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Aggression Mapping: Brain Functional Connectivity in Tehran's At-Risk Youth

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Abstract

Aggression, a multifaceted behavior influenced by neural, environmental, and psychological factors, is associated with distinct patterns of brain functional connectivity. This study examines the neural correlates of aggression in adolescents with Conduct Disorder (CD) and Oppositional Defiant Disorder (ODD) from underprivileged areas of Tehran. Using resting-state functional connectivity (rsFC) and fMRI analysis, we compared 14 adolescents with aggression to 13 healthy controls. Behavioral assessments included the Child Behavior Checklist (CBCL) and Buss-Perry Aggression Questionnaire (BPAQ), while fMRI data were processed using standard pipelines. Results revealed hyperconnectivity in the default mode and fronto-parietal networks among aggressive individuals, reflecting overactive self-referential processing and impaired cognitive flexibility. Increased connectivity between fronto-parietal and salience networks pointed to emotional regulation deficits, while disruptions between language and salience networks indicated challenges in interpreting emotional speech. Hypoconnectivity in executive, attention, and emotional regulation networks suggested impaired integration of goal-directed behavior and perceptual control. These findings highlight the role of large-scale functional networks in aggression, providing insights into potential neural biomarkers and therapeutic targets. By exploring the socio-cultural and economic influences specific to Tehran, this study underscores the importance of localized approaches for understanding and managing aggression in at-risk youth.

Keywords: Aggression, resting-state functional connectivity, brain networks.

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1. Introduction and preliminaries

Aggression is a complex behavior influenced by various brain networks, with significant implications for understanding and managing aggressive tendencies. Research indicates that specific neural circuits are consistently associated with aggression, highlighting the role of structural and functional brain networks. The subcortical network, including the amygdala and lateral orbitofrontal cortex, is crucial for processing emotions and regulating aggressive behavior. The default mode network, involving the dorsal medial prefrontal cortex and middle temporal gyrus, is associated with mentalizing and social cognition. The salience network, comprising the anterior cingulate cortex and anterior insula, is linked to cognitive control and emotional responses (Wang et al., 2024). Connectome-based predictive modeling suggests that connectivity within and between networks related to cognitive control, social functioning, and emotion processing can predict aggression severity in children. Variability in aggression is linked to individual differences in large-scale functional networks, indicating potential neural biomarkers for targeted interventions(Ibrahim et al., 2022). Furthermore, non-invasive brain stimulation techniques such as tDCS and cTBS, targeting the dorsolateral and ventromedial prefrontal cortices, have shown potential in modulating aggressive behavior, offering a promising therapeutic avenue (Knehans et al., 2022). While these findings provide insights into the neural underpinnings of aggression, it is essential to consider its multifaceted nature. Environmental and psychological factors can also influence aggression, complicating the development of universal interventions.

Aggression is defined as behavior aimed at harming someone who is trying to avoid harm(Baron, 1994). It can be categorized into reactive and proactive aggression (J. E. Werhahn et al., 2021). Reactive aggression, also known as impulsive aggression, is emotional and "hot," leading to heightened arousal and is typically triggered by provocation. It is linked to hostile interpretations of situations. In contrast, proactive aggression, or instrumental aggression, is "cold," calculated, and often driven by the goal of controlling someone or gaining personal advantage (Walters, 2005). In the DSM-5-TR, Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD) are both categorized under Disruptive, Impulse-Control, and Conduct Disorders. ODD is characterized by a pattern of angry/irritable mood, argumentative/defiant behavior, or vindictiveness lasting at least six months, with symptoms such as frequent temper loss, defiance, and spitefulness. In contrast, CD involves a repetitive and persistent pattern of behavior that violates the basic rights of others or societal norms, including aggression towards people or animals, destruction of property, deceitfulness or theft, and serious rules violations. Both disorders can significantly impact social, academic, and occupational functioning(First, 2013).

The I3 model, developed by Eli J. Finkel, provides a comprehensive framework for understanding aggressive behavior, particularly in response to provocation, by integrating three key processes: instigation, impellance, and inhibition. **Instigation** refers to immediate environmental triggers, such as insults or physical threats, that normatively afford an aggressive response. **Impellance** determines the intensity of the aggressive reaction based on dispositional or situational factors, such as trait aggressiveness or past experiences. For instance, individuals with high trait aggressiveness are more likely to react intensely to provocation. **Conversely, inhibition** moderates aggression by introducing self-regulatory mechanisms such as executive functioning or self-control, which help suppress aggressive impulses. When inhibiting forces are weak, aggression is more likely to be expressed(Finkel, 2014; Finkel & Hall, 2018). The **perfect storm theory**, derived from the I3 model, suggests that the most intense aggression occurs when instigation is strong (e.g., direct provocation), impellance is high (e.g., heightened aggression-prone traits), and inhibition is weak (e.g., low self-control)(Caiozzo, 2014; Massa et al., 2020). This model has been applied to various forms of aggression, including intimate partner violence, offering valuable insights into when and why violence is most likely to occur.

