur, R. E. (2009). Regional differences in the coupling between resting cerebral blood flow and metabolism may indicate action preparedness as a default state. *Cerebral Cortex (New York, N.Y.: 1991)*, *19*(2), 375–382. https://doi.org/10.1093/cercor/bhn087

Gusnard, D. A., & Raichle, M. E. (2001). Searching for a baseline: Functional imaging and the resting human brain. *Nature Reviews Neuroscience*, *2*(10), 685–694. https://doi.org/10.1038/35094500

Hagmann, P., Cammoun, L., Gigandet, X., Meuli, R., Honey, C. J., Wedeen, V. J., & Sporns, O. (2008). Mapping the structural core of human cerebral cortex. *PLoS Biology*, *6*(7), e159. https://doi.org/10.1371/journal.pbio.0060159

Hämäläinen, A., Pihlajamäki, M., Tanila, H., Hänninen, T., Niskanen, E., Tervo, S., Karjalainen, P. A., Vanninen, R. L., & Soininen, H. (2007). Increased fMRI responses during encoding in mild cognitive impairment. *Neurobiology of Aging*, *28*(12), 1889–1903. https://doi.org/10.1016/j.neurobiolaging.2006.08.008

Hare, R. D. (2003). *The Hare Psychopathy Checklist Revised (2nd ed.)*. Multi-Health Systems.

Hariri, A. R., Bookheimer, S. Y., & Mazziotta, J. C. (2000). Modulating emotional responses: Effects of a neocortical network on the limbic system. *Neuroreport*, *11*(1), 43–48. https://doi.org/10.1097/00001756-200001170-00009

Haxby, null, Hoffman, null, & Gobbini, null. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223–233. https://doi.org/10.1016/s1364-6613(00)01482-0

Hazlett, E. A., Zhang, J., New, A. S., Zelmanova, Y., Goldstein, K. E., Haznedar, M. M., Meyerson, D., Goodman, M., Siever, L. J., & Chu, K.-W. (2012). Potentiated amygdala response to repeated emotional pictures in borderline personality disorder. *Biological Psychiatry*, *72*(6), 448–456. https://doi.org/10.1016/j.biopsych.2012.03.027

Hentze, C., Walter, H., Schramm, E., Drost, S., Schoepf, D., Fangmeier, T., Mattern, M., Normann, C., Zobel, I., & Schnell, K. (2016). Functional Correlates of childhood maltreatment and symptom severity during affective theory of mind tasks in chronic depression. *Psychiatry Research: Neuroimaging*, *250*, 1–11. https://doi.org/10.1016/j.pscychresns.2016.02.004

Herpertz, S. C., Nagy, K., Ueltzhöffer, K., Schmitt, R., Mancke, F., Schmahl, C., & Bertsch, K. (2017). Brain Mechanisms Underlying Reactive Aggression in Borderline Personality Disorder-Sex Matters. *Biological Psychiatry*, *82*(4), 257–266. https://doi.org/10.1016/j.biopsych.2017.02.1175

Hoaken, P. N. S., Shaughnessy, V. K., & Pihl, R. o. (2003). Executive cognitive functioning and aggression: Is it an issue of impulsivity? *Aggressive Behavior*, *29*(1), 15–30. https://doi.org/10.1002/ab.10023

Hsu, C.-T., Jacobs, A. M., Citron, F. M. M., & Conrad, M. (2015). The emotion potential of words and passages in reading Harry Potter – An fMRI study. *Brain and Language*, *142*, 96–114. https://doi.org/10.1016/j.bandl.2015.01.011

Ishikawa, S. S., & Raine, A. (2003). Prefrontal deficits and antisocial behavior: A causal model. In *Causes of conduct disorder and juvenile delinquency* (pp. 277–304). The Guilford Press.

Jacobson, L., Javitt, D. C., & Lavidor, M. (2011). Activation of inhibition: Diminishing impulsive behavior by direct current stimulation over the inferior frontal gyrus. *Journal of Cognitive Neuroscience*, *23*(11), 3380–3387. https://doi.org/10.1162/jocn_a_00020

Jehna, M., Neuper, C., Ischebeck, A., Loitfelder, M., Ropele, S., Langkammer, C., Ebner, F., Fuchs, S., Schmidt, R., Fazekas, F., & Enzinger, C. (2011). The functional correlates of face perception and recognition of emotional facial expressions as evidenced by fMRI. *Brain Research*, *1393*, 73–83. https://doi.org/10.1016/j.brainres.2011.04.007

Johnson, S. B., Blum, R. W., & Giedd, J. N. (2009). Adolescent Maturity and the Brain: The Promise and Pitfalls of Neuroscience Research in Adolescent Health Policy. *The Journal of Adolescent Health : Official Publication of the Society for Adolescent Medicine*, *45*(3), 216–221. https://doi.org/10.1016/j.jadohealth.2009.05.016

Jones, A. D. (2012). Intimate partner violence in military couples: A review of the literature. *Aggression and Violent Behavior*, *17*(2), 147–157. https://doi.org/10.1016/j.avb.2011.12.002

Kaufman, J., Birmaher, B., Brent, D., Rao, U., Flynn, C., Moreci, P., Williamson, D., & Ryan, N. (1997). Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL): Initial reliability and validity data. *Journal of the American Academy of Child and Adolescent Psychiatry*, *36*(7), 980–988. https://doi.org/10.1097/00004583-199707000-00021

Klapwijk, E. T., Lelieveld, G.-J., Aghajani, M., Boon, A. E., van der Wee, N. J. A., Popma, A., Vermeiren, R. R. J. M., & Colins, O. F. (2016). Fairness decisions in response to emotions: A functional MRI study among criminal justice-involved boys with conduct disorder. *Social Cognitive and Affective Neuroscience*, *11*(4), 674–682. https://doi.org/10.1093/scan/nsv150

Kober, H., Barrett, L. F., Joseph, J., Bliss-Moreau, E., Lindquist, K., & Wager, T. D. (2008). Functional grouping and cortical–subcortical interactions in emotion: A meta-analysis of neuroimaging studies. *NeuroImage*, *42*(2), 998–1031. https://doi.org/10.1016/j.neuroimage.2008.03.059

Kober, H., & Wager, T. D. (2010). Meta-analysis of neuroimaging data. *Wiley Interdisciplinary Reviews. Cognitive Science*, *1*(2), 293–300. https://doi.org/10.1002/wcs.41

Krämer, U. M., Jansma, H., Tempelmann, C., & Münte, T. F. (2007). Tit-for-tat: The neural basis of reactive aggression. *NeuroImage*, *38*(1), 203–211. https://doi.org/10.1016/j.neuroimage.2007.07.029

Krämer, U. M., Riba, J., Richter, S., & Münte, T. F. (2011). An fMRI Study on the Role of Serotonin in Reactive Aggression. *PLoS ONE*, *6*(11), e27668. https://doi.org/10.1371/journal.pone.0027668

Krauch, M., Ueltzhöffer, K., Brunner, R., Kaess, M., Hensel, S., Herpertz, S. C., & Bertsch, K. (2018). Heightened Salience of Anger and Aggression in Female Adolescents With Borderline Personality Disorder—A Script-Based fMRI Study. *Frontiers in Behavioral Neuroscience*, *12*. https://doi.org/10.3389/fnbeh.2018.00057

