Associations of bullying perpetration and peer victimization subtypes with preadolescent's suicidality, non-suicidal self-injury, neurocognition, and brain development

Xue Wen[1,2], Yinuo Shu[3], Diyang Qu[1,2], Yinzhe Wang[1], Zaixu Cui[3], Xiaoqian Zhang[4*] and Runsen Chen[1,2*]

Abstract

Background Although both peer victimization and bullying perpetration negatively impact preadolescents' development, the underlying neurobiological mechanism of this adverse relationship remains unclear. Besides, the specific psycho-cognitive patterns of different bullying subtypes also need further exploration, warranting large-scale studies on both general bullying and specific bullying subtypes.

Methods We adopted a retrospective methodology by utilizing the data from the Adolescent Brain and Cognitive Development[SM] Study (ABCD Study®) cohort collected between July 2018 and January 2021. Participants were preadolescents aged from 10 to 13 years. The main purpose of our study is to examine the associations of general and specific peer victimization/bullying perpetration with preadolescents' (1) suicidality and non-suicidal self-injury; (2) executive function and memory, including attention inhibition, processing speed, emotion working memory, and episodic memory; (3) brain structure abnormalities; and (4) brain network disturbances. Age, sex, race/ethnicity, body mass index (BMI), socioeconomic status (SES), and data acquisition site were included as covariates.

Results A total of 5819 participants aged from 10 to 13 years were included in this study. Higher risks of suicide ideation, suicide attempt, and non-suicidal self-injury were found to be associated with both bullying perpetration/ peer victimization and their subtypes (i.e., overt, relational, and reputational). Meanwhile, poor episodic memory was shown to be associated with general victimization. As for perpetration, across all four tasks, significant positive associations of relational perpetration with executive function and episodic memory consistently manifested, yet opposite patterns were shown in overt perpetration. Notably, distinct psycho-cognitive patterns were shown among different subtypes. Additionally, victimization was associated with structural brain abnormalities in the bilateral paracentral and posterior cingulate cortex. Furthermore, victimization was associated with brain network disturbances between default mode network and dorsal attention network, between default mode network and fronto-parietal network, and ventral attention network related connectivities, including default mode network, dorsal attention network,

---

*Correspondence:
Xiaoqian Zhang
xiaoqian1211@tsinghua.edu.cn
Runsen Chen
runsenchen@tsinghua.edu.cn
Full list of author information is available at the end of the article

Wen *et al. BMC Medicine*   (2023) 21:141

Page 2 of 12

cingulo-opercular network, cingulo-parietal network, and sensorimotor hand network. Perpetration was also associated with brain network disturbances between the attention network and the sensorimotor hand network.

Conclusions Our findings offered new evidence for the literature landscape by emphasizing the associations of bullying experiences with preadolescents' clinical characteristics and cognitive functions, while distinctive psycho-cognitive patterns were shown among different subtypes. Additionally, there is evidence that these associations are related to neurocognitive brain networks involved in attention control and episodic retrieval. Given our findings, future interventions targeting ameliorating the deleterious effect of bullying experiences on preadolescents should consider their subtypes and utilize an ecosystemic approach involving all responsible parties.

Keywords Bullying, Subtype, Brain network, Suicide, NSSI

Background

Defined as the misuse of power during which one person (perpetrator) engages in repeated aggression against another (victim) that is intentional and involves an imbalance of power [1], peer bullying has adverse psychosocial impacts on participating parties' mental health and [2] cognition [3, 4], with the long-term effect that can persist to later adulthood [5]. Determined by the intention embedded in the perpetrator's actions, peer bullying can be overt, relational, or reputational. Overt perpetration is frequently manifested in the perpetrator's actions to physically damage or threat of such damage to the victim. In contrast, relational perpetration aims to incur relational damage to the victim through harming peer relationships. Similarly, reputational perpetration also aims to inflict damage on the victim emotionally by damaging the victim's reputation among peers [6–9]. To date, the prevalence of peer bullying in school-aged children was 30–60% [10], and the global prevalence was 9–32% [11–13]. It is alarming that the incidence rate of peer bullying has not been declining as expected globally in recent years, although many efforts have been made.

Specifically, ample research evidence has underscored both bullying victimization and peer perpetration as established risk factors for suicide ideation (SI), suicide attempt (SA), and non-suicidal self-injury (NSSI) [14–20], while these associations might be different across subtypes of peer bullying. For instance, previous studies have confirmed the predictive effect of direct victimization (i.e., overt) rather than indirect victimization (i.e., relational, reputational) on SI [9, 21–23], while inconsistent results exist [24, 25]. Meanwhile, according to a meta-analysis, relational victimization is strongly associated with higher risk of SI, while the association with SA is still controversial, and no study has yet found an association between relational victimization and NSSI [26]. Additionally, the predictive role of indirect aggression rather than direct aggression on NSSI among adolescents has been reported [27]. However, it is still worth noting that research on the relationship between bullying subtypes and NSSI and SA remains scarce.

Additionally, as one of the critical neurocognitive functions for building peer relationships [28], individuals' executive function has been considered to be closely related to peer bullying [29–36, 20]. Herein, poor working memory was strongly associated with both bullying victimization and peer perpetration [37–39]. However, it remained unknown whether the same pattern exists in other domains of executive function (e.g., inhibition control, processing speed, emotion working memory) and other memory construct (e.g., episodic memory). Besides, such associations could differ among different subtypes of peer bullying [3]. Indeed, executive function deficits were uniquely associated with physical aggression, while better executive functions were associated with relational aggression [40]. Additionally, inhibition control was found to be significantly positively associated with relational aggression rather than physical aggression [38].

While there has been a strong interest in both the effects of peer victimization and bully perpetration, the related structural and functional brain abnormalities are not well understood. Relevant research is needed since chronic peer victimization during adolescence has already been proven to induce psychopathology-relevant deviations from normative structural brain development [41]. However, the potential association between bullying perpetration and brain structure remains unclear. Additionally, to the best of our knowledge, no research has yet explored their resting-state functional connectivity characteristics. Although a recent neuroimaging meta-analysis had underlined the change in neurobiological characteristics of victims, including altered brain structure and activated regions implicated in processing reward, social pain, emotion processing and regulation, social cognition, and risk-taking [42], there is still a need to observe whether such a change persists in a large sample.

In balance, there has been a dearth of research exploring the unique effects of different subtypes on peer bullying. Such a topic requires more research with large sample sizes, which is crucial for guiding interventions.

Wen *et al. BMC Medicine*   (2023) 21:141

Page 3 of 12

Specifically, the associations between bullying subtypes and preadolescents' self-harm behaviors (i.e., NSSI and SA), executive function, memory, and brain network characteristics need further exploration. Therefore, there are gaps in the existing literature that can be addressed, including elucidating the effects of general and specific peer bullying on preadolescents' suicidality/NSSI, neurocognition, brain structure, and brain function. To bridge these gaps, we aimed to (1) explore the influences of peer bullying and its subtypes on preadolescents' SI, SA, and NSSI; (2) explore the influences of peer bullying and its subtypes on preadolescents' executive function and memory; and (3) elaborate on the neuro-correlates of peer bullying, including brain structure and brain network. We hypothesized that different bullying subtypes might operate under distinct psycho-cognitive patterns in preadolescents. Additionally, given the accumulating evidence of the associations between bullying and abnormal psychological and cognitive functioning, we predicted the associations of bullying with disturbances in functional connectivity between or within neurocognitive brain networks.