Research has shown that both reactive and proactive aggression are linked to distinct patterns of brain connectivity, particularly in networks related to emotion regulation, cognitive control, and social functioning. Neural correlates of aggression have been identified through various neuroimaging studies, revealing distinct patterns associated with different types of aggressive behavior. Studies show that reactive aggression is associated with hyper-connectivity in regions like the posterior cingulate cortex and parahippocampus, while proactive aggression shows increased connectivity between the amygdala and precuneus (Julia E Werhahn et al., 2021a; Werhahn et al., 2023).These patterns suggest different underlying neural mechanisms for each subtype.

Functional connectivity is the identification of correlated activity patterns between different brain regions that are involved in fundamental brain functions or more complex information processing (Hämäläinen et al., 2020). Resting-State Functional Connectivity refers to the measurement of correlations in brain activity when individuals are at rest, without any external stimuli. It involves identifying intrinsic connectivity networks based on low-frequency fluctuations in the brain, which reflect more permanent brain states and are linked to anatomical connectivity. Altered rsFC in the default mode and salience networks has been observed in youths with disruptive behavior, highlighting the importance of these networks in aggression (Werhahn et al., 2023; Wenfeng Zhu et al., 2019; W. Zhu et al., 2019). Disruptions in frontoparietal networks, which support emotion regulation, are predictive of aggression severity, emphasizing the role of large-scale functional networks in maladaptive aggression(Ibrahim et al., 2022).

Resting-state functional MRI (rs-fMRI) has conceptual and practical strengths that can facilitate brain function research, especially with a psychiatric population. Conceptually, rs-fMRI allows for the parameters of the brain's intrinsic functional architecture and its spontaneous neural fluctuations, in which cognitive and behavioral forms of complexity exist. It also reduces the purer insertion assumptions or uncertainty in task experiments while at the same time limiting the interference or unaccounted cognitive key demands of attention and working memory(Bijsterbosch et al., 2017; Buckner et al., 2013). Clinically, rs-fMRI remains highly feasible for a large number of populations, including a population who cannot participate in cognitive tasks (e.g. children, elderly or clinical patients). As it requires a straightforward procedure to acquire, requires limited subject compliance and have relatively low technical complexity, rs-fMRI can be beneficial for more data acquisition and easier replication via large-scale multi-modal imaging can be successful. More importantly, the relatively consistent and reproducible functional connectivity patterns within individuals and across studies highlights rs-fMRI's potential for functional biomarkers in mental health studies. While some criticism remains on the implications of the cognitive content without models of a "purposive state," fairly strong evidence still backs the quality of consistency and telemetry of stable patterns of connectivity.These features collectively justify the use of rs-fMRI in studies seeking to understand the neural correlates of psychiatric symptoms such as aggression (Abravani et al., 2023; Bijsterbosch et al., 2017; Coccaro et al., 2007; Jin et al., 2025; Julia E Werhahn et al., 2021a; Yao et al., 2025; Zhou et al., 2025).

Understanding the neural underpinnings of aggression in at-risk youth is crucial for developing targeted interventions. In Tehran, a city with unique socio-cultural dynamics, mapping brain functional connectivity in aggressive youth can provide insights into the specific neural patterns associated with different aggression subtypes. Identifying specific neural patterns associated with aggression can inform the development of targeted interventions, potentially improving outcomes for at-risk youth in Tehran. Our study explores neural correlates' current understanding and implications for addressing aggression in Tehran's youth.

2. Method

The population of this study includes all adolescents from underprivileged areas in need of intervention in Tehran. The sampling method will be convenience sampling from the mentioned areas, and the sample size is 27 individuals. This includes 14 adolescents (11 to 18 years old) with CD and ODD living in underprivileged areas of Tehran, and 13 healthy adolescents (11 to 18 years old) from the same areas. Based on previous studies, variables such as attention deficit and hyperactivity, parents' education level, parents' mental illness, family economic status, presence or absence of domestic violence, gender, age, and IQ will be considered as intervening variables, and all children and adolescents in both groups will be homogenized.

To select the research participants, the following inclusion criteria have been considered:

1. Absence of any acute or chronic mental illness in the control group, substance use disorder, major depression, anxiety, and bipolar disorder in the target group.
2. No history of head trauma, cerebrovascular accident, epilepsy, or seizures in infancy.
3. No use of psychiatric or thyroid medications in recent months.
4. Having an average or above-average IQ and no intellectual disability.
5. Ability to perform computer tasks (sensory and motor coordination, all computer tasks include a practice phase to show that if the participant cannot successfully complete it, they cannot perform the main task).