Kreifelts, B., Ethofer, T., Grodd, W., Erb, M., & Wildgruber, D. (2007). Audiovisual integration of emotional signals in voice and face: An event-related fMRI study. *NeuroImage*, *37*(4), 1445–1456. https://doi.org/10.1016/j.neuroimage.2007.06.020

Kuhlen, A. K., Bogler, C., Swerts, M., & Haynes, J.-D. (2015). Neural coding of assessing another person's knowledge based on nonverbal cues. *Social Cognitive and Affective Neuroscience*, *10*(5), 729–734. https://doi.org/10.1093/scan/nsu111

Kupers, R., Beaulieu-Lefebvre, M., Schneider, F. C., Kassuba, T., Paulson, O. B., Siebner, H. R., & Ptito, M. (2011). Neural correlates of olfactory processing in congenital blindness. *Neuropsychologia*, *49*(7), 2037–2044. https://doi.org/10.1016/j.neuropsychologia.2011.03.033

Lane, S. D., Kjome, K. L., & Moeller, F. G. (2011). Neuropsychiatry of Aggression. *Neurologic Clinics*, *29*(1), 49–vii. https://doi.org/10.1016/j.ncl.2010.10.006

Lavoie, R., Main, K., King, C., & King, D. (2021). Virtual experience, real consequences: The potential negative emotional consequences of virtual reality gameplay. *Virtual Reality*, *25*(1), 69–81. https://doi.org/10.1007/s10055-020-00440-y

LeDoux, J. E. (1996). *The emotional brain: The mysterious underpinnings of emotional life* (p. 384). Simon & Schuster.

Lee, T. M. C., Chan, S.-C., & Raine, A. (2009). Hyperresponsivity to threat stimuli in domestic violence offenders: A functional magnetic resonance imaging study. *The Journal of Clinical Psychiatry*, *70*(1), 36–45. https://doi.org/10.4088/jcp.08m04143

Leech, R., Braga, R., & Sharp, D. J. (2012). Echoes of the Brain within the Posterior Cingulate Cortex. *Journal of Neuroscience*, *32*(1), 215–222. https://doi.org/10.1523/JNEUROSCI.3689-11.2012

Lin, D., Boyle, M. P., Dollar, P., Lee, H., Perona, P., Lein, E. S., & Anderson, D. J. (2011). Functional identification of an aggression locus in the mouse hypothalamus. *Nature*, *470*(7333), 221–226. https://doi.org/10.1038/nature09736

Liu, X., Hairston, J., Schrier, M., & Fan, J. (2011). Common and distinct networks underlying reward valence and processing stages: A meta-analysis of functional neuroimaging studies. *Neuroscience and Biobehavioral Reviews*, *35*(5), 1219–1236. https://doi.org/10.1016/j.neubiorev.2010.12.012

Lobbestael, J., Cima, M., & Arntz, A. (2013). The Relationship Between Adult Reactive and Proactive Aggression, Hostile Interpretation Bias, and Antisocial Personality Disorder. *Journal of Personality Disorders*, *27*(1), 53–66. http://dx.doi.org/101521pedi201327153

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and Inhibitory Control. *Psychological Science*, *8*(1), 60–64. https://doi.org/10.1111/j.1467-9280.1997.tb00545.x

Lopopolo, A., Frank, S. L., Bosch, A. van den, & Willems, R. M. (2017). Using stochastic language models (SLM) to map lexical, syntactic, and phonological information processing in the brain. *PLOS ONE*, *12*(5), e0177794. https://doi.org/10.1371/journal.pone.0177794

Loranger, A. W. (1997). International personality disorder examination (IPDE). Assessment and Diagnosis of Personality Disorders, 43–51.

Lotze, M., Veit, R., Anders, S., & Birbaumer, N. (2007). Evidence for a different role of the ventral and dorsal medial prefrontal cortex for social reactive aggression: An interactive fMRI study. *NeuroImage*, *34*(1), 470–478. https://doi.org/10.1016/j.neuroimage.2006.09.028

Mancke, F., Herpertz, S. C., & Bertsch, K. (2015). Aggression in borderline personality disorder: A multidimensional model. *Personality Disorders*, *6*(3), 278–291. https://doi.org/10.1037/per0000098

Mars, R. B., Passingham, R. E., & Jbabdi, S. (2018). Connectivity Fingerprints: From Areal Descriptions to Abstract Spaces. *Trends in Cognitive Sciences*, *22*(11), 1026–1037. https://doi.org/10.1016/j.tics.2018.08.009

Mccloskey, M., Phan, K. L., Angstadt, M., Fettich, K., Keedy, S., & Coccaro, E. (2016). Amygdala hyperactivation to angry faces in intermittent explosive disorder. *Journal of Psychiatric Research*, *79*. https://doi.org/10.1016/j.jpsychires.2016.04.006

McDonald, A. J. (1998). Cortical pathways to the mammalian amygdala. *Progress in Neurobiology*, *55*(3), 257–332. https://doi.org/10.1016/s0301-0082(98)00003-3

Mégevand, P., Groppe, D. M., Bickel, S., Mercier, M. R., Goldfinger, M. S., Keller, C. J., Entz, L., & Mehta, A. D. (2017). The Hippocampus and Amygdala Are Integrators of Neocortical Influence: A CorticoCortical Evoked Potential Study. *Brain Connectivity*, *7*(10), 648–660. https://doi.org/10.1089/brain.2017.0527

Minzenberg, M. J., Fan, J., New, A. S., Tang, C. Y., & Siever, L. J. (2008). Frontolimbic structural changes in borderline personality disorder. *Journal of Psychiatric Research*, *42*(9), 727–733. https://doi.org/10.1016/j.jpsychires.2007.07.015

Mlinarić, A., Horvat, M., & Šupak Smolčić, V. (2017). Dealing with the positive publication bias: Why you should really publish your negative results. *Biochemia Medica*, *27*(3). https://doi.org/10.11613/BM.2017.030201

Mobbs, D., Marchant, J. L., Hassabis, D., Seymour, B., Tan, G., Gray, M., Petrovic, P., Dolan, R. J., & Frith, C. D. (2009). From Threat to Fear: The Neural Organization of Defensive Fear Systems in Humans. *The Journal of Neuroscience*, *29*(39), 12236–12243. https://doi.org/10.1523/JNEUROSCI.2378-09.2009

Mobbs, D., Petrovic, P., Marchant, J. L., Hassabis, D., Weiskopf, N., Seymour, B., Dolan, R. J., & Frith, C. D. (2007). When fear is near: Threat imminence elicits prefrontal-periaqueductal gray shifts in humans. *Science (New York, N.Y.)*, *317*(5841), 1079–1083. https://doi.org/10.1126/science.1144298

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ (Clinical Research Ed.)*, *339*, b2535. https://doi.org/10.1136/bmj.b2535

Morland, L. A., Love, A. R., Mackintosh, M., Greene, C. J., & Rosen, C. S. (2012). Treating anger and aggression in military populations: Research updates and clinical implications. *Clinical Psychology: Science and Practice*, *19*(3), 305–322. https://doi.org/10.1111/cpsp.12007

Mulukom, V. van, Schacter, D. L., Corballis, M. C., & Addis, D. R. (2013). Re-Imagining the Future: Repetition Decreases Hippocampal Involvement in Future Simulation. *PLOS ONE*, *8*(7), e69596. https://doi.org/10.1371/journal.pone.0069596

Nelson, R. J., & Trainor, B. C. (2007). Neural mechanisms of aggression. *Nature Reviews. Neuroscience*, *8*(7), 536–546. https://doi.org/10.1038/nrn2174

Nilsson, J., Ferrier, I. N., Coventry, K., Bester, A., & Finkelmeyer, A. (2013). Negative BOLD response in the hippocampus during short-term spatial memory retrieval. *Journal of Cognitive Neuroscience*, *25*(8), 1358–1371. https://doi.org/10.1162/jocn_a_00396

Ochsner, K. N., Bunge, S. A., Gross, J. J., & Gabrieli, J. D. E. (2002). Rethinking feelings: An FMRI study of the cognitive regulation of emotion. *Journal of Cognitive Neuroscience*, *14*(8), 1215–1229. https://doi.org/10.1162/089892902760807212

Ochsner, K. N., & Gross, J. J. (2014). The neural bases of emotion and emotion regulation: A valuation perspective. In *Handbook of emotion regulation, 2nd ed* (pp. 23–42). The Guilford Press.