Methods

Participants

We included data from the Adolescent Brain and Cognitive Development^{SM} Study (ABCD Study$^®$) "Curated Annual Released 4.0 version." Data for all included measures were collected at the 2-year follow-up assessment between July 2018 and January 2021, with the exception of demographic data being collected at baseline. For the origin sample conclude 10,414 participants, while preadolescents with incomplete information about our interested covariates were excluded, and participants with outlier BMI values (below 10 kg/m^2 or above 50 kg/m^2) were also excluded (see detailed information in Additional file 1: Fig. S1) [43]. Furthermore, only one individual from each family was selected at random to remove any possible effects of relatedness between subjects, resulting in a sample size of 5819 participants. Nonresponse analysis was conducted to explore the differences between those who were excluded from analyses and the final sample.

Measurements

Exposures

The Peer Experiences Questionnaire (PEQ) was used to assess whether the child has either experienced overt, relational, or reputational victimization from peers or perpetrated overt, relational, or reputational aggression towards peers [44]. Each of these six domains was scored on a 5-point Likert scale ranging from 1 ("Never") to 5 ("A few times a week"). The specific score of six bullying

subtypes was calculated, and the general victimization score and general perpetration score were further obtained by summing up the domain scores. The present study only used data from the 2-year follow-up from the ABCD database since relevant data were only collected in that year.

Outcomes

Suicidality/NSSI   The child-report version of the suicide module from the computerized Kiddle Schedule for Affective Disorders and Schizophrenia (KSADS, Lifetime version) was used to assess children's past and current SI, NSSI, and SA [45], while past and current diagnoses were collapsed into a single binary measurement.

Neurocognition   The emotional 2-back task was used to access preadolescents' emotional working memory [46]; meanwhile, the NIH Toolbox Flanker task and Pattern Comparison Processing Speed task were used to access preadolescents' attention inhibition and processing speed, with age-corrected standard scores used in final analyses [47]. All these measures have loaded onto a common component indicating the unity of executive function in preadolescents [48]. Besides, the NIH Toolbox Picture Sequence Memory task was further used to assess preadolescents' episodic memory.

Brain structure   All preadolescents underwent structural magnetic resonance imaging (sMRI) according to standardized protocols, while the scanning parameters, pre-processing, and analytical pipelines are described elsewhere [46, 49]. The T1-weighted images acquired from 21 sites were processed at the Data Analysis, Informatics, and Resource Center (DAIRC) of the ABCD study. FreeSurfer v5.3 (http://surfer.nmr.mgh.harvard.edu) was used to process the locally acquired T1-weighted images and to estimate mean cortical thickness (CT), total cortical area (CA), and total cortical volume (CV). According to the Destrieux atlas, the cerebral cortex was parcellated into 74 regions in total [50]. Only scans that passed protocol compliance and quality control were used for corresponding analyses (see Table S1).

Brain network   Twenty minutes of resting-state functional magnetic resonance imaging (rsfMRI) were collected simultaneously. According to the Gordon parcellation accompanied by subcortical and cerebellar atlases, regions of interests (ROIs) were grouped into 12 predefined large-scale networks: (1) eight neurocognitive networks, including cingulo-opercular network (CON), cingulo-parietal network (CPN), default mode network (DMN), dorsal attention network (DAN), frontoparietal

Wen *et al. BMC Medicine*   (2023) 21:141

Page 4 of 12

network (FPN), retrosplenial-temporal network (RTN), salience network (SN), and ventral attention network (VAN), and (2) 4 sensory networks, including auditory network (AUN), sensorimotor hand network (SMH), sensorimotor mouth network (SMM), and visual network (VN) [51]. Then, average time courses between each ROI were calculated, while average pairwise ROI correlations within and between each network were further computed. In total, 78 cortical (66 inter- and 12 intra-network correlations) network correlations were selected in our analyses, which were then calculated using the Fisher *r*-to-*z* transformation. Only scans that passed protocol compliance and quality control were used for corresponding analyses (see Additional file 1: Table S1).

Sociodemographic variables Sociodemographic information, including children's age, sex, race/ethnicity, marital status, parental education level, combined household income, and data acquisition site, were collected. The highest level of parental attained education was selected and recoded into five categories (i.e., Below High School, High School Graduate/GED, Some College, Bachelor Degree, and Postgraduate Degree). Moreover, household income was recoded into three levels (i.e., < 50 K, ≥ 50 K and < 100 K, and ≥ 100 K USD). All these adjustments have been implemented in previous studies [52, 53].

Statistical analysis

All statistical analyses were performed using R (version 4.2.1). The associations of peer bullying (including both the victimization dimension and perpetration dimension) with suicidality/NSSI, neurocognition, and brain development in preadolescents were investigated. Since the dependent variables conclude both binary variables (i.e., SI, NSSI, and SA) and continuous variables (cognitive performances, brain morphometrics, and functional connectivities), generalized linear mixed models were performed using R package glmmTMB (logit link) and lmeTest (identity link) respectively, with data acquisition site modeled as a random intercept [54, 55]. All the continuous variables were standardized, including age, income, education, and BMI. Other categorical variables were dummy coded before being included in the model, including sex, race/ethnicity, marital status, and handedness. The conditional R-square for each model was calculated.

For sMRI analysis, only 4954 scans that passed the quality control were taken into the subsequent analyses. Given no hypotheses regarding lateralized effects, values for the right and left hemispheres were summed in our study. The associations between bullying, peer bullying, and global brain morphometrics were first explored,

including mean CT, total CA, and total CV. Additionally, to determine which regions were associated with peer bullying, 74 (regions) *3 (brain morphometrics, including CT, CA, and CV) linear mixed models were conducted to examine all regions in each modality. To control for multiple testing across regions, false discovery rate (FDR) was further used through R package stats [56]. For brain network analyses, 3830 qualified scans were included. The associations between peer bullying and (1) within-network connectivity for 12 Gordon networks (12 FDR-corrected comparisons) and (2) between-network connectivity (11 FDR-corrected comparisons per network) were examined.

Covariables

For behavior and neurocognition analysis, age, sex, race/ethnicity, BMI, and SES (i.e., marital status, income, and parental highest education) were considered as covariables. For sMRI analysis, handedness and intracranial volume (ICV) were further added as covariates, while handedness and mean motion were further added as covariables in brain network analysis. BMI and SES variables were added as additional covariates in accordance with prior research showing associations of those factors with brain structure and brain network in preadolescents [53, 57–61].

Results

A summary of the sociodemographic characteristics of the analyzed sample can be found in Table 1 and Additional file 1: Table s2. In comparison to those excluded from analyses, the final sample was younger in age and had a lower proportion of females, a lower proportion of racial/ethnic minority status individuals, a higher proportion of household married, and higher parental education.

Association between peer bullying and preadolescents' suicidality/NSSI

First of all, we sought to delineate the association of peer bullying with SI, NSSI, and SA. Both general victimization and general perpetration were found to be negatively associated with higher risks of SI, NSSI, and SA (Table 2). With regard to specific subtypes, all three types of victimization (i.e., overt, relational, reputational) were shown to be associated with higher risks of suicidality/NSSI. Besides, overt perpetration was positively associated with suicidality (including SI and SA), while relational and reputational perpetration performed significant positive associations with NSSI (Fig. 1 and Additional file 1: Table s3).