All individuals in the conduct disorder and ODD group have been selected using the CBCL checklist. These individuals also had aggression criteria.

2.1 Materials:

2.1.1. Behavioral assessment:

The Child Behavior Checklist (CBCL) is part of the Achenbach System of Empirically Based Assessment (ASEBA). It evaluates children's and adolescents' problems in eight factors: anxiety/depression, withdrawal/depression, somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, and aggressive behavior. The last two factors form the second-order factor of externalizing problems. The CBCL assesses emotional-behavioral problems and academic and social competencies of children aged 6-18 from the parents' perspective and typically takes 20-25 minutes to complete. It can be filled out by a parent or another person familiar with the child's competencies and behavioral issues, either as a self-report or through an interview. The CBCL can also be used to measure behavioral changes over time or following treatment. This questionnaire was translated and standardized in Iran by Tehrani-Doost, et al.(Tehrani-Doost et al., 2011). The internal consistency coefficients of the scales, using Cronbach's alpha, ranged from 0.63 to 0.95, and the test-retest reliability over a 5-8 week interval ranged from 0.32 to 0.67. The agreement between respondents varied from 0.09 to 0.67. Overall, the CBCL has been found to have high reliability and validity for assessing emotional-behavioral disorders in children and adolescents aged 6-18.

The Buss-Perry Aggression Questionnaire (BPAQ), established in 1992, stands as a widely utilized tool for evaluating human aggressive tendencies(Buss & Perry, 1992). Comprising 29 items, the questionnaire delves into four distinct factors: Physical aggression (9 items), verbal aggression (5 items), anger (7 items), and hostility (8 items). Thus, it offers a comprehensive assessment of aggression, encompassing both physical and verbal manifestations, alongside the associated emotional dimensions of anger and hostility(Javela et al., 2023). The BPAQ has undergone rigorous validation and cross-cultural application, with successful implementations observed in various countries and languages(Javela et al., 2023; Morren & Meesters, 2002; Vigil-Colet et al., 2005).

2.1.2. fMRI - Image Acquisition

All participants were scanned using a 3 Tesla SIEMENS MAGNETOM Prisma scanner. Each scanning session began with a localizing scan, followed by the acquisition of a high-resolution anatomical image through an MPRAGE sequence, characterized by the following parameters: repetition time (TR) of 1800 ms, echo time (TE) of 3.5 ms, inversion time (TI) of 1100 ms, a flip angle of 7 degrees, and a resolution of 1 × 1 × 1 mm. Functional data were collected at the same slice locations as the T1-weighted anatomical images, utilizing a T2*-sensitive gradient-recalled single-shot echo-planar pulse sequence with parameters of TR = 3000 ms, TE = 30 ms, a flip angle of 90 degrees, a field of view (FOV) of 192 mm, and a voxel size of 3.0 × 3.0 × 3.0 mm. Participants engaged in a single resting-state run consisting of 120 volumes, which lasted 6 minutes and 11 seconds. During this resting period, participants were instructed to maintain their gaze on a centrally positioned cross mark with their eyes open.

2.1.3. Image Pre-processing:

In this investigation, we utilized the standard pre-processing pipeline of CONN, a prominent MATLAB-based toolbox for functional connectivity analysis, to prepare our functional MRI data. This pipeline encompasses several essential steps: Functional Realignment and Unwarp to rectify head motion and non-linear distortions; Slice-Timing Correction to synchronize the acquisition times of each slice within a volume; and ART-based Outlier Detection to identify and address outliers resulting from motion and intensity fluctuations. Furthermore, Normalization was executed to transform both functional and structural images into the Montreal Neurological

Institute (MNI) space, while Segmentation was applied to differentiate anatomical images into gray matter, white matter, and cerebrospinal fluid. Spatial Smoothing with a 6mm Full Width at Half Maximum (FWHM) Gaussian kernel was employed to improve the signal-to-noise ratio and enhance statistical validity. Lastly, Denoising was performed to eliminate confounding effects by regressing out nuisance variables and applying temporal filtering. These procedures collectively ensured the integrity and reliability of the data for subsequent analysis.

In the current research, we explicitly opted for resting-state functional connectivity (rs-fMRI) techniques because of their appropriateness to our particular research aims. Although the General Linear Model (GLM) is a popular choice for task-based fMRI in order to detect brain areas activated by external stimuli (Friston et al., 1994), resting-state analysis necessitates fundamentally different analytical approaches. seed-based correlation and independent component analysis (ICA) that are specifically geared towards the detection of low-frequency, synchronous disparities throughout distributed networks of the brain (Cole et al., 2010). As our primary objective was the examination of intrinsic aggression-related connectivity patterns rather than those of task-evoked responses, connectivity-focused methods were more aligned with this study's conceptual model and objective.