Ogilvie, J., Stewart, A., CHAN, R., & Shum, D. (2011). Neuropsychological Measures of Executive Function and Antisocial Behavior: A Meta-Analysis. *Criminology*, *49*, 1063–1107. https://doi.org/10.1111/j.1745-9125.2011.00252.x

O'Neill, A., D'Souza, A., Carballedo, A., Joseph, S., Kerskens, C., & Frodl, T. (2013). Magnetic resonance imaging in patients with borderline personality disorder: A study of volumetric abnormalities. *Psychiatry Research*, *213*(1), 1–10. https://doi.org/10.1016/j.pscychresns.2013.02.006

Pawliczek, C. M., Derntl, B., Kellermann, T., Kohn, N., Gur, R. C., & Habel, U. (2013). Inhibitory control and trait aggression: Neural and behavioral insights using the emotional stop signal task. *NeuroImage*, *79*, 264–274. https://doi.org/10.1016/j.neuroimage.2013.04.104

Pearson, J. M., Heilbronner, S. R., Barack, D. L., Hayden, B. Y., & Platt, M. L. (2011). Posterior cingulate cortex: Adapting behavior to a changing world. *Trends in Cognitive Sciences*, *15*(4), 143–151. https://doi.org/10.1016/j.tics.2011.02.002

Peciña, M., Stohler, C. S., & Zubieta, J.-K. (2014). Neurobiology of placebo effects: Expectations or learning? *Social Cognitive and Affective Neuroscience*, *9*(7), 1013–1021. https://doi.org/10.1093/scan/nst079

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neural and emotional stimuli. *Brain Research. Cognitive Brain Research*, *15*(1), 31–45. https://doi.org/10.1016/s0926-6410(02)00214-8

Pfefferbaum, A., Chanraud, S., Pitel, A.-L., Müller-Oehring, E., Shankaranarayanan, A., Alsop, D. C., Rohlfing, T., & Sullivan, E. V. (2011). Cerebral blood flow in posterior cortical nodes of the default mode network decreases with task engagement but remains higher than in most brain regions. *Cerebral Cortex (New York, N.Y.: 1991)*, *21*(1), 233–244. https://doi.org/10.1093/cercor/bhq090

Pfohl, B., Blum, N.S., & Zimmerman, M. (1997). Structured interview for DSM-IV personality: SIDP-IV, American Psychiatric Press, Washington, DC

Phelps, E. A. (2004). Human emotion and memory: Interactions of the amygdala and hippocampal complex. *Current Opinion in Neurobiology*, *14*(2), 198–202. https://doi.org/10.1016/j.conb.2004.03.015

Poldrack, R. A. (2010). Mapping mental function to brain structure: How can cognitive neuroimaging succeed? *Perspectives on Psychological Science : A Journal of the Association for Psychological Science*, *5*(5), 753–761. https://doi.org/10.1177/1745691610388777

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

Raine, A., Ishikawa, S. S., Arce, E., Lencz, T., Knuth, K. H., Bihrle, S., LaCasse, L., & Colletti, P. (2004). Hippocampal structural asymmetry in unsuccessful psychopaths. *Biological Psychiatry*, *55*(2), 185–191. https://doi.org/10.1016/s0006-3223(03)00727-3

Raine, A., Meloy, J. R., Bihrle, S., Stoddard, J., Lacasse, L., & Buchsbaum, M. S. (1998). Reduced prefrontal and increased subcortical brain functioning assessed using positron emission tomography in predatory and affective murderers. *Behavioral Sciences & the Law*, *16*(3), 319–332. https://doi.org/10.1002/(SICI)1099-0798(199822)16:3<319::AID-BSL311>3.0.CO;2-G

Regenbogen, C., Axelsson, J., Lasselin, J., Porada, D. K., Sundelin, T., Peter, M. G., Lekander, M., Lundström, J. N., & Olsson, M. J. (2017). Behavioral and neural correlates to multisensory detection of sick humans. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(24), 6400–6405. https://doi.org/10.1073/pnas.1617357114

Reggente, N., Essoe, J. K.-Y., Aghajan, Z. M., Tavakoli, A. V., McGuire, J. F., Suthana, N. A., & Rissman, J. (2018). Enhancing the Ecological Validity of fMRI Memory Research Using Virtual Reality. *Frontiers in Neuroscience*, *12*, 408. https://doi.org/10.3389/fnins.2018.00408

Rehman, A., & Al Khalili, Y. (2021). Neuroanatomy, Occipital Lobe. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK544320/

Richardson, M. P., Strange, B. A., & Dolan, R. J. (2004). Encoding of emotional memories depends on amygdala and hippocampus and their interactions. *Nature Neuroscience*, *7*(3), 278–285. https://doi.org/10.1038/nn1190

Roberton, T., Daffern, M., & Bucks, R. S. (2012). Emotion regulation and aggression. *Aggression and Violent Behavior*, *17*(1), 72–82. https://doi.org/10.1016/j.avb.2011.09.006

Roberts, R. P., Hach, S., Tippett, L. J., & Addis, D. R. (2016). The Simpson's paradox and fMRI: Similarities and differences between functional connectivity measures derived from within-subject and across-subject correlations. *NeuroImage*, *135*, 1–15. https://doi.org/10.1016/j.neuroimage.2016.04.028

Rodrigues, S. M., LeDoux, J. E., & Sapolsky, R. M. (2009). The influence of stress hormones on fear circuitry. *Annual Review of Neuroscience*, *32*, 289–313. https://doi.org/10.1146/annurev.neuro.051508.135620

Ruiz, S., Buyukturkoglu, K., Rana, M., Birbaumer, N., & Sitaram, R. (2014). Real-time fMRI brain computer interfaces: Self-regulation of single brain regions to networks. *Biological Psychology*, *95*, 4–20. https://doi.org/10.1016/j.biopsycho.2013.04.010

Rüsch, N., van Elst, L. T., Ludaescher, P., Wiike, M., Huppertz, H.-J., Thiel, T., Schmahl, C., Bohus, M., Lieb, K., Hesslinger, B., Hennig, J., & Ebert, D. (2003). A voxel-based morphometric MRI study in female patients with borderline personality disorder. *NeuroImage*, *20*(1), 385–392. https://doi.org/10.1016/s1053-8119(03)00297-0