Wen *et al. BMC Medicine*   (2023) 21:141

Page 5 of 12

Table 1 Demographic characteristics of the analyzed sample and the excluded sample

Characteristic	Final sample (*N* = 5819)	Excluded (*N* = 4595)	*P* value[a]
Age, mean (SD), years	11.9 (0.6)	12.1 (0.7)	< 0·001
Sex			0.046
Male	3098 (53.2)	2355 (51.3)	
Female	2721 (46.8)	2240 (48.7)	
Race/ethnicity			< 0·001
Non-Hispanic White	3347 (57.5)	2255 (49.1)	
Non-Hispanic Black	643 (11.1)	779 (17.0)	
Hispanic	1122 (19.3)	964 (21.0)	
Asian	128 (2.2)	88 (1.9)	
Other	579 (10.0)	509 (11.1)	
Household married			< 0·001
Married	4141 (71.2)	3044 (66.2)	
Unmarried	1678 (28.8)	1485 (32.8)	
Household income			0.093
< 50 k	1590 (27.3)	1097 (29.1)	
≥ 50 k and < 100 k	1718 (29.5)	1051 (27.9)	
≥ 100 k	2511 (43.2)	1618 (43.0)	
Parental highest attained education level[b]			< 0·001
Below High School	211 (3.6)	252 (5.5)	
High School Grad/GED	423 (7.3)	487 (10.6)	
Some College	1412 (24.3)	1208 (26.4)	
Bachelor Degree	1596 (27.4)	1146 (25.0)	
Postgraduate Degree	2177 (37.4)	1490 (32.5)	
BMI, mean (SD)	20.59 (4.84)	20.56 (4.90)	0.811

[a] Differences among two groups were calculated with *t*-tests and χ^2 tests

[b] GED, graduate equivalency degree

Table 2 Associations of peer bullying with suicidality/NSSI and cognition in preadolescents

Predictor		95% CI		
	Estimate	Lower	Upper	*P* value
Suicidality/NSSI[a]				
Suicide ideation				
Victimization	1.79	1.64	1.95	<.001
Perpetration	1.22	1.12	1.33	<.001
Non-suicidal self-injury				
Victimization	1.66	1.50	1.83	<.001
Perpetration	1.30	1.18	1.43	<.001
Suicide attempt				
Victimization	1.74	1.50	2.03	<.001
Perpetration	1.26	1.09	1.45	0.001
Neurocognition[b]				
Flanker task				
Victimization	− 0.005	− 0.036	0.026	0.762
Perpetration	0.040	0.008	0.071	0.013
Picture Sequence Memory task				
Victimization	− 0.044	− 0.075	− 0.014	0.005
Perpetration	0.012	− 0.018	0.043	0.433
Pattern Comparison Processing Speed task				
Victimization	− 0.013	− 0.044	0.019	0.431
Perpetration	0.010	− 0.021	0.042	0.526
Emotion 2-back task				
Victimization	− 0.017	− 0.047	0.012	0.256
Perpetration	0.017	− 0.013	0.047	0.255

[a] Odds radio was reported for binary suicidality/NSSI variables

[b] β coefficient was reported for continuous neurocognition variables

Adjusted for age, sex, race/ethnicity, site, BMI, marital status, income, and parental highest education

Association between peer bullying and preadolescents' neurocognition

Next, the association between peer bullying and cognition was explored. Significant negative associations between general victimization and cognitive performances in the Picture Sequence Memory task were found ($\beta = -0.044$, $P = 0.005$). However, there is a significant positive association between general perpetration and Flanker task scores ($\beta = 0.040$, $P = 0.013$). Notably, across all four tasks, significant positive associations between relational perpetration and better executive function and episodic memory were consistently shown ($P < 0.05$), while opposite patterns were shown in overt perpetration (Fig. 1 and Additional file 1: Table s4).

Association between peer bullying and preadolescents' brain structure

We also elucidated the brain structures of peer bullying. We found a significant negative association between victimization and bilateral CT in the paracentral lobule and

sulcus ($\beta = -0.052$, $P_{fdr} = 0.047$) and an approximately significant positive association between victimization and bilateral CA in the posterior dorsal part of the cingulate gyrus ($\beta = 0.044$, $P_{fdr} = 0.045$), as shown in Fig. 2 and Additional file 1: Table s5.

Association between peer bullying and preadolescents' brain network

Specific network-level connectivity patterns were shown to be significantly associated with both victimization and perpetration. Notably, victimization seems to be associated with functional connectivity between DMN and DAN ($\beta = 0.048$, $P_{fdr} = 0.022$) and between DMN and FPN ($\beta = 0.050$, $P_{fdr} = 0.024$). Five functional connectivity related to VAN have also shown to be associated with victimization, including (1) DMN ($\beta = -0.065$, $P_{fdr} = 0.004$); (2) DAN ($\beta = 0.041$, $P_{fdr} = 0.045$); (3) CON ($\beta = 0.051$, $P_{fdr} = 0.018$); and (4) CPN (ventral: $\beta = -0.057$, $P_{fdr} = 0.012$). The functional connectivity between the
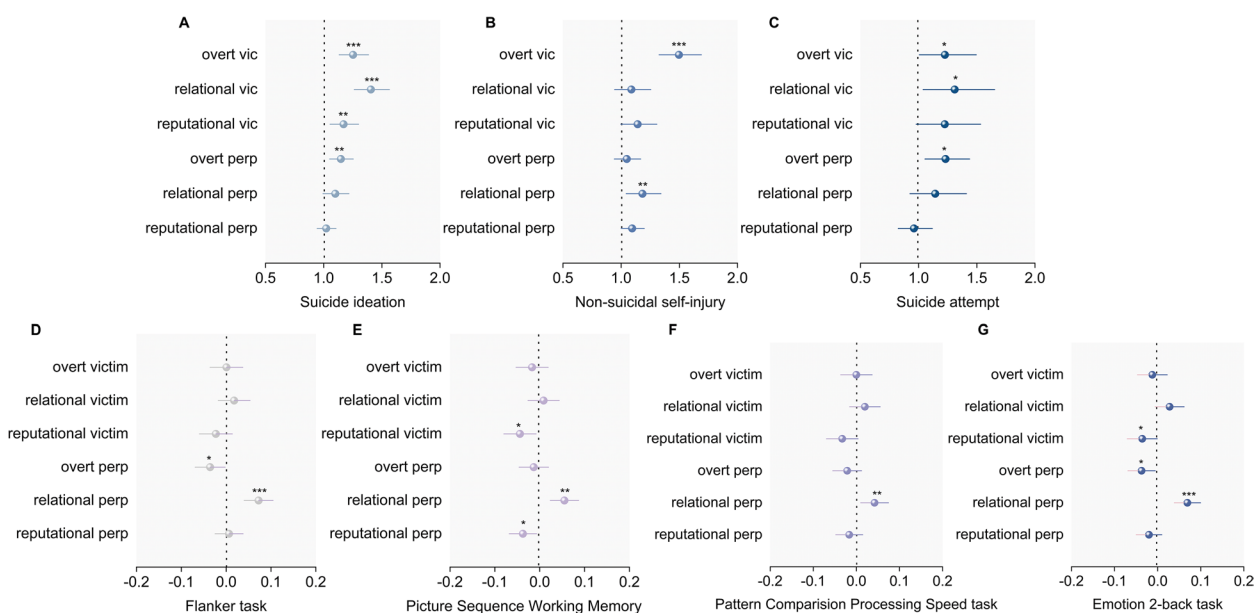
Fig. 1 Associations of bullying subtypes with suicidality/NSSI and neurocognition in preadolescents. Adjusted for age, sex, race/ethnicity, site, BMI, marital status, income, and parental highest education. (1) **A**–**C** Odds radio was reported for binary suicidality/NSSI variables; (2) **D**–**G** coefficient was reported for continuous cognitive variables. vic, victimization; perp, perpetration
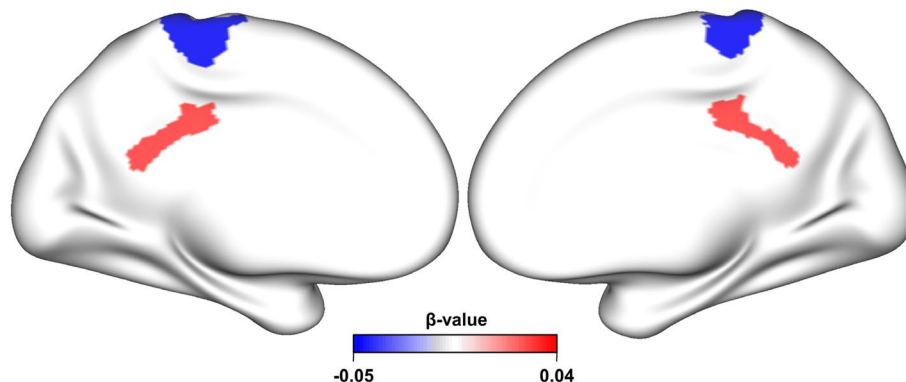