3. Result

Table1. Analysis of Brain Networks in Aggressive Adolescents and Controls: Functional Connectivity Results Using CONN Software

Brain region		**T(25)**	**p-value**
FrontoParietal.PPC[1] (L[4])	Salience.AInsula (L)	4.16	0.000328
Language.pSTG[2] (L)	Salience.AInsula (L)	3.53	0.001656
DefaultMode.PCC	FrontoParietal.PPC (L)	**-3.48**	0.001833
FrontoParietal.PPC (L)	Salience.AInsula (R)	3.33	0.002721
FrontoParietal.PPC (L)	FrontoParietal.PPC (R)	**-3.19**	0.003845
DefaultMode.PCC	FrontoParietal.PPC (R)	**-2.82**	0.009216
Cerebellar.Anterior	Language.IFG[3] (L)	2.67	0.013063
Language.pSTG (R[5])	Salience.AInsula (L)	2.65	0.013623
DefaultMode.LP (L)	Salience.RPFC (R)	**-2.58**	0.016148
DefaultMode.PCC	DorsalAttention.IPS (R)	2.56	0.016936
FrontoParietal.LPFC (L)	Salience.AInsula (L)	2.55	0.017442
DefaultMode.LP (L)	DefaultMode.MPFC	2.49	0.019753
FrontoParietal.PPC (L)	Language.IFG (R)	2.48	0.020304

FrontoParietal.PPC (R)	Salience.AInsula (L)	2.46	0.021099
DefaultMode.PCC	Cerebellar.Posterior	**-2.45**	0.021503
Visual.Lateral (R)	DefaultMode.PCC	2.32	0.028536
DefaultMode.LP (L)	Language.IFG (L)	2.32	0.028916
Cerebellar.Anterior	DorsalAttention.FEF (R)	**-2.3**	0.029772
FrontoParietal.PPC (R)	Language.pSTG (L)	**-2.3**	0.029787
Visual.Medial	Language.pSTG (L)	2.22	0.035567
DefaultMode.PCC	DorsalAttention.IPS (L)	2.21	0.036509
DefaultMode.LP (R)	Language.IFG (R)	2.21	0.036721
FrontoParietal.LPFC (L)	Language.pSTG (R)	**-2.19**	0.038386
Salience.AInsula (L)	DorsalAttention.FEF (R)	**-2.17**	0.039491
FrontoParietal.PPC (L)	Language.pSTG (R)	**-2.15**	0.041007
Cerebellar.Posterior	Salience.AInsula (L)	2.14	0.042203
Visual.Medial	DorsalAttention.FEF (R)	**-2.14**	0.042425
FrontoParietal.PPC (L)	Language.IFG (L)	2.11	0.044789
Language.IFG (R)	DorsalAttention.FEF (L)	**-2.1**	0.045765
1.Posterior parietal cortex 2. posterior superior temporal gyrus 3. inferior frontal gyrus 4. left 5. right			

The results of the analysis of brain networks in aggressive adolescents and controls, considering functional connectivity using the CONN software, are as follows:

1. FrontoParietal and Salience Networks Stronger Connectivity in Controls:

FrontoParietal PPC (L4) ↔ Salience AInsula (L) (T = 4.16, p = 0.000328) suggests better integration of executive and emotional processing in controls.

Language.pSTG2 (L) ↔ Salience.AInsula (L) (T = 3.53, p = 0.001656) highlights better language-emotion interaction in controls.

2. Weaker Connectivity in Controls (Stronger in Aggressive group):

DefaultMode.PCC ↔ FrontoParietal.PPC (L) (T = -3.48, p = 0.001833) suggests that the aggressive group has hyperconnectivity between self-referential thought and executive control regions, possibly related to rumination or rigid cognitive styles.

FrontoParietal.PPC (L) ↔ FrontoParietal.PPC (R) ($T = -3.19$, $p = 0.003845$) suggests heightened bilateral executive function connectivity in the aggressive group, which may overload cognitive control systems.

3. Language and Salience Networks:

Language.pSTG (R) ↔ Salience.AInsula (L) ($T = 2.65$, $p = 0.013623$) implies better speech-emotion integration in controls, suggesting emotional regulation deficits in the aggressive group.

4. Default Mode and Attention Networks:

DefaultMode.PCC ↔ DorsalAttention.IPS (R) ($T = 2.56$, $p = 0.016936$) suggests better functional switching between internal and external focus in controls.