Sanfey, A. G., Rilling, J. K., Aronson, J. A., Nystrom, L. E., & Cohen, J. D. (2003). The neural basis of economic decision-making in the Ultimatum Game. *Science (New York, N.Y.)*, *300*(5626), 1755–1758. https://doi.org/10.1126/science.1082976

Schienle, A., Wabnegger, A., Leitner, M., & Leutgeb, V. (2017). Neuronal correlates of personal space intrusion in violent offenders. *Brain Imaging and Behavior*, *11*(2), 454–460. https://doi.org/10.1007/s11682-016-9526-5

Schoenbaum, G., Setlow, B., Saddoris, M. P., & Gallagher, M. (2003). Encoding predicted outcome and acquired value in orbitofrontal cortex during cue sampling depends upon input from basolateral amygdala. *Neuron*, *39*(5), 855–867. https://doi.org/10.1016/s0896-6273(03)00474-4

Schuit, E., Roes, K. C., Mol, B. W., Kwee, A., Moons, K. G., & Groenwold, R. H. (2015). Meta-analyses triggered by previous (false-)significant findings: Problems and solutions. *Systematic Reviews*, *4*(1), 57. https://doi.org/10.1186/s13643-015-0048-9

Schulze, L., Schmahl, C., & Niedtfeld, I. (2016). Neural Correlates of Disturbed Emotion Processing in Borderline Personality Disorder: A Multimodal Meta-Analysis. *Biological Psychiatry*, *79*(2), 97–106. https://doi.org/10.1016/j.biopsych.2015.03.027

Sedgwick, P. (2015). Meta-analysis: Testing for reporting bias. *BMJ (Clinical Research Ed.)*, *350*, g7857. https://doi.org/10.1136/bmj.g7857

Séguin, J. R. (2009). The frontal lobe and aggression. *The European Journal of Developmental Psychology*, *6*(1), 100–119. https://doi.org/10.1080/17405620701669871

Seok, J.-W., & Cheong, C. (2020). Gray Matter Deficits and Dysfunction in the Insula Among Individuals With Intermittent Explosive Disorder. *Frontiers in Psychiatry*, *11*. https://doi.org/10.3389/fpsyt.2020.00439

Siep, N., Tonnaer, F., van de Ven, V., Arntz, A., Raine, A., & Cima, M. (2019). Anger provocation increases limbic and decreases medial prefrontal cortex connectivity with the left amygdala in reactive aggressive violent offenders. *Brain Imaging and Behavior*, *13*(5), 1311–1323. https://doi.org/10.1007/s11682-018-9945-6

Siever, L. J. (2008). Neurobiology of Aggression and Violence. *The American Journal of Psychiatry*, *165*(4), 429–442. https://doi.org/10.1176/appi.ajp.2008.07111774

Sim, M. E., Lyoo, I. K., Streeter, C. C., Covell, J., Sarid-Segal, O., Ciraulo, D. A., Kim, M. J., Kaufman, M. J., Yurgelun-Todd, D. A., & Renshaw, P. F. (2007). Cerebellar gray matter volume correlates with duration of cocaine use in cocaine-dependent subjects. *Neuropsychopharmacology: Official Publication of the American College of Neuropsychopharmacology*, *32*(10), 2229–2237. https://doi.org/10.1038/sj.npp.1301346

Soloff, P. H., & Chiappetta, L. (2017). Suicidal behavior and psychosocial outcome in Borderline Personality Disorder at 8-year follow-up. *Journal of Personality Disorders*, *31*(6), 774–789. https://doi.org/10.1521/pedi_2017_31_280

Specht, K., Osnes, B., & Hugdahl, K. (2009). Detection of differential speech-specific processes in the temporal lobe using fMRI and a dynamic "sound morphing" technique. *Human Brain Mapping*, *30*(10), 3436–3444. https://doi.org/10.1002/hbm.20768

Spielberger, C. D. (2010). State-Trait Anger Expression Inventory. In *The Corsini Encyclopedia of Psychology* (pp. 1–1). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470479216.corpsy0942

Squire, L. R. (1992). Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. *Psychological Review*, *99*(2), 195–231. https://doi.org/10.1037/0033-295x.99.2.195

Straube, B., Green, A., Jansen, A., Chatterjee, A., & Kircher, T. (2010). Social cues, mentalizing and the neural processing of speech accompanied by gestures. *Neuropsychologia*, *48*(2), 382–393. https://doi.org/10.1016/j.neuropsychologia.2009.09.025

Strobel, A., Zimmermann, J., Schmitz, A., Reuter, M., Lis, S., Windmann, S., & Kirsch, P. (2011). Beyond revenge: Neural and genetic bases of altruistic punishment. *NeuroImage*, *54*(1), 671–680. https://doi.org/10.1016/j.neuroimage.2010.07.051

Suda, A., Osada, T., Ogawa, A., Tanaka, M., Kamagata, K., Aoki, S., Hattori, N., & Konishi, S. (2020). Functional Organization for Response Inhibition in the Right Inferior Frontal Cortex of Individual Human Brains. *Cerebral Cortex*, *30*(12), 6325–6335. https://doi.org/10.1093/cercor/bhaa188

Sukhodolsky, D., Golub, A., & Cromwell, E. (2001). Development and validation of the Anger Rumination Scale. *Personality and Individual Differences*, *31*, 689–700. https://doi.org/10.1016/S0191-8869(00)00171-9

Suzuki, W. A., & Amaral, D. G. (2004). Functional Neuroanatomy of the Medial Temporal Lobe Memory System. *Cortex*, *40*(1), 220–222. https://doi.org/10.1016/S0010-9452(08)70958-4

Tabbert, K., Stark, R., Kirsch, P., & Vaitl, D. (2005). Hemodynamic responses of the amygdala, the orbitofrontal cortex and the visual cortex during a fear conditioning paradigm. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *57*(1), 15–23. https://doi.org/10.1016/j.ijpsycho.2005.01.007

Takahashi, E., Ohki, K., & Miyashita, Y. (2002). The role of the parahippocampal gyrus in source memory for external and internal events. *Neuroreport*, *13*(15), 1951–1956. https://doi.org/10.1097/00001756-200210280-00024

Tamietto, M., & de Gelder, B. (2010). Neural bases of the non-conscious perception of emotional signals. *Nature Reviews Neuroscience*, *11*(10), 697–709. https://doi.org/10.1038/nrn2889

Taylor, S. P. (1967). Aggressive behavior and physiological arousal as a function of provocation and the tendency to inhibit aggression. *Journal of Personality*, *35*(2), 297–310. https://doi.org/10.1111/j.1467-6494.1967.tb01430.x

Tedeschi, J. T., & Quigley, B. M. (1996). Limitations of laboratory paradigms for studying aggression. *Aggression and Violent Behavior*, *1*(2), 163–177. https://doi.org/10.1016/1359-1789(95)00014-3

Thomas, L. A., Kim, P., Bones, B. L., Hinton, K. E., Milan, H. S., Reynolds, R. C., Adleman, N. E., Marsh, A. A., Blair, R. J. R., Pine, D. S., & Leibenluft, E. (2013). Elevated amygdala responses to emotional faces in youths with chronic irritability or bipolar disorder. *NeuroImage. Clinical*, *2*, 637–645. https://doi.org/10.1016/j.nicl.2013.04.007