Fig. 2 Association of brain structure with victimization. After adjusting for age, sex, race/ethnicity, site, handedness, BMI, SES, and ICV, victimization was found to be positively associated with total cortical area of bilateral posterior dorsal part of the cingulate gyrus, while negatively associated with mean cortical thickness of bilateral paracentral lobule and sulcus

VAN and SMH was associated with both victimization ($\beta = 0.045$, $P_{fdr} = 0.044$) and perpetration ($\beta = -0.056$, $P_{fdr} = 0.015$) while in the opposite direction. Besides, perpetration was also found to be associated with other SMH-related function connectivities, including CON ($\beta = 0.053$, $P_{fdr} = 0.015$) and CPN ($\beta = 0.059$, $P_{fdr} = 0.015$), as shown in Fig. 3 and Additional file 1: Table s6).

Discussion

This is the first study investigating the effects of peer bullying and its subtypes on preadolescents' suicidality/NSSI, executive function and memory, brain structure, and brain network with a large sample size. Our findings

provided four clinically informative insights on (1) higher risk of SI, NSSI, and SA associated with bullying perpetration/peer victimization and their subtypes (i.e., overt, relational, and reputational) in preadolescents; (2) association between poor episodic memory and victimization, especially for reputation victimization; (3) association between better executive function and general perpetration, yet distinct pattern between overt perpetration and relational perpetration; (4) associations of victimization with structural brain abnormalities in the bilateral paracentral cortex and posterior cingulate cortex; (5) associations of victimization with brain network disturbances between DMN and DAN, between DMN and FPN, and
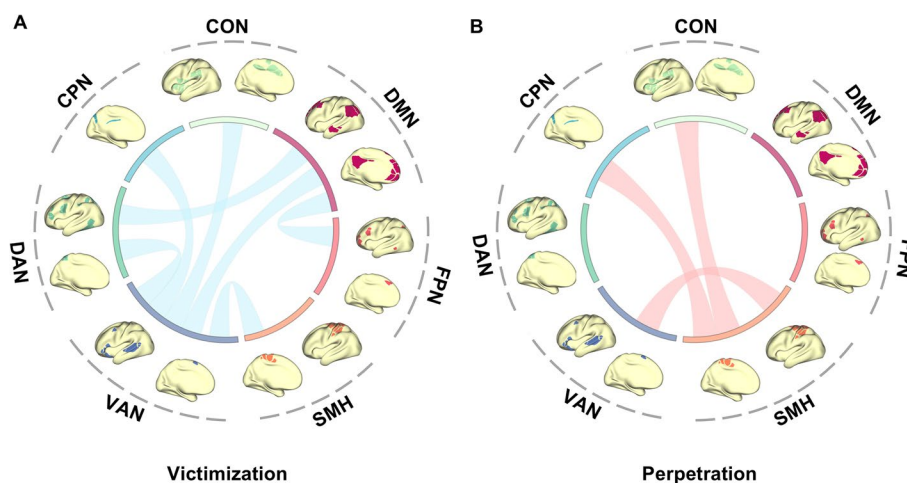
Fig. 3 Associations of resting-state functional connectivity with victimization and perpetration. **A.** After adjusting for age, sex, race/ethnicity, site, handedness, and mean motion, significant associations between victimization and DMN-FPN, DMN-DAN, VAN-DMN, VAN-DAN, VAN-CPN, VAN-CON, and VAN-SMH were found. **B.** As for perpetration, significant associations were found in SMH-CON, SMH-VAN, SMH-CPN (DMN, default mode network; FPN, fronto-parietal network; SMH, sensorimotor hand network; VAN, ventral attention network; DAN, dorsal attention network; CPN, cingulo-parietal network; CON, cingulo-opercular network)

VAN-related functional connectivities (i.e., DMN, DAN, CON, CPN, and SMH); and (6) associations of perpetration with brain network disturbances between VAN and SMH.

Peer bullying and mental health development

Our study found the positive associations of all types of victimization on preadolescents' suicidality, which is largely consistent with previous studies [26]. Notably, relational victimization was only associated with self-harm behaviors with suicide intention, suggesting the relationship between relational victimization and SA might be primarily driven by increased odds of SI. Relatively, only overt perpetration showed an association with suicidality. It may be the case that the victim's responses might reinforce the perpetrator's overt aggressive behaviors (e.g., retaliation, crying, or withdrawing) [62, 63], which could impose worse impacts on preadolescents. Besides, previous research has consistently shown that individuals' self-harm and other-harm behaviors (i.e., aggressive behaviors) co-occur across various populations (known as "dual-harm") [64, 65], and those who performed dual-harm exhibit significantly higher levels of psychopathology [66]. Additionally, indirect perpetration (i.e., relational, reputational) has been shown to be associated with NSSI in our study, which mirrored a previous study [27]. This might be explained by the transition of aggression strategy with age, as children develop in their social understanding and social ability. One possible piece of evidence could be the increased tendency for indirect aggression and decreased tendency for overt aggression in children when they grow up [67].

Peer bullying and neurocognition development

The association between general victimization and lower executive function was not found in our study, which is inconsistent with a recent study also conducted using ABCD data [20]. This might due to the differences in the way bullying was measured, as parent-reported dichotomous victimization (yes or no) variable based on KSADS was used in Menken et al.'s study, whereas continuous victimization and perpetration variables measured by total score of 18 items in the self-reported PEQ questionnaire were used in our study, and we included both victimization and perpetration in the GLMM model in order to obtain a clearer picture of the relationship between peer bullying and children's developmental outcomes. However, reputation victimization has shown to be associated with impaired working memory according to our findings. Our findings also confirmed the association between general victimization and preadolescents' poor episodic memory, especially for reputational victimization. Rumination may play a crucial role in this association, as it disrupts adolescents' episodic memory, [68] and adolescents with rumination tend to behave in a clingy, needy, yet hostile manner, which creates a breeding ground for reputational victimization [69].

Additionally, general perpetration was found to be associated with better executive function. Compared to the negative association between overt perpetration and neurocognition, relational perpetration has performed positive association with better episodic memory (Picture Sequence Memory task) and executive function, including inhibition (Flanker task), processing speed (Pattern

Wen *et al. BMC Medicine*   (2023) 21:141

Page 8 of 12

Comparison Processing Speed task), and emotion working memory (Emotion 2-back task). Indeed, substantial heterogeneity of this association has been observed across studies due to methodological issues, such as small sample sizes, age differences in the target group, and the selection of covariates [3, 37–40]. To the best of our knowledge, this is the first large-population study to examine the associations of executive function and memory with all subtypes of peer bullying in preadolescents. As shown in the previous study, relational perpetration was considered as a more cognitively engaged and covert way of expressing aggression [70], while preadolescents with relational perpetration performed higher social information processing and social intelligence [71, 72]. Therefore, to achieve their goal wisely and successfully, relational perpetrators not only need to be flexible in using their social skills but also need to reasonably inhibit their immediate aggressive impulses, which might explain their better executive function and episodic memory. Otherwise, individuals with better neurocognition skills might also tend to choose relational perpetration rather than overt perpetration to reach a higher social hierarchy and gather more social capital among peers.