DefaultMode.LP (L) ↔ Salience.RPFC (R) ($T = -2.58$, $p = 0.016148$) implies difficulty in controlling salience responses in the aggressive group, contributing to impulsivity.

5. Cerebellar and Language Networks:

Cerebellar.Anterior ↔ Language.IFG3 (L) ($T = 2.67$, $p = 0.013063$) highlights better speech-motor coordination in controls.

Figure 1 illustrates the functional connectivity differences between the control and aggressive groups, as analyzed using the CONN toolbox in MATLAB. The connectivity strengths are visualized through colored lines, where orange/red lines indicate stronger connectivity in the control group compared to the aggressive group (Control > Aggressive), and blue lines represent stronger connectivity in the aggressive group compared to controls (Aggressive > Control). The thickness of the lines reflects the magnitude of the T-statistic, with thicker lines indicating more robust group differences. Key regions of interest (ROIs) are labeled and include areas such as the anterior insula (Salience Network), posterior parietal cortex (FrontoParietal Network), posterior cingulate cortex (Default Mode Network), and posterior superior temporal gyrus (Language Network). These findings reveal enhanced executive and emotional regulation connectivity in controls, whereas the aggressive group demonstrates hyperconnectivity in self-referential and default mode regions, potentially reflecting deficits in cognitive flexibility and emotional regulation.

Figure 2 illustrates the group differences in functional connectivity between aggressive and control adolescents across key brain networks. Orange/red lines represent stronger connectivity in the control group compared to aggressives, while blue lines indicate stronger connectivity in the aggressive group. The thickness of the lines reflects the strength of the T-