Tonnaer, F., Siep, N., van Zutphen, L., Arntz, A., & Cima, M. (2017). Anger provocation in violent offenders leads to emotion dysregulation. *Scientific Reports*, *7*(1), 3583. https://doi.org/10.1038/s41598-017-03870-y

Utevsky, A. V., Smith, D. V., & Huettel, S. A. (2014). Precuneus is a functional core of the default-mode network. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *34*(3), 932–940. https://doi.org/10.1523/JNEUROSCI.4227-13.2014

van Elst, L. T., Woermann, F. G., Lemieux, L., Thompson, P. J., & Trimble, M. R. (2000). Affective aggression in patients with temporal lobe epilepsy: A quantitative MRI study of the amygdala. *Brain*, *123*(2), 234–243. https://doi.org/10.1093/brain/123.2.234

van Strien, N. M., Cappaert, N. L. M., & Witter, M. P. (2009). The anatomy of memory: An interactive overview of the parahippocampal–hippocampal network. *Nature Reviews Neuroscience*, *10*(4), 272–282. https://doi.org/10.1038/nrn2614

von dem Hagen, E. A. H., Stoyanova, R. S., Rowe, J. B., Baron-Cohen, S., & Calder, A. J. (2014). Direct Gaze Elicits Atypical Activation of the Theory-of-Mind Network in Autism Spectrum Conditions. *Cerebral Cortex (New York, NY)*, *24*(6), 1485–1492. https://doi.org/10.1093/cercor/bht003

Wager, T. D., Lindquist, M. A., Nichols, T. E., Kober, H., & Van Snellenberg, J. X. (2009). Evaluating the consistency and specificity of neuroimaging data using meta-analysis. *NeuroImage*, *45*(1 Suppl), S210-221. https://doi.org/10.1016/j.neuroimage.2008.10.061

Wager, T. D., Lindquist, M., & Kaplan, L. (2007). Meta-analysis of functional neuroimaging data: Current and future directions. *Social Cognitive and Affective Neuroscience*, *2*(2), 150–158. https://doi.org/10.1093/scan/nsm015

Wagner, G., Gussew, A., Köhler, S., de la Cruz, F., Smesny, S., Reichenbach, J. R., & Bär, K.-J. (2016). Resting state functional connectivity of the hippocampus along the anterior–posterior axis and its association with glutamatergic metabolism. *Cortex*, *81*, 104–117. https://doi.org/10.1016/j.cortex.2016.03.022

Wehrum, S., Degé, F., Ott, U., Walter, B., Stippekohl, B., Kagerer, S., Schwarzer, G., Vaitl, D., & Stark, R. (2011). Can you hear a difference? Neuronal correlates of melodic deviance processing in children. *Brain Research*, *1402*, 80–92. https://doi.org/10.1016/j.brainres.2011.05.057

Wendt, J., Weike, A. I., Lotze, M., & Hamm, A. O. (2011). The functional connectivity between amygdala and extrastriate visual cortex activity during emotional picture processing depends on stimulus novelty. *Biological Psychology*, *86*(3), 203–209. https://doi.org/10.1016/j.biopsycho.2010.11.009

White, S. F., Brislin, S. J., Meffert, H., Sinclair, S., & Blair, R. J. R. (2013). Callous-unemotional traits modulate the neural response associated with punishing another individual during social exchange. A preliminary investigation. *Journal of Personality Disorders*, *27*(1), 99–112. https://doi.org/10.1521/pedi.2013.27.1.99

Wilson, L. B., Tregellas, J. R., Slason, E., Pasko, B. E., Hepburn, S., & Rojas, D. C. (2012). Phonological processing in first-degree relatives of individuals with autism: An fMRI study. *Human Brain Mapping*, *34*(6), 1447–1463. https://doi.org/10.1002/hbm.22001

Wiswede, D., Taubner, S., Münte, T. F., Roth, G., Strüber, D., Wahl, K., & Krämer, U. M. (2011). Neurophysiological Correlates of Laboratory-Induced Aggression in Young Men with and without a History of Violence. *PLOS ONE*, *6*(7), e22599. https://doi.org/10.1371/journal.pone.0022599

Wong, T. Y., Sid, A., Wensing, T., Eickhoff, S. B., Habel, U., Gur, R. C., & Nickl-Jockschat, T. (2019). Neural networks of aggression: ALE meta-analyses on trait and elicited aggression. *Brain Structure & Function*, *224*(1), 133–148. https://doi.org/10.1007/s00429-018-1765-3

World Health Organization. (2007). Third milestones of a Global Campaign for Violence Prevention report, 2007: scaling up. World Health Organization.

World Health Organization (2019). International Statistical Classification of Diseases and Related Health Problems (11th ed.).

Wright, C. I., Fischer, H., Whalen, P. J., McInerney, S. C., Shin, L. M., & Rauch, S. L. (2001). Differential prefrontal cortex and amygdala habituation to repeatedly presented emotional stimuli. *Neuroreport*, *12*(2), 379–383. https://doi.org/10.1097/00001756-200102120-00039

Yoo, W.-K., You, S. H., Ko, M.-H., Tae Kim, S., Park, C., Park, J.-W., Hoon Ohn, S., Hallett, M., & Kim, Y.-H. (2008). High frequency rTMS modulation of the sensorimotor networks: Behavioral changes and fMRI correlates. *NeuroImage*, *39*(4), 1886–1895. https://doi.org/10.1016/j.neuroimage.2007.10.035

Zevin, J. (2009). Word Recognition. In L. R. Squire (Ed.), *Encyclopedia of Neuroscience* (pp. 517–522). Academic Press. https://doi.org/10.1016/B978-008045046-9.01881-7

Zhou, Y., Shu, N., Liu, Y., Song, M., Hao, Y., Liu, H., Yu, C., Liu, Z., & Jiang, T. (2008). Altered resting-state functional connectivity and anatomical connectivity of hippocampus in schizophrenia. *Schizophrenia Research*, *100*(1), 120–132. https://doi.org/10.1016/j.schres.2007.11.039

Zijlstra, F., Veltman, D. J., Booij, J., van den Brink, W., & Franken, I. H. A. (2009). Neurobiological substrates of cue-elicited craving and anhedonia in recently abstinent opioid-dependent males. *Drug and Alcohol Dependence*, *99*(1), 183–192. https://doi.org/10.1016/j.drugalcdep.2008.07.012

Zimmer, U., & Macaluso, E. (2007). Processing of multisensory spatial congruency can be dissociated from working memory and visuo-spatial attention. *European Journal of Neuroscience*, *26*(6), 1681–1691. https://doi.org/10.1111/j.1460-9568.2007.05784.x

Table 1. Demographic characteristics of participants

Study	Sample size			Age in years M (SD)		Sex/Gender Female (n)		Males (n)		Ethnicity % of the total		Education in years M (SD)	
	Total	AG	HC	AG	CG	AG	CG	AG	CG	AG	CG	AG	CG
Coccaro et al., 2007	20	10	10	34.30 (7.30)	30.80 (5.60)	5	5	5	5	50% White, 30 % AA, 10% ASA, 10% Other	70% White, 20% AA, 10% ASA	15.60 (1.30)	13.40 (1.00)
Herpertz et al., 2017	112	56	56	28.12 (7.23	29.39 (6.52)	33	30	23	26	N/R	N/R	11.26 (3.59)	11.97 (1.31)
Klapwijk et al., 2016	65	32	33	16.8 (1.2)	17.20 (1.2)	0	0	32	33	15.6% White, 84.4% Other	72.7 % White, 27.3% Other	N/R	N/R
Krauch et al., 2018	106	54	52	21.02 (0.85)	21.59 (3.59)	54	52	0	0	N/R	N/R	N/R	N/R
Lee, Chan & Raine, 2009	23	10	13	43.80 (5.10)	47.08 (6.25)	0	0	10	13	100% AS	100% AS	10.70 (4.11)	9.85 (2.04)
McCloskey et al., 2016	40	20	20	33.2 (N/R)	32.8 (N/R)	8	8	12	12	60% White, 30% AA, 10% AS	60% White, 30% AA, 10% AS	15.00 (1.70)	15.90 (1.90)