Peer bullying and brain development

Our further work extended the psycho-cognitive characteristics of peer bullying by elucidating its brain signatures. Victimization has been shown to be associated with structural abnormalities of both the paracentral cortex and posterior cingulate cortex (PCC). At the same time, victimization was richly associated with functional connectivities between several neurocognitive networks (e.g., DMN, DAN, VAN), which might serve as a common biomarker for vulnerability to mental disorders [73–75]. Accumulating evidence reveals the association of suicide with the structural and functional abnormalities of the PCC, forming a key hub for cognitive control and serving as a crucial part of the DMN [76–78]. Indeed, as shown in previous research, DMN has been considered to play an important role in episodic retrieval, regulating internally directed cognition (e.g., future imaging events), and self-referential processing [79, 78, 80]. Additionally, FPN might aid the memory retrieve process by representing retrieval targets and prioritizing relevant environmental cues [79, 81]. Notably, interactivity between DMN and FPN was found to be associated with episodic retrieval [79, 82]. Current study suggests that victimization was strongly associated with functional connectivity between DMN and FPN, similar to a recent study suggesting the association of gamma connectivity between DMN and FPN with suicide risk [83]. Thus, the association between impaired episodic memory and victimization might be closely related to disturbed functional connectivity

between DMN and FPN. Meanwhile, the DMN-DAN anticorrelation presented optimal allocation of the cognitive resource by the brain and thus was always considered a helpful property in the human brain [84]. However, decreased DMN-DAN anticorrelation was linked to multiple neurological and psychiatric disorders [85–89]. Combined with the decreased DMN-DAN anticorrelation discovered in our study, it might partially explain suicidality/NSSI and neurocognition deficits associated with victimization.

Notably, the current study highlights the associations of victimization with disrupted interaction related to the VAN and DMN, DAN, CON, CPN, and SMH. As shown in the previous study, impaired attention network function was associated with psychopathology in children since functional connectivities between VAN and DAN, CON were found to be significantly associated with children's social, thinking, and attention difficulties [90]. Additionally, among children with a history of depression or anxiety, abnormal attention network functioning was found to be closely related to their "attention bias" (i.e., changes in attention to stimuli of negative valence) but not to their current psychopathological symptoms [91]. Meanwhile, such "attention bias" was also shown to be associated with children's suicide risk or NSSI behavior [92–94]. Additionally, the CPN has been consistently shown to be associated with executive function [95]. Thus, the neurobiological basis underlying the associations between executive function deficits and victimization might be the disturbed functional connectivities between VAN and CPN.

The above findings imply that the impaired interaction of the VAN might explain higher risks of suicidal behaviors and executive function deficits related to victimization. As opposed to victimization, perpetration is negatively associated with functional connectivity between VAN and SMH. Back to the nature of the emergence of aggressive behaviors, according to the social information processing (SIP) model, the perpetrator's aggressive behaviors might stem from cognitive distortions in the processing of social information, especially for the encoding of information [96–99]. However, the hostile pattern inherent in aggressive preadolescents would direct their attention to non-hostile cues that are inconsistent with the pattern, preventing further processing and recalling of such information, which could eventually lead to their aggressive behaviors [100]. The dynamic regulation of attention involved in this process requires the recruitment of multiple attentional networks, and VAN was considered to play a crucial role in detecting the pattern-relevant salient cues [101]. Thus, it is reasonable to infer that the negative association of the functional connectivity between VAN and SMH

Wen *et al. BMC Medicine* (2023) 21:141

Page 9 of 12

with perpetration might explain perpetrators' particular "attention bias" (i.e., abnormal social information processing), thereby explaining their aggressive behaviors. The results of the current study provided a novel neurobiological basis for preadolescent victims and perpetrators underlying their behavioral mechanisms.

A few methodological limitations should be taken into consideration. Firstly, ABCD does not differentiate by specific age of bullying exposure, and only self-reported information about peer bullying was collected. Future studies should use more detailed assessments and consider incorporating information reported from other vital sources from various aspects of preadolescents' life, such as peers, parents, and teachers. Secondly, although the American Community Survey post-stratification weights data in the wave of 2-year follow-up was not provided by ABCD, it should be considered in further analysis to avoid the biased estimates of sociodemographic characteristics of the sample. Thirdly, the associations of other meaningful variables like early life adversities and psychopathology (e.g., internalizing/externalizing problems) with peer bullying could be further explored in future studies [102, 103]. Finally, future research should incorporate more influential protective factors into the model to gain more accurate assessments of the impact of per-time bullying on preadolescents.

Despite these limitations, our study underscores that future interventions should consider the distinct psycho-cognitive patterns among bullying subtypes, and subdividing the target group into different subtypes may be necessary for enhancing the efficacy of traditional intervention programs. Specifically, cognitive training interventions that directly target executive function deficits may hold promise for addressing overt perpetration. Nevertheless, these approaches are unlikely to help preadolescents with relational perpetration due to their good executive function skills. Instead, interventions may need more effort into channeling their high cognitive skills for prosocial behaviors. Moreover, the differences among bullying subtypes should be considered to optimize anti-bullying intervention programs in schools and to benefit their early prevention. For instance, implementing a new curriculum (including videotapes and lectures) for students about the adverse impacts of bullying and its subtypes to promote attitudes against all forms of bullying and prosocial behaviors [104]. Meanwhile, training about corresponding handling strategies should also be given to teachers and other school staff to offer timely help and give extra attention to those who participated in bullying to reduce the adverse effects of the bullying experience on their suicidality/NSSI, neurocognition, and brain development.

Conclusions

Overall, peer bullying had a pervasive effect on preadolescents' suicidality/NSSI, cognitive functions, brain structure, and brain function. Meanwhile, different bullying subtypes presented distinct psycho-cognitive patterns among preadolescents. As the observations in the ABCD cohort continue to accumulate, the longitudinal effects of peer bullying and its subtypes on preadolescents' behavioral- and neural- development could be further elucidated.

Abbreviations

ABCD	Adolescent Brain Cognitive Development
AUN	Auditory network
BMI	Body mass index
CA	Cortical area
CON	Cingulo-opercular network
CPN	Cingulo-parietal network
CT	Cortical thickness
CV	Cortical volume
DAN	Dorsal attention network
DMN	Default mode network
FPN	Frontoparietal network
KSADS	Kiddle Schedule for Affective Disorders and Schizophrenia
NSSI	Non-suicidal self-injury
PEQ	Peer Experience Questionnaire
rsfMRI	Resting-state functional magnetic resonance imaging
RTN	Retrosplenial-temporal network
SA	Suicide attempt
SES	Socioeconomic status
SI	Suicide ideation
SMH	Sensorimotor hand network
SMM	Sensorimotor mouth network
sMRI	Structural magnetic resonance imaging
SN	Salience network
VAN	Ventral attention network
VN	Visual network

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-023-02808-8.

> **Additional file 1: Table S1.** ABCD data release 4.0 variables used in current analysis. **Figure S1.** Flowchart indicating exclusions for primary analyses. **Table S2.** Demographic characteristics of the analyzed samples. **Table S3.** Associations of peer bullying subtypes with suicidality/NSSI in preadolescents. **Table S4.** Associations of peer bullying subtypes with cognition in preadolescents. **Table S5.** Associations between peer bullying and brain structure. **Table S6.** Associations between peer bullying and brain network.

and U24DA041147. A full list of supporters is available at https://abcdstudy.org/federal-partners.html. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/principal-investigators/. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in the analyses or writing of this report. This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH or ABCD consortium investigators. The ABCD repository grows and changes over time. The ABCD data used in this report came from http://dx.doi.org/10.15154/1523041. DOIs can be found at nda.nih.gov.

Authors' contributions
CRS, WX, and ZXQ were responsible for the conception, organization, and execution of the study. WX, SYN, and QDY were responsible for the statistical analyses. WX were responsible for the manuscript preparation. WX, SYN, and QDY were responsible for the manuscript revision. CRS, ZXQ, and CZX were responsible for project supervision. All authors read and approved the final manuscript. All authors had full access to all the data in the study and confirmed their responsibility for the decision to submit it for publication.