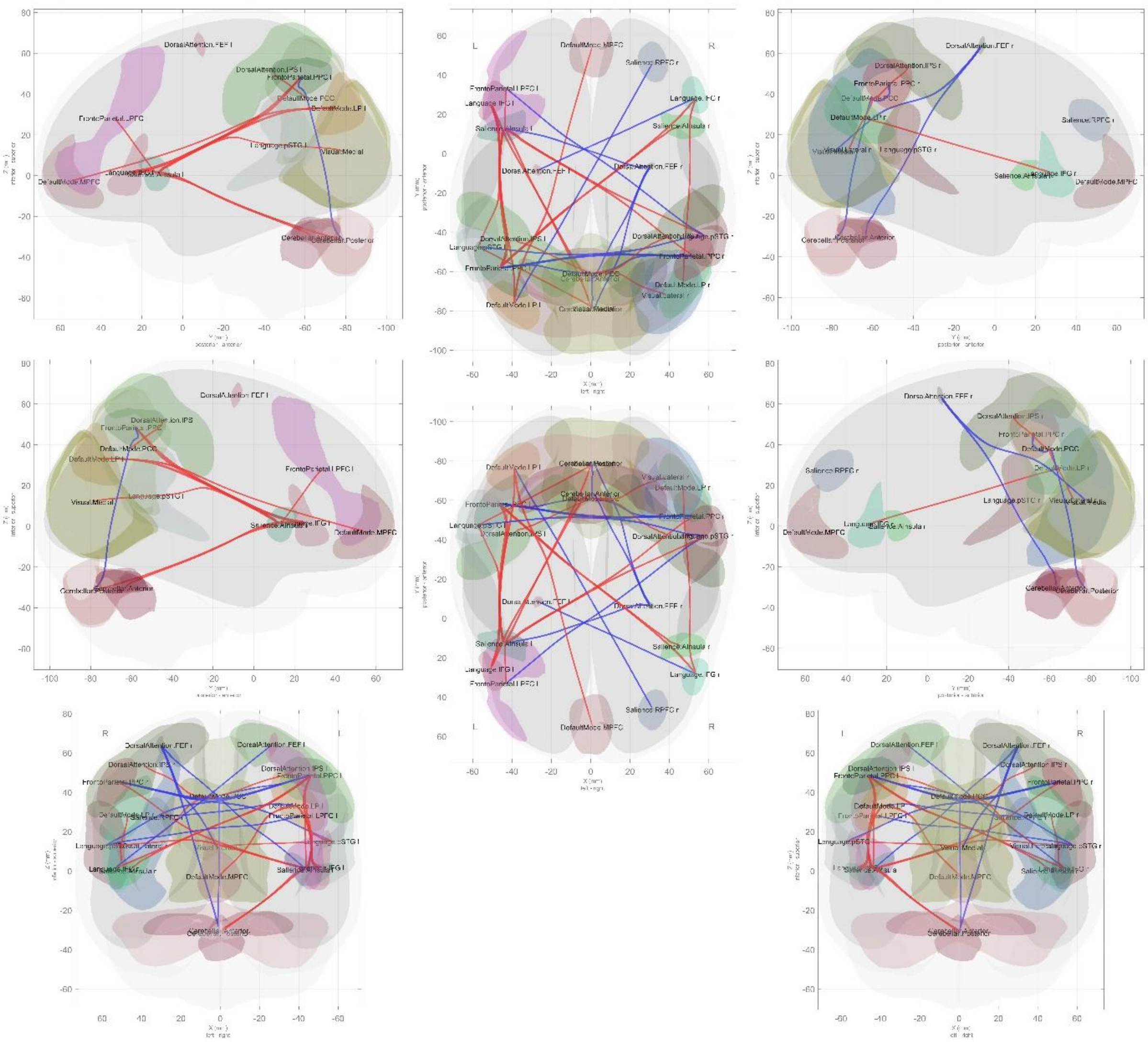

FIGURE 1 Functional Connectivity Differences Between Control and Aggressive Groups: ROI-to-ROI Analysis Highlighting Network-Level Disruptions

statistic, with thicker lines indicating greater differences between groups. The color scale (top-right corner) displays T-values ranging from -4.16 to 4.16, where positive values (red) correspond to higher connectivity in controls and negative values (blue) represent higher connectivity in aggressives. Regions of interest (ROIs) are labeled according to their network affiliations, including the Salience Network (e.g., left anterior insula), FrontoParietal Network (e.g., left posterior parietal cortex), Default Mode Network (e.g., posterior cingulate cortex), and Language Network (e.g., left posterior superior temporal gyrus). These findings highlight the reduced connectivity in executive and emotional regulation networks and increased connectivity in self-referential regions in aggressive individuals, underscoring their potential cognitive and emotional regulation deficits.

4. Discussion

Our study examined functional connectivity differences between the control group and

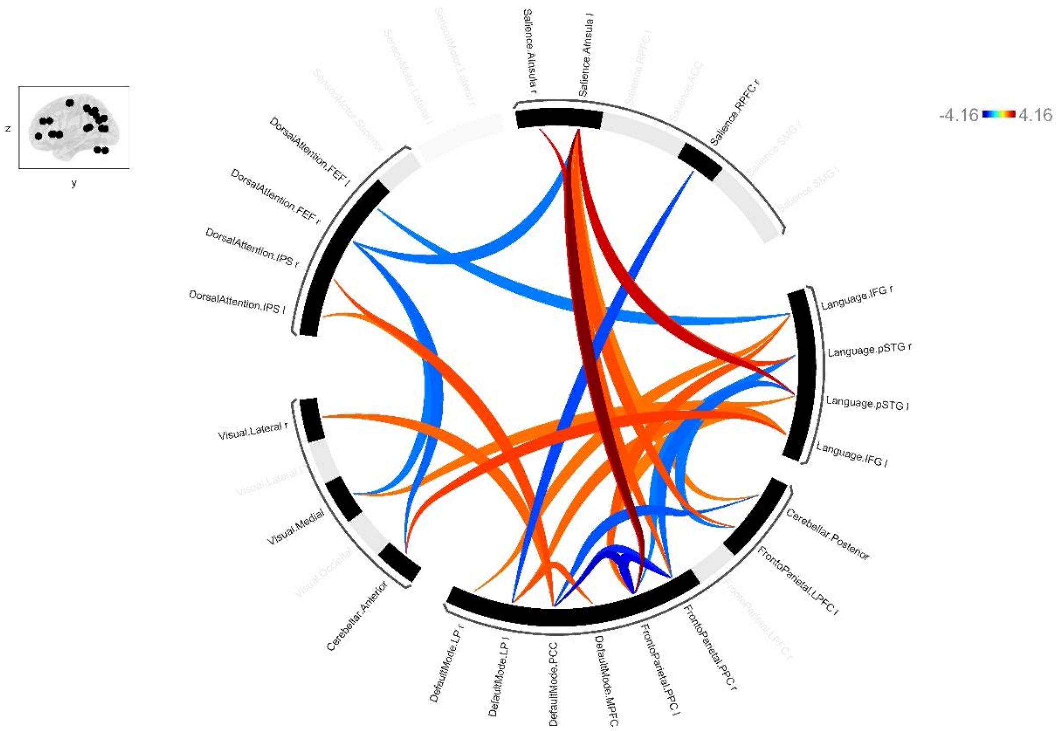

FIGURE 2 Connectivity plot generated by CONN software, Brain regions (ROIs): FrontoParietal Network (FPN), Salience Network (SN), Default Mode Network (DMN), Dorsal Attention Network (DAN), Language Network, Visual Network, Cerebellar Network

aggressive individuals using ROI-to-ROI functional connectivity analysis. Key observations revealed that aggressive individuals exhibit hyperconnectivity in the default mode and fronto-parietal networks, indicating overactive self-referential processing and difficulty in cognitive flexibility. Additionally, hyperconnectivity in the connections between the fronto-parietal and salience networks points to emotional regulation impairments and inefficient top-down control. Disruptions in connectivity between the language and salience networks suggest difficulties in emotional interpretation of speech, while deficits in visual and attention networks indicate challenges in goal-directed behavior and perceptual control. Compared to the control group, aggressive individuals generally display weaker integration in executive, attentional, and emotional regulation networks, providing insights into the neural mechanisms underlying aggression.