Schienle et al.,2017	35	17	18	34.82 (12.54)	37.89 (9.21)	0	0	17	18	100% White	100% White	11.18 (2.07)	11.78 (1.73)
Seok & Cheong, 2020	30	15	15	28.53 (2.36)	28.60 (4.40)	0	0	15	15	N/R	N/R	N/R	N/R
Tonnaer et al., 2017	34	16	18	35.81 (7.17)	34.39 (13.37)	0	0	16	18	100% White	100% White	N/R	N/R

Note. AG = Aggression group; CG = Control group. AA = African American, AS = Asian, ASA = Asian American, Other = Not specified. Sex/Gender = Three studies measured gender (E. F. Coccaro et al., 2007; McCloskey et al., 2016; Seok & Cheong, 2020), two measured sex (Herpertz et al., 2017; Krauch et al., 2018), and four did not specify (Klapwijk et al., 2016; Lee et al., 2009; Schienle et al., 2017; Tonnaer et al., 2017).

Table 2. Clinical characteristics of participants (aggression group)

Psychiatric assessment Study	Psychiatric diagnosis? (Y/N)	Primary psychiatric diagnosis	Diagnostic assessment	Secondary psychiatric diagnosis	Psychotropic medication (Y/N)	Medication type	Psychotherapy type	Psychotherapy type
(E. Coccaro et al., 2007)	Y	IED	IED-M, SCID-I, SIDP-IV	5/10 had lifetime history of other Axis I disorders: childhood ADHD and cannabis abuse, full remission (*n* = 1), specific phobia-animal type (*n* = 1), MDE and alcohol dependence, full remission (*n* = 1), GAD (*n* = 1), alcohol abuse, full remission (*n* =1) 10/10 had current Axis II PD: not otherwise specified (*n* = 6), borderline (*n* = 1), narcissistic (*n* = 1), obsessive compulsive (*n* = 1), paranoid and narcissistic (*n* = 1)	Y	N=2 subjects received antidepressants 8 weeks prior to scan	N/R	N/R
(Herpertz et	Y	BPD	SCID-I,	Current Affective Disorders	N	N/A	N/R	N/R

al., 2017)			IPDE	(*n*=20), Lifetime Substance-Associated Disorders (*n* =11), Current Anxiety Disorders (*n*=31), Current PTSD (*n*=15), Current Somatoform Disorders (*n*=5), Current Eating Disorders (*n*=20), Current Adjustment Disorder (*n*=6), Current Antisocial PD (*n*=4), Avoidant PD (*n*=17)				
(Klapwijk et al., 2016)	Y	CD	K-SADS-PL, DSM-IV-TR	Current Axis-I Disorders: ADHD (n=8)	N	N/A	N/R	N/R
(Krauch et al., 2018)	Y	BPD	SCID-I, IPDE	Current Affective disorders (*n*=21), Lifetime Substance Ass. Disorders (*n*=7), Current Anxiety disorders (*n*=20), Current PTSD (*n*=9), Current Somatoform Disorders (*n*=5), Current Eating Disorders (*n*=17), Current Antisocial PD (*n*=1)	Y	N=4 patients in adolescent group took antidepressants	N/R	N/R
(Lee et al., 2009)	N	N/A	BDI	N/A	N/R	N/R	N/R	N/R
(McCloskey et al., 2016)	Y	IED	SCID-I, SIDP-IV	12/20 had current Axis-I disorders: PTSD (*n* = 3), alcohol abuse (*n* =3), anxiety disorder NOS (*n* =3), depressive disorder NOS (*n* = 2), ADHD (*n* = 1), adjustment disorder (*n* =1). 20/20 had current PD : NOS (n = 15), compulsive (n = 3), paranoid (n = 2), avoidant (n = 2)	N/R	N/R	N/R	N/R
(Schienle et al., 2017)	N	N/A	SCID-I	Current Axis-II PD: ASPD (n=5)	N/R	N/R	N/R	N/R

(Seok & Cheong, 2020)	Y	IED	SCID-I, SCL-90-R	N	N	N/A	N	N/A
(Tonnaer et al., 2017)	N	N/A	Semi-structured interviews based on DSM-IV	Substance dependence (*n*=13), Depressive episode past (*n*=5), PTSS (*n*=8), Antisocial PD (*n*=9), BPD (*n*=3), Other PD (*n*=4)	Y	Psychotropic medications, mostly antidepressants (n=9)	N/R	N/R

Note: IED = Intermittent Explosive Disorder, BPD = Borderline Personality Disorder , CD= Conduct Disorder, MDE = Major Depressive Episode, GAD = Generalized Anxiety Disorder, PD = Personality Disorder, ASPD= Antisocial Personality Disorder, ADHD = Attention Deficit Hyperactivity Disorder, PTSD = Post Traumatic Stress Disorder, NOS = Not Otherwise Specified, IED-M = IED-IR Interview Module (E. F. Coccaro et al., 2007) , SCID-I = Structured Clinical Interview for DSM Diagnoses for Axis I disorders (First et al., 1995), SCID-II= Structured Clinical Interview for DSM Diagnoses for Axis II disorders (First et al., 1997), SIDP-IV = Structured Interview for the Diagnosis of DSM-IV Personality Disorder for Axis II disorders (Pfohl et al., 1997), IPDE = International Personality Disorder Examination IPDE (Loranger, 1997), K-SADS-PL= Kiddie Schedule for Affective Disorders and Schizophrenia (Kaufman et al., 1997), DSM-IV-TR= Diagnostic and Statistical Manual of Mental Disorders (First, 2004), BDI = Depression Inventory (Beck, 1996), SCL-90-R = Symptom Check List-90-Revised (Derogatis, 2010). N/R=Not reported, N/A= Not applicable.

Table 3. Offense histories and assessments of antisocial behavior

	Offense Records		Antisocial Behavior Assessment		
Author	Offense history (Y/N)	Offense type	Assessment measure(s)	Aggression group M (SD)	Control group M (SD)
Coccaro et al., 2007	N/R	N/R	LHA	21.5 (2)	5.3 (2.6)
Herpertz et al., 2017	N/R	N/R	AQ	70.67 (13.69)	43.74 (7.53)
Klapwijk et al., 2016	Y	Violent crime	RPQ	16.8 (10.1)	8.1 (3.2)
Krauch et al., 2018	N	N/A	AQ	61.94 (14.42)	42.36 (7.96)
Lee, Chan & Raine, 2009	Y	Spouse battering	STAXI-I	19.10 (5.28)	16.15 (3.13)
McCloskey et al., 2016	N/R	N/R	LHA	16.9 (4.5)	4.5 (3.2)
Schienle et al.,2017	Y	Violent crime	PCL-R	17.8 (8.3)	1.67 (1.54)
Seok & Cheong, 2020	N/R	N/R	LHA	11.67 (3.64)	4.73 (3.41)

Tonnaer et al., 2017	Y	Violent crime	RPQ	21.9 (8.7)	6.0 (4.3)

Note: LHA = Lifetime History of Aggression scale (E. F. Coccaro et al., 1997), AQ = Buss and Perry Aggression Questionnaire (Buss & Perry, 1992), RPQ = Reactive-Proactive Questionnaire (Raine et al., 2006), STAXI-I = State-Trait Anger Expression Inventory (Spielberger, 2010), PCL-R= Hare Psychopathy Checklist-Revised (Hare, 2003).