Funding
The authors declare that they have no funding.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
In the ABCD study, written informed consent from caregivers and verbal assent from children were obtained. All procedures received approval from the centralized institutional review board (IRB) from the University of California, San Diego, and each study site obtained approval from its local IRB (e.g., Washington University in St. Louis) (https://www.sciencedirect.com/science/article/pii/S1878929317300622). In the Danish national study, the study was approved by the Data Protection Agency (record number 2013–41–2569). By Danish law, no informed consent is required for a register-based study of anonymized data.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
¹Vanke School of Public Health, Tsinghua University, Beijing 100084, China. ²Institute for Healthy China, Tsinghua University, Beijing, China. ³Chinese Institute for Brain Research, Beijing 102206, China. ⁴Department of Psychiatry, Tsinghua University Yuquan Hospital, Beijing, China.

References
1. Gladden RM, Vivolo-Kantor AM, Hamburger ME, Lumpkin CD. Bullying surveillance among youths: uniform definitions for public health and recommended data elements, version 1.0. 2014.
2. Klomek AB, Sourander A, Elonheimo H. Bullying by peers in childhood and effects on psychopathology, suicidality, and criminality in adulthood. Lancet Psychiatry. 2015;2:930–41.
3. Crothers LM, Kolbert JB, Schmitt AJ, Wells DS, Meidl C, Berbary C, et al. Cognitive predictors of relational and social bullying, overt aggression, and interpersonal maturity in a late adolescent female sample. Int J Bullying Prev. 2019;1:136–46.
4. Kellij S, Lodder G, van den Bedem N, Güroğlu B, Veenstra R. The social cognitions of victims of bullying: a systematic review. Adolesc Res Rev. 2022;7:1–48.
5. Wolke D, Lereya ST. Long-term effects of bullying. Arch Dis Child. 2015;100:879–85.
6. Casper DM, Card NA. Overt and relational victimization: a meta-analytic review of their overlap and associations with social–psychological adjustment. Child Dev. 2017;88:466–83.
7. Nansel TR, Overpeck M, Pilla RS, Ruan WJ, Simons-Morton B, Scheidt P. Bullying behaviors among US youth: prevalence and association with psychosocial adjustment. JAMA. 2001;285:2094–100.
8. Nansel TR, Craig W, Overpeck MD, Saluja G, Ruan WJ. Cross-national consistency in the relationship between bullying behaviors and psychosocial adjustment. Arch Pediatr Adolesc Med. 2004;158:730–6.
9. Dempsey AG, Haden SC, Goldman J, Sivinski J, Wiens BA. Relational and overt victimization in middle and high schools: associations with self-reported suicidality. J Sch Violence. 2011;10:374–92.
10. Card NA, Hodges EV. Peer victimization among schoolchildren: correlations, causes, consequences, and considerations in assessment and intervention. Sch Psychol Q. 2008;23:451.
11. Huang H, Hong JS, Espelage DL. Understanding factors associated with bullying and peer victimization in Chinese schools within ecological contexts. J Child Fam Stud. 2013;22:881–92.
12. Pouwels JL, Souren PM, Lansu TA, Cillessen AH. Stability of peer victimization: a meta-analysis of longitudinal research. Dev Rev. 2016;40:1–24.
13. Jadambaa A, Thomas HJ, Scott JG, Graves N, Brain D, Pacella R. Prevalence of traditional bullying and cyberbullying among children and adolescents in Australia: a systematic review and meta-analysis. Aust N Z J Psychiatry. 2019;53:878–88.
14. Giletta M, Prinstein MJ, Abela JR, Gibb BE, Barrocas AL, Hankin BL. Trajectories of suicide ideation and nonsuicidal self-injury among adolescents in mainland China: Peer predictors, joint development, and risk for suicide attempts. J Consult Clin Psychol. 2015;83:265.
15. Holt MK, Vivolo-Kantor AM, Polanin JR, Holland KM, DeGue S, Matjasko JL, et al. Bullying and suicidal ideation and behaviors: a meta-analysis. Pediatrics. 2015;135:e496–509.
16. Serafini G, Aguglia A, Amerio A, Canepa G, Adavastro G, Conigliaro C et al. The relationship between bullying victimization and perpetration and non-suicidal self-injury: a systematic review. Child Psychiatry Hum Dev. 2021:1–22.
17. Vergara GA, Stewart JG, Cosby EA, Lincoln SH, Auerbach RP. Non-suicidal self-injury and suicide in depressed adolescents: impact of peer victimization and bullying. J Affect Disord. 2019;245:744–9.
18. Claes L, Luyckx K, Baetens I, Van de Ven M, Witteman C. Bullying and victimization, depressive mood, and non-suicidal self-injury in adolescents: the moderating role of parental support. J Child Fam Stud. 2015;24:3363–71.
19. Arnon S, Brunstein Klomek A, Visoki E, Moore TM, Argabright ST, DiDomenico GE, et al. Association of cyberbullying experiences and perpetration with suicidality in early adolescence. JAMA Netw Open. 2022;5:e2218746.
20. Menken MS, Isaiah A, Liang H, Rivera PR, Cloak CC, Reeves G, et al. Peer victimization (bullying) on mental health, behavioral problems, cognition, and academic performance in preadolescent children in the ABCD Study. Front Psychol. 2022;13:5750.
21. Bonanno RA, Hymel S. Cyber bullying and internalizing difficulties: above and beyond the impact of traditional forms of bullying. J Youth Adolesc. 2013;42:685–97.
22. Heilbron N, Prinstein MJ. Adolescent peer victimization, peer status, suicidal ideation, and nonsuicidal self-injury: examining concurrent and longitudinal associations. Merrill-Palmer Q Wayne State Univ Press. 2010;56:388.
23. Van der Wal MF, De Wit CA, Hirasing RA. Psychosocial health among young victims and offenders of direct and indirect bullying. Pediatrics. 2003;111:1312–7.
24. Stewart JG, Valeri L, Esposito EC, Auerbach RP. Peer victimization and suicidal thoughts and behaviors in depressed adolescents. J Abnorm Child Psychol. 2018;46:581–96.
25. Tsypes A, Gibb BE. Peer victimization mediates the impact of maternal depression on risk for suicidal ideation in girls but not boys: a prospective study. J Abnorm Child Psychol. 2015;43:1439–45.

Wen *et al. BMC Medicine*   (2023) 21:141

Page 11 of 12

26. Cheek SM, Reiter-Lavery T, Goldston DB. Social rejection, popularity, peer victimization, and self-injurious thoughts and behaviors among adolescents: a systematic review and meta-analysis. Clin Psychol Rev. 2020;82:101936.

27. Tang J, Ma Y, Guo Y, Ahmed NI, Yu Y, Wang J. Association of aggression and non-suicidal self injury: a school-based sample of adolescents. PLoS One. 2013;8:e78149.

28. Holmes CJ, Kim-Spoon J, Deater-Deckard K. Linking executive function and peer problems from early childhood through middle adolescence. J Abnorm Child Psychol. 2016;44:31–42.

29. Coolidge FL, DenBoer JW, Segal DL. Personality and neuropsychological correlates of bullying behavior. Personal Individ Differ. 2004;36:1559–69.

30. Monks CP, Smith PK, Swettenham J. Psychological correlates of peer victimisation in preschool: social cognitive skills, executive function and attachment profiles. Aggress Behav Off J Int Soc Res Aggress. 2005;31:571–88.

31. Verlinden M, Veenstra R, Ringoot AP, Jansen PW, Raat H, Hofman A, et al. Detecting bullying in early elementary school with a computerized peer-nomination instrument. Psychol Assess. 2014;26:628.