The present study reveals significant differences in functional connectivity patterns between aggressive adolescents and their non-aggressive counterparts. Non-aggressive individuals exhibited stronger connections between the frontoparietal and salience networks, such as the posterior parietal cortex (PPC) and anterior insula (AInsula). These stronger connections indicate better integration of executive and emotional processing, which is essential for adaptive decision-making and emotion regulation. In contrast, aggressive individuals showed hyperconnectivity between the default mode network (DMN) and the frontoparietal network, potentially reflecting excessive rumination and rigid cognitive styles (Abravani et al., 2023; Callaghan et al., 2017; Ibrahim et al., 2022). The observed hyperconnectivity between bilateral PPC regions within the frontoparietal network in aggressive adolescents may represent a compensatory mechanism for impaired cognitive control. However, this excessive connectivity could also overload executive systems, leading to deficits in inhibition and increased impulsivity ((Martín-Luengo et al., 2023). These findings align with evidence suggesting that executive dysfunction is a hallmark of aggressive behavior, particularly when accompanied by emotional dysregulation(Callaghan et al., 2017). The aggressive group exhibited weaker functional connectivity between the salience network (AInsula) and language networks, indicative of deficits in speech-emotion integration. These impairments may hinder the interpretation of emotional cues, exacerbating impulsivity and reactive aggression (Wenfeng Zhu et al., 2019). These findings emphasize the importance of enhancing emotion regulation and communication skills in therapeutic interventions for aggression. Increased connectivity between the DMN, particularly the posterior cingulate cortex (PCC), and the frontoparietal network in aggressive individuals reflects excessive self-referential processing. This overactivity may foster maladaptive rumination and cognitive inflexibility, traits commonly associated with aggression(Callaghan et al., 2017). Stronger connections between the DMN (PCC) and the dorsal attention network (e.g., intraparietal sulcus, IPS) in the non-aggressive group indicate better capacity for switching between internal and external focus. This ability is crucial for attention regulation and goal-directed behavior. In contrast, aggressive individuals may struggle with such transitions, leading to attention deficits and maladaptive behaviors(Ibrahim et al., 2022). Interventions like neurofeedback that target attention regulation could benefit this subgroup. Hypoconnectivity observed between the cerebellar anterior region and language networks in the aggressive group indicates deficits in speech-motor coordination. Such impairments may intensify communication challenges, increase misunderstandings, and escalate conflicts contributing to aggressive outbursts(Murphy et al., 2018). Incorporating speech-motor coordination exercises into intervention programs could address these challenges effectively. Environmental factors, such as exposure to violence and hostile parenting, can influence functional connectivity patterns associated with aggression. Changes in amygdala-prefrontal connectivity under such conditions may heighten sensitivity to perceived threats and reduce inhibitory control (Callaghan et al., 2017; Saxbe et al., 2018). Addressing these factors through family-based interventions could complement neurocognitive therapies, offering a comprehensive approach to managing aggression. Differentiating between proactive and reactive aggression provides valuable insights for targeted therapeutic strategies. Reactive aggression is linked to hyperactivity in the salience network, particularly in the amygdala and insula, while proactive aggression is associated with DMN disruptions affecting moral reasoning and empathy(W. Zhu et al., 2019). Recognizing these distinctions can guide the development of targeted interventions tailored to the neurofunctional profiles of each aggression subtype. Emerging neuroimaging evidence highlights biomarkers, such as DMN and salience network connectivity patterns, that predict aggression severity. These biomarkers could facilitate precision medicine approaches, tailoring interventions like cognitive-behavioral therapy (CBT) or neurofeedback to individual neurofunctional profiles(Ibrahim et al., 2022). Integrating these advancements holds promise for improving treatment outcomes for aggressive adolescents. Our findings underscore the complex interplay between cognitive, emotional, and motor networks in aggressive behavior. Longitudinal studies examining changes in functional connectivity patterns during developmental stages could provide deeper insights into the trajectory of aggression. Furthermore, combining neuroimaging with behavioral assessments could refine intervention designs, enhancing their accessibility and effectiveness for at-risk youth. Our results correspond with prior evidence identifying different functional brain connectivity patterns based on different subtypes of aggression. It has been shown that reactive and proactive aggression have different neural systems underlying their assertions, particularly in networks responsible for cognitive control, emotion regulation, and social processing. For example, reactive aggression is associated with hyperconnectivity in the posterior cingulate cortex (PCC) and parahippocampal regions while proactive aggression showed increased connectivity between the amygdala and precuneus (Coccaro et al., 2011; Passamonti et al., 2010; Julia E Werhahn et al., 2021a). Within our study, the observed hyperconnectivity between the default mode network (DMN) and the frontoparietal network in the aggressive group, specifically the PCC, is indicative of maladaptive excessive self-referential processing and cognitive rigidity, features of reactive aggression. Hypoconnectivity between the salience and language networks may reflect impaired emotional interpretation of speech, thus reinforcing impulsive and reactive responding. These findings add to evidence that suggests alterations in large-scale functional networks (particularly the DMN, salience and frontoparietal networks) produce aggressive actions. Also, as the majority of participants in this study were from high-risk settings, where reactive aggression is more prevalent - the pattern of connectivity is consistent with previous studies(Aghajani et al., 2017; Bolhuis et al., 2019; Van Den Heuvel & Pol, 2010; Julia E Werhahn et al., 2021b; Wenfeng Zhu et al., 2019).