Table 4. Functional Magnetic Resonance Imaging (fMRI) tasks

Study	Task	Stimuli	Design	Conditions	
				Active	Control
Coccaro et al., 2007	Implicit emotion processing	Ekman and Friesen set (Ekman and Friesen 1976)	Block	Angry face viewing	Rest (blank gray-screen)
Herpertz et al., 2017	Listening to harsh interpersonal rejections and physical aggression toward others	Four script phases (baseline, anger induction, other-directed aggression, relaxation)	Order of presentation of aggression and auto-aggression scripts were pseudo-randomized. All scripts randomly ordered.	Harsh interpersonal rejection script, and other-directed aggression script	Baseline (neutral script)
Klapwijk et al., 2016	Receiving opponent's angry reaction following unfair distribution of tokens	Written emotional reactions from opponents (angry, disappointed, happy)	Block	Reading angry emotional reaction	Reading happy emotional reaction
Krauch et al., 2018	Listening to harsh interpersonal rejections and physical aggression towards others	Four script phases (baseline, anger induction, other-directed aggression, relaxation)	Order of presentation of aggression and auto-aggression scripts were pseudo-randomized. All scripts randomly ordered.	Harsh interpersonal rejection script, and other-directed aggression script	Baseline (neutral script)
Lee, Chan & Raine, 2009	Passive viewing of images	Neutral, positive, "aggressive-threat" (i.e., depicting violence), and "aggressive-women" (i.e., depicting violence against women) images	Block	Aggression images viewing	Neutral images viewing
McCloskey et al., 2016	Emotion expression identification task	Ekman and Friesen set (Ekman and Friesen 1976)	Block	Angry face	Neutral face
Schienle et al.,2017	Passive viewing of approaching neutral facial expressions	Approaching and static images of neutral male or female silhouette	Event-related	Approaching	Static
Seok & Cheong, 2020	Passive viewing of video clips	Anger and neutral video clips from movies, dramas or news	Block	Anger clips viewing	Neutral clips viewing

Tonnaer et al., 2017	Anger Articulated Thoughts during Simulated Situations (ATSS) paradigm	Happy, neutral, anger audio tapes	Condition presentations were counterbalanced & order of audio-tape situation was randomized	Anger engagement	Neutral engagement

Table 5. Peak activations in aggression >control groups during aggression-eliciting relative to control conditions

Cluster	x	y	z	k (voxels)	Brain region
A) Overall analysis					
1	-30	-12	-26	515	Left hippocampus/amygdala (Regenbogen et al., 2017)
"	-32	-16	-30	121	Left parahippocampal gyrus (Clark et al., 2017)
"	-28	-8	-28	178	Left hippocampus/amygdala (Peciña et al., 2014)
"	-30	-14	-22	216	Left parahippocampal gyrus (Zijlstra et al., 2009)
2	52	2	-22	515	Right superior temporal sulcus/middle temporal gyrus (Nilsson et al., 2013)
"	52	2	-28	100	Right middle temporal gyrus/superior temporal sulcus (Corradi-Dell'Acqua et al., 2014)
"	52	-4	-20	104	Right middle temporal gyrus (Straube et al., 2010)
"	58	2	-22	79	Right middle temporal gyrus and inferior temporal gyrus (Hsu et al., 2015)
"	50	4	-20	232	Right middle temporal gyrus (Hentze et al., 2016)
B) Additional regions at extent threshold: stringent and size >= 10					
1	-26	-2	-24	74	Left amygdala (von Hagen et al., 2014)

Table 6. Peak activations in control>aggression groups during aggression-eliciting relative to control conditions (overall analysis)

Cluster	x	y	z	k (voxels)	Brain region
1	-22	-73	4	358	Left occipital cortex, left medial occipital cortex (Tabbert et al., 2005; Zimmer & Macaluso, 2007)
"	-22	-76	0	150	Left lingual gyrus (Mulukom et al., 2013)
"	-22	-72	8	208	Left calcarine cortex (Dulas & Duarte, 2011)
2	-30	-80	6	11	Left V2 (Kupers et al., 2011)

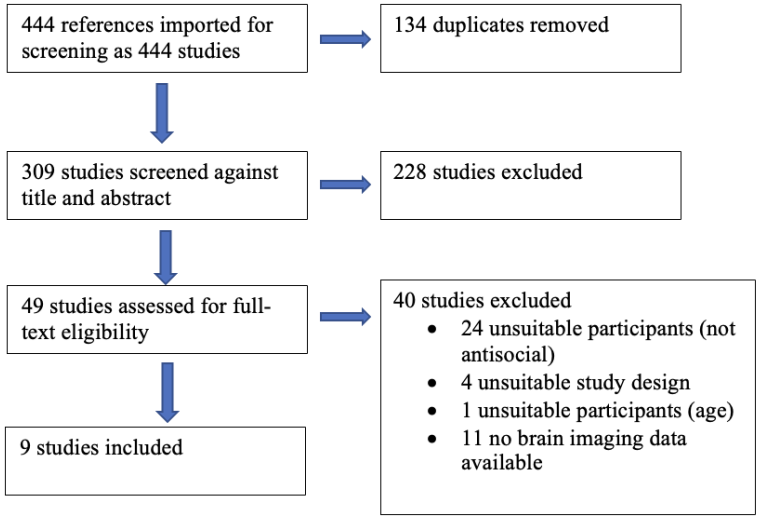
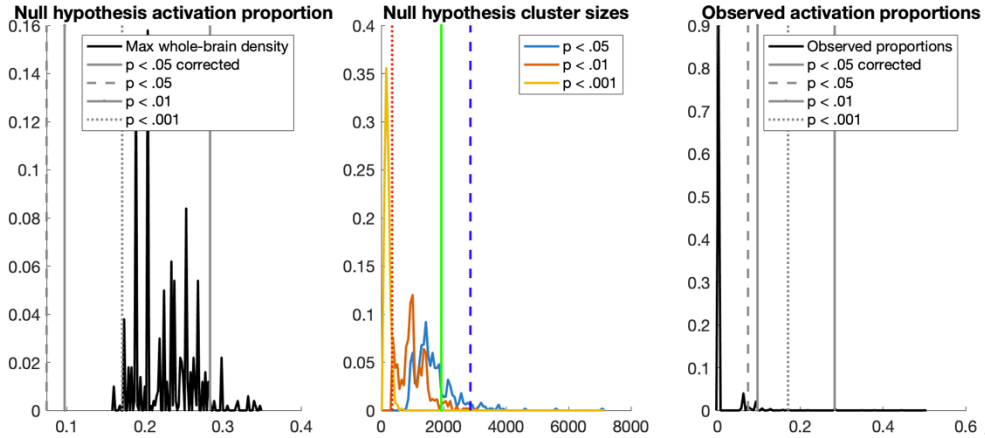


Figure 1. PRISMA flowchart illustrating the literature search and study selection process.