32. Medeiros W, Torro-Alves N, Malloy-Diniz LF, Minervino CM. Executive functions in children who experience bullying situations. Front Psychol. 2016;7. https://doi.org/10.3389/fpsyg.2016.01197.

33. Liu TL, Guo NW, Hsiao RC, Hu HF, Yen CF. Relationships of bullying involvement with intelligence, attention, and executive function in children and adolescents with attention-deficit/hyperactivity disorder. Res Dev Disabil. 2017;70:59–66.

34. Potard C, Henry A, Pochon R, Kubiszewski V, Combes C, Brouté V, et al. Sex differences in the relationships between school bullying and executive functions in adolescence. J Sch Violence. 2021;20:483–98.

35. Wolke D, Baumann N, Strauss V, Johnson S, Marlow N. Bullying of preterm children and emotional problems at school age: cross-culturally invariant effects. J Pediatr. 2015;166:1417–22.

36. Bonilla-Santos G, Gantiva C, González-Hernández A, Padilla-García T, Bonilla-Santos J. Emotional processing in bullying: an event-related potential study. Sci Rep. 2022;12:1–8.

37. McQuade JD, Murray-Close D, Shoulberg EK, Hoza B. Working memory and social functioning in children. J Exp Child Psychol. 2013;115:422–35.

38. Poland SE, Monks CP, Tsermentseli S. Cool and hot executive function as predictors of aggression in early childhood: differentiating between the function and form of aggression. Br J Dev Psychol. 2016;34:181–97.

39. Waller R, Hyde LW, Baskin-Sommers AR, Olson SL. Interactions between callous unemotional behaviors and executive function in early childhood predict later aggression and lower peer-liking in late-childhood. J Abnorm Child Psychol. 2017;45:597–609.

40. McQuade JD, Breaux RP, Miller R, Mathias L. Executive functioning and engagement in physical and relational aggression among children with ADHD. J Abnorm Child Psychol. 2017;45:899–910.

41. Quinlan EB, Barker ED, Luo Q, Banaschewski T, Bokde AL, Bromberg U, et al. Peer victimization and its impact on adolescent brain development and psychopathology. Mol Psychiatry. 2020;25:3066–76.

42. Ke T, De Simoni S, Barker E, Smith P. The association between peer-victimisation and structural and functional brain outcomes: a systematic review. JCPP Adv. 2022;2. https://doi.org/10.1002/jcv2.12081.

43. Rapuano KM, Laurent JS, Hagler DJ Jr, Hatton SN, Thompson WK, Jernigan TL, et al. Nucleus accumbens cytoarchitecture predicts weight gain in children. Proc Natl Acad Sci. 2020;117:26977–84.

44. Prinstein MJ, Boergers J, Vernberg EM. Overt and relational aggression in adolescents: social-psychological adjustment of aggressors and victims. J Clin Child Psychol. 2001;30:479–91.

45. Kaufman J, Birmaher B, Brent D, Rao U, Flynn C, Moreci P, et al. Schedule for affective disorders and schizophrenia for school-age children-present and lifetime version (K-SADS-PL): initial reliability and validity data. J Am Acad Child Adolesc Psychiatry. 1997;36:980–8.

46. Casey BJ, Cannonier T, Conley MI, Cohen AO, Barch DM, Heitzeg MM, et al. The Adolescent Brain Cognitive Development (ABCD) study: imaging acquisition across 21 sites. Dev Cogn Neurosci. 2018;32:43–54.

47. Slotkin J, Kallen M, Griffith J, Magasi S, Salsman J, Nowinski C. NIH toolbox. Technical Manual. [Google Scholar]. 2012. https://repository.niddk.nih.gov/media/studies/lookahead/Forms/Look_AHEAD_Cognitive_Function/NIH%20Toolbox%20Scoring%20and%20Interpretation%20Manual%209-27-12.pdf.

48. Thompson WK, Barch DM, Bjork JM, Gonzalez R, Nagel BJ, Nixon SJ, et al. The structure of cognition in 9 and 10 year-old children and associations with problem behaviors: findings from the ABCD study's baseline neurocognitive battery. Dev Cogn Neurosci. 2019;36:100606.

49. Hagler DJ Jr, Hatton S, Cornejo MD, Makowski C, Fair DA, Dick AS, et al. Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. Neuroimage. 2019;202:116091.

50. Destrieux C, Fischl B, Dale A, Halgren E. Automatic parcellation of human cortical gyri and sulci using standard anatomical nomenclature. Neuroimage. 2010;53:1–15.

51. Gordon EM, Laumann TO, Adeyemo B, Huckins JF, Kelley WM, Petersen SE. Generation and evaluation of a cortical area parcellation from resting-state correlations. Cereb Cortex. 2016;26:288–303.

52. Assari S, Islam S. Diminished protective effects of household income on internalizing symptoms among African American than European American pre-adolescents. J Econ Trade Mark Manag. 2020;2:38.

53. Dennis E, Manza P, Volkow ND. Socioeconomic status, BMI, and brain development in children. Transl Psychiatry. 2022;12:33.

54. Brooks ME, Kristensen K, Van Benthem KJ, Magnusson A, Berg CW, Nielsen A, et al. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 2017;9:378–400.

55. Kuznetsova A, Brockhoff PB, Christensen RH. lmerTest package: tests in linear mixed effects models. J Stat Softw. 2017;82:1–26.

56. Noble WS. How does multiple testing correction work? Nat Biotechnol. 2009;27:1135–7.

57. Augustijn MJ, Di Biase MA, Zalesky A, Van Acker L, De Guchtenaere A, D'Hondt E, et al. Structural connectivity and weight loss in children with obesity: a study of the "connectobese." Int J Obes. 2019;43:2309–21.

58. Griffiths LJ, Wolke D, Page AS, Horwood J. Obesity and bullying: different effects for boys and girls. Arch Dis Child. 2006;91:121–5.

59. Rakesh D, Zalesky A, Whittle S. Similar but distinct–Effects of different socioeconomic indicators on resting state functional connectivity: findings from the Adolescent Brain Cognitive Development (ABCD) Study®. Dev Cogn Neurosci. 2021;51:101005.

60. Noble KG, Houston SM, Brito NH, Bartsch H, Kan E, Kuperman JM, et al. Family income, parental education and brain structure in children and adolescents. Nat Neurosci. 2015;18:773–8.

61. Tippett N, Wolke D. Socioeconomic status and bullying: a meta-analysis. Am J Public Health. 2014;104:e48–59.

62. Tapper K, Boulton MJ. Victim and peer group responses to different forms of aggression among primary school children. Aggress Behav. 2005;31:238–53.

63. Patterson GR, Littman RA, Bricker W. Assertive behavior in children: a step toward a theory of aggression. Monogr Soc Res Child Dev. 1967;32:iii–43.

64. Shafti M, Taylor PJ, Forrester A, Pratt D. The co-occurrence of self-harm and aggression: a cognitive-emotional model of dual-harm. Front Psychol. 2021;12:586135.

65. Slade K. Dual harm: the importance of recognising the duality of self-harm and violence in forensic populations. Med Sci Law. 2019;59:75–7.

66. Steinhoff A, Bechtiger L, Ribeaud D, Eisner M, Shanahan L. Self-, other-, and dual-harm during adolescence: a prospective-longitudinal study of childhood risk factors and early adult correlates. Psychol Med. 2022;17:1–9.

67. Nishina A, Juvonen J, Witkow MR. Sticks and stones may break my bones, but names will make me feel sick: the psychosocial, somatic, and scholastic consequences of peer harassment. J Clin Child Adolesc Psychol. 2005;34:37–48.

68. Forner-Phillips NA, Mills C, Ross RS. Tendency to ruminate and anxiety are associated with altered alpha and beta oscillatory power dynamics during memory for contextual details. Cogn Affect Behav Neurosci. 2020;20:698–716.