In summary, our study revealed functional connectivity differences between aggressive individuals and the control group through ROI-to-ROI functional connectivity analysis, offering insights into the neural mechanisms underlying aggression. Findings revealed that aggressive individuals exhibit hyperconnectivity within the default mode network (DMN) and frontoparietal networks, suggesting excessive self-referential processing and cognitive inflexibility, which align with the **I3 model's** concept of **impellance,** as these factors increase the intensity of aggressive responses. Additionally, hyperconnectivity between the frontoparietal and salience networks points to deficits in emotional regulation and inefficient top-down control, indicating weakened **inhibition** mechanisms that fail to suppress aggressive impulses. Disruptions in connectivity between language and salience networks suggest difficulties in interpreting emotional speech, while impaired visual and attentional networks highlight challenges in goal-directed behavior, further contributing to impulsive aggression. Compared to the control group, non-aggressive individuals exhibited stronger integration between executive, attentional, and emotional regulation networks, particularly between the posterior parietal cortex (PPC) and anterior insula (AInsula), suggesting better cognitive control and emotion regulation—key factors in preventing **instigation**-driven aggression. In contrast, the aggressive group’s hyperconnectivity within the frontoparietal network, especially between bilateral PPC regions, may represent a compensatory mechanism for impaired cognitive control. However, this excessive connectivity may also overload executive functions, leading to inhibition deficits and increased impulsivity, reinforcing the **perfect storm theory,** which posits that aggression peaks when instigation and impellance are strong while inhibition is weak. Notably, hypoconnectivity between the cerebellar anterior region and language networks in aggressive individuals suggests speech-motor coordination deficits, potentially exacerbating communication difficulties and misunderstandings that contribute to reactive aggression. Environmental influences, such as exposure to violence and hostile parenting, may further shape functional connectivity patterns by altering amygdala-prefrontal interactions, heightening threat sensitivity, and weakening inhibitory control. Differentiating between proactive and reactive aggression in relation to **I3 model dynamics** reveals that reactive aggression correlates with hyperactivity in the salience network (e.g., amygdala and insula), while proactive aggression is associated with DMN disruptions, affecting moral reasoning and empathy. Identifying distinct neurofunctional profiles of aggression subtypes could refine intervention strategies, such as neurofeedback and cognitive-behavioral therapy (CBT), by targeting specific connectivity patterns that drive aggression severity. These findings underscore the intricate interplay between cognitive, emotional, and motor networks in aggressive behavior and highlight the potential for precision medicine approaches in aggression management. Future research integrating neuroimaging with behavioral assessments and longitudinal studies could further elucidate developmental trajectories of aggression, paving the way for more effective and personalized interventions.

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Author Contributions

The contributions of each author are specified as follows: Conception and study design (Parya Abravani, Mohammadreza Bigdeli and Shahid Shateripour), data collection and acquisition (Parya Abravani, and Aliasghar Sadabadi), statistical analysis (Parya Abravani), interpretation of results (Parya Abravani and Mohammadreza Bigdeli), drafting the manuscript or revising it critically for intellectual content (All authors), and approval of the final version to be published and agreement to be accountable for the integrity and accuracy of all aspects of the work (All authors).

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Compliance with Ethical Standards

Ethical approval for this study was granted by the Research Ethics Committee of Shahid Beheshti University (Approval ID: IR.SBU.REC.1401.089) on 2022-09-03. Written informed consent/assent was obtained from all participants, and parental consent was secured for participants under the age of 18.

Conflict of Interest

The authors declare no conflict of interest related to this study.

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