2A



2B

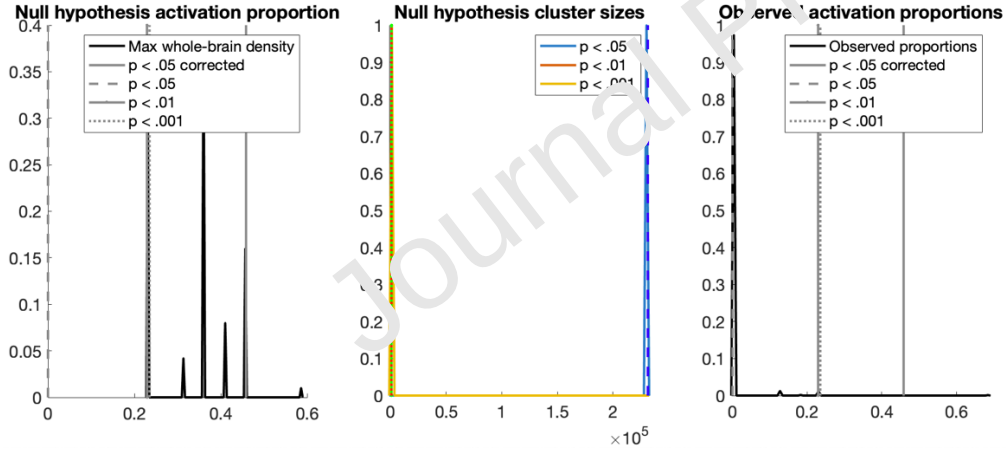
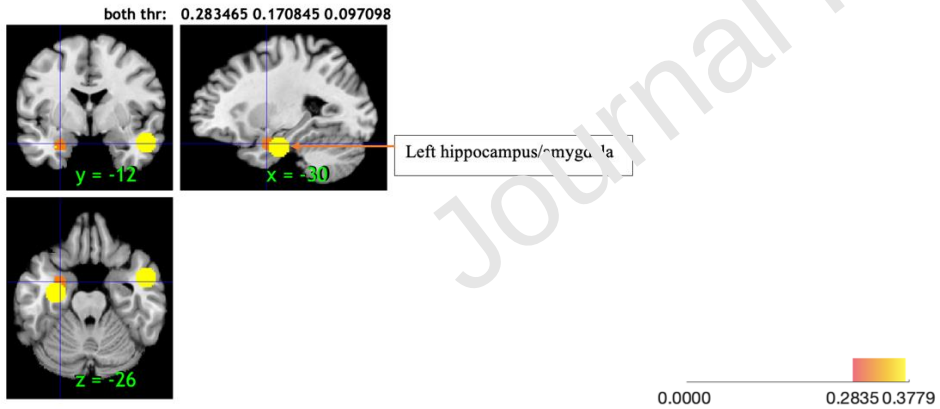


Figure 2. Monte Carlo null hypothesis activation proportion and thresholding for aggression vs. control group (2A) and control vs. aggression group (2B). Null hypothesis activation proportion: The weighted proportions of comparison, namely the maximum proportion of activated comparison maps under the null hypothesis, are plotted on the x axis. Null hypothesis cluster sizes: The largest

cluster of contiguous voxels, which is important for extent-based thresholding, is reported on the x axis. Observed activation proportions: the maximum density value (height threshold) across all studies following each Monte Carlo iteration is presented on the x axis. In Figure 2A, p<.05 MKDA height-corrected represents a height threshold of .28 and includes 1030 voxels; p<0.001 represents a height threshold of .17 and extent threshold of 350 (includes 1104 significant voxels); p<.01 represents a height threshold of .10 and extent threshold of 1926 (includes 0 significant voxels); p<.05 represents a height threshold of .07 and extent threshold of 2858 (includes 0 significant voxels). In Figure 2B, p<.05 MKDA height-corrected represents a height threshold of .46 and includes 369 voxels; p<.001 represents a height threshold of .24 and extent threshold of 896 (0 significant voxels); p<0.01 represents a height threshold of .23 and extent threshold of 902 (0 significant voxels); p<0.05 represents a height threshold of 0 and extent threshold of 231202 (0 significant voxels).

3A



3B

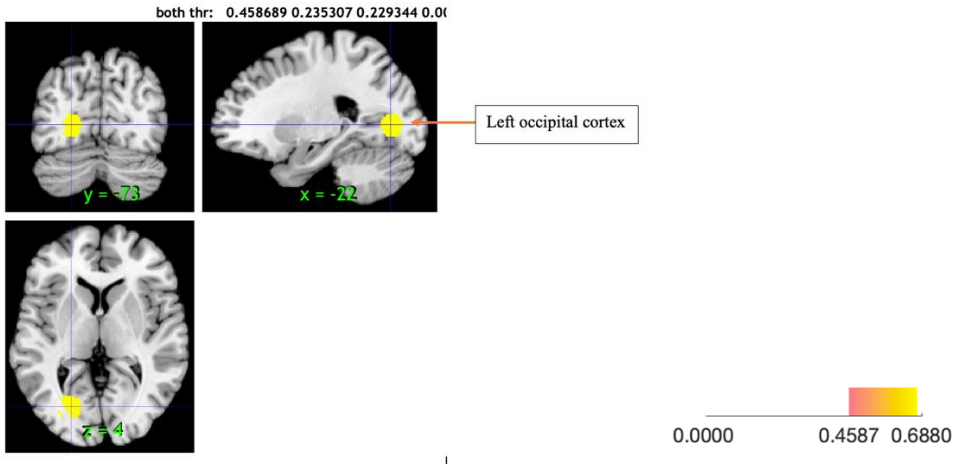


Figure 3. Proportion of activated CIMs (significant regions) in the at aggression vs. control group (3A) and in the control vs. aggression group (3B). Regions depicted in yellow: significant at p<.05 MKDA-height corrected (representing threshold 0.28 with 1030 voxels in 3A and threshold 0.46 with 369 voxels in 3B). In those regions, the proportion of SCMs activated within r mm of the voxel was greater than would be expected by chance. Regions depicted in orange: significant at p<.05 cluster-extent corrected with primary alpha levels of .001 (representing threshold .17 with 1104 significant voxels in 3A. 3B has no orange regions because there are 0 significant voxels at threshold 0.24. Those regions were large enough in size to expect that we would only see such a cluster in the brain by chance 5% of the time (Kober & Wager, 2010; Wager et al., 2007). In those regions, MKDA was extent-based thresholded, meaning that the largest set of contiguous voxels was saved at each Monte Carlo simulation, and cluster extent threshold

value was determined as the 95th percentile of these values across each iteration (in this case: 1, 350, 1926, 2858 for 3A, and 1, 896, 902, 231202 for 3B; Kober & Wager, 2010).

Highlights

- Replicated findings of increased limbic responsiveness in people with a history of aggression
- No direct support for prefrontal hypoactivity models of reactive aggression
- Some evidence of left hemispheric lateralization in people with a history of aggression
- Novel findings of increased temporal and decreased occipital activity during aggression tasks