69. McLaughlin KA, Nolen-Hoeksema S. Interpersonal stress generation as a mechanism linking rumination to internalizing symptoms in early adolescents. J Clin Child Adolesc Psychol. 2012;41:584–97.

70. Heilbron N, Prinstein MJ. A review and reconceptualization of social aggression: adaptive and maladaptive correlates. Clin Child Fam Psychol Rev. 2008;11:176–217.

71. Andreou E. Social preference, perceived popularity and social intelligence: relations to overt and relational aggression. Sch Psychol Int. 2006;27:339–51.

72. Kaukiainen A, Björkqvist K, Lagerspetz K, Österman K, Salmivalli C, Roth-berg S, et al. The relationships between social intelligence, empathy, and three types of aggression. Aggress Behav Off J Int Soc Res Aggress. 1999;25:81–9.

73. Xia CH, Ma Z, Ciric R, Gu S, Betzel RF, Kaczkurkin AN, et al. Linked dimensions of psychopathology and connectivity in functional brain networks. Nat Commun. 2018;9:1–14.

74. Sha Z, Wager TD, Mechelli A, He Y. Common dysfunction of large-scale neurocognitive networks across psychiatric disorders. Biol Psychiatry. 2019;85:379–88.

75. Lees B, Squeglia LM, McTeague LM, Forbes MK, Krueger RF, Sunderland M, et al. Altered neurocognitive functional connectivity and activation patterns underlie psychopathology in preadolescence. Biol Psychiatry Cogn Neurosci Neuroimaging. 2021;6:387–98.

76. Li W, Wang C, Lan X, Fu L, Zhang F, Ye Y, et al. Aberrant dynamic functional connectivity of posterior cingulate cortex subregions in major depressive disorder with suicidal ideation. Front Neurosci. 2022;16:937145.

77. Schmaal L, van Harmelen AL, Chatzi V, Lippard ET, Toenders YJ, Averill LA, et al. Imaging suicidal thoughts and behaviors: a comprehensive review of 2 decades of neuroimaging studies. Mol Psychiatry. 2020;25:408–27.

78. Buckner RL, Andrews-Hanna JR, Schacter DL. The brain's default network: anatomy, function, and relevance to disease. Ann N Y Acad Sci. 2008;1124:1–38.

79. Westphal AJ, Wang S, Rissman J. Episodic memory retrieval benefits from a less modular brain network organization. J Neurosci. 2017;37:3523–31.

80. Andrews-Hanna JR, Reidler JS, Huang C, Buckner RL. Evidence for the default network's role in spontaneous cognition. J Neurophysiol. 2010;104:322–35.

81. Nyhus E, Badre D. Memory retrieval and the functional organization of frontal cortex. In: Addis DR, Barense M, Duarte A, editors. The Wiley handbook on the cognitive neuroscience of memory, 1st edition. Hoboken: Wiley. p. 131–49.

82. Spreng RN, Stevens WD, Chamberlain JP, Gilmore AW, Schacter DL. Default network activity, coupled with the frontoparietal control network, supports goal-directed cognition. Neuroimage. 2010;53:303–17.

83. Dai Z, Shao J, Zhou H, Chen Z, Zhang S, Wang H, et al. Disrupted frontoparietal network and default-mode network gamma interactions distinguishing suicidal ideation and suicide attempt in depression. Prog Neuropsychopharmacol Biol Psychiatry. 2022;113:110475.

84. Kelly AC, Uddin LQ, Biswal BB, Castellanos FX, Milham MP. Competition between functional brain networks mediates behavioral variability. Neuroimage. 2008;39:527–37.

85. Posner J, Cha J, Wang Z, Talati A, Warner V, Gerber A, et al. Increased default mode network connectivity in individuals at high familial risk for depression. Neuropsychopharmacology. 2016;41:1759–67.

86. Pu W, Luo Q, Jiang Y, Gao Y, Ming Q, Yao S. Alterations of brain functional architecture associated with psychopathic traits in male adolescents with conduct disorder. Sci Rep. 2017;7:1–11.

87. Sun L, Cao Q, Long X, Sui M, Cao X, Zhu C, et al. Abnormal functional connectivity between the anterior cingulate and the default mode network in drug-naïve boys with attention deficit hyperactivity disorder. Psychiatry Res Neuroimaging. 2012;201:120–7.

88. Hu ML, Zong XF, Mann JJ, Zheng JJ, Liao YH, Li ZC, et al. A review of the functional and anatomical default mode network in schizophrenia. Neurosci Bull. 2017;33:73–84.

89. Whitfield-Gabrieli S, Fischer AS, Henricks AM, Khokhar JY, Roth RM, Brunette MF, et al. Understanding marijuana's effects on functional connectivity of the default mode network in patients with schizophrenia and co-occurring cannabis use disorder: a pilot investigation. Schizophr Res. 2018;194:70–7.

90. Wainberg M, Jacobs GR, Voineskos AN, Tripathy SJ. Neurobiological, familial and genetic risk factors for dimensional psychopathology in the Adolescent Brain Cognitive Development study. Mol Psychiatry. 2022;27:2731–41.

91. Sylvester CM, Barch DM, Corbetta M, Power JD, Schlaggar BL, Luby JL. Resting state functional connectivity of the ventral attention network in children with a history of depression or anxiety. J Am Acad Child Adolesc Psychiatry. 2013;52:1326–36.

92. Tsypes A, Owens M, Gibb BE. Suicidal ideation and attentional biases in children: an eye-tracking study. J Affect Disord. 2017;222:133–7.

93. Stewart JG, Glenn CR, Esposito EC, Cha CB, Nock MK, Auerbach RP. Cognitive control deficits differentiate adolescent suicide ideators from attempters. J Clin Psychiatry. 2017;78:3157.

94. Demers LA, Schreiner MW, Hunt RH, Mueller BA, Klimes-Dougan B, Thomas KM, et al. Alexithymia is associated with neural reactivity to masked emotional faces in adolescents who self-harm. J Affect Disord. 2019;249:253–61.

95. Niendam TA, Laird AR, Ray KL, Dean YM, Glahn DC, Carter CS. Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. Cogn Affect Behav Neurosci. 2012;12:241–68.

96. Dodge KA, Coie JD. Social-information-processing factors in reactive and proactive aggression in children's peer groups. J Pers Soc Psychol. 1987;53:1146.

97. Crick NR, Dodge KA. A review and reformulation of social information-processing mechanisms in children's social adjustment. Psychol Bull. 1994;115:74.

98. Crick NR, Dodge KA. Social information-processing mechanisms in reactive and proactive aggression. Child Dev. 1996;67:993–1002.

99. Lemerise EA, Arsenio WF. An integrated model of emotion processes and cognition in social information processing. Child Dev. 2000;71:107–18.

100. Horsley TA, de Castro BO, Van der Schoot M. In the eye of the beholder: eye-tracking assessment of social information processing in aggressive behavior. J Abnorm Child Psychol. 2010;38:587–99.

101. Corbetta M, Patel G, Shulman GL. The reorienting system of the human brain: from environment to theory of mind. Neuron. 2008;58:306–24.

102. Chahal R, Miller JG, Yuan JP, Buthmann JL, Gotlib IH. An exploration of dimensions of early adversity and the development of functional brain network connectivity during adolescence: implications for trajectories of internalizing symptoms. Dev Psychopathol. 2022;34:557–71.

103. Luby JL, Baram TZ, Rogers CE, Barch DM. Neurodevelopmental optimization after early-life adversity: cross-species studies to elucidate sensitive periods and brain mechanisms to inform early intervention. Trends Neurosci. 2020;43:744–51.

104. Arseneault L. Annual research review: the persistent and pervasive impact of being bullied in childhood and adolescence: implications for policy and practice. J Child Psychol Psychiatry. 2018;59:405–21.

Publisher's Note