Brain structure is linked to the association between family environment and behavioral problems in children in the ABCD study

Weikang Gong1,9, Edmund T. Rolls2,3,4,5,9, Jingnan Du2,3,9, Jianfeng Feng2,3,4,6,7,8 & Wei Cheng2,3,6✉

Children's behavioral problems have been associated with their family environments. Here, we investigate whether specific features of brain structures could relate to this link. Using structural magnetic resonance imaging of 8756 children aged 9-11 from the Adolescent Brain Cognitive Developmental study, we show that high family conflict and low parental monitoring scores are associated with children's behavioral problems, as well as with smaller cortical areas of the orbitofrontal cortex, anterior cingulate cortex, and middle temporal gyrus. A longitudinal analysis indicates that psychiatric problems scores are associated with increased family conflict and decreased parental monitoring 1 year later, and mediate associations between the reduced cortical areas and family conflict, and parental monitoring scores. These results emphasize the relationships between the brain structure of children, their family environments, and their behavioral problems.
Parental behavior and parent–child relationships play an important role in children's physical, cognitive, and mental development, as well as predicting patterns of future adolescent brain development. Population-based studies have shown that parental behaviors are associated with the prevalence of social, emotional, behavioral problems, and mental illness in the children. Consistent with this, conflict in the family is associated with emotional, behavioral, and social outcome and depression in the children. Parental behaviors and conflict are also associated with the children's cognitive control and risk-taking behaviors, cognitive skills and academic performance, and pubertal timing. Although in many of these studies it is assumed that the parental behavior influences the children's conduct problems, it has also been reported that adolescent conduct problems predicted changes over time in the parental monitoring behaviors, suggesting that parental behavior can potentially be a reaction to and not only a predictor of conduct problems in adolescence.

A substantial body of literature has also documented the link between parental behaviors and brain structure and function in children. One longitudinal study reported that positive maternal parenting can reduce the impact of the neighborhood and socioeconomic disadvantage on the development of brain structure in adolescents. Another study showed that supportive parenting can predict larger hippocampal volume in children. In addition, parental behaviors also have an impact on brain development. For example, adults with a childhood trauma history, such as exposure to major family disturbances, have reduced gray matter volume in prefrontal-limbic brain regions, and an altered structural connectivity across many brain regions including the temporal pole, the insula, and the ventromedial prefrontal cortex. However, most of the previous investigations were only based on small-sized and cross-sectional datasets. In addition, none of the previous neuroimaging studies have compared the association of scores of parental monitoring and family conflict with brain structure in the children. Moreover, how neural differences in the children and their mental health and cognition are related to the family environment have still not been explored comprehensively.

The literature cited above shows that high parental monitoring is associated with reduced social, emotional, and behavioral problems in the children. Parental monitoring was measured in some previous studies with a parent–child interaction task in the present study, parental monitoring was measured by scores on questions such as "How often do your parents/guardians know where you are?" as shown in the Supplementary Material. Conflict in the family and between parents is associated with emotional, behavioral, and social outcomes and depression in children, and with cognitive skills, cognitive control, and academic performance in children. It is not yet fully established whether some of these associations reflect family effects on the children or children's effects on the families. There is also evidence that differences in the brains of the children are related to these associations between the family environment and the children's behavior.

Here, we performed a large-scale investigation of the relationships between family environment (based on self-reported scales of family conflict and parental monitoring that are available within the Adolescent Brain Cognitive Development (ABCD) dataset and are shown in the Supplementary Material) and children's behavioral problems and cognitive scores, and brain structure, using data from 8756 children from the ABCD study. In this study, we set out to answer the following questions: (1) What is the relationship between child reported family conflict scores and parental monitoring scores, and parent-reported behavioral problems as assessed by the Child Behavior Checklist (CBCL) in the children? (2) How often do your parents/guardians know where you are? (3) What are the relations between the family conflict and parental monitoring scores, and the cognitive scores in the children? (4) Using a longitudinal design, are differences after 1 year for the family conflict and parental monitoring scores related to the children's behavioral problem scores 1 year earlier or are associations found in both directions? Both directions were tested, as there is some evidence for effects in different directions in the literature. (5) What is the relationship between scores of family conflict and parental monitoring and brain structure in the children? A voxel-level analysis was performed to assess this, and results are presented in the main text for the area of different cortical regions. The area and volume of cortical regions is strongly correlated in the ABCD dataset, and we chose to present the results for area in the main text and volume in the Supplementary Material

### Results

**Association of family conflict and parental monitoring scores with other behavioral scores.** We first correlated family conflict and parental monitoring scores with a broad range of behavioral measures (listed in Table S1) in the children of the sample, with potential confounds regressed out (see "Methods" section). The CBCL measures for behavioral problems in the children (abcd_cbcl01) were significantly positively correlated with family conflict score (Fig. 1a). Overall, 45 out of 120 items were significant (Bonferroni correction, p < 0.05). Overall, 17 out of the 49 neurocognition measures (abcd_tbsso1) were negatively correlated with higher family conflict scores (Bonferroni corrected, p < 0.05, Fig. 1a). Overall, 31 out of the 45 lifetime mental disorder diagnoses scores based on the KSADS assessment (abcd_ksa01) were significantly associated with the family conflict scores (Table S2). Screen time utilization (e.g., mobile phone, TV, internet, and video games) (abcd_stq01), behavioral inhibition and activation (abcd_bisbas01), mental health (abcd_kmads01, abcd_kkads01, abcd_kmhy02), conduct disorder (abcd_pksad01), impulsivity (abcd_upps01), school, family, social relations (dibf01), and prodromal psychosis levels (ppps01) were all positively correlated with family conflict score (Fig. 1a). The school risk and protective factors (srpp01) were negatively correlated with family conflict score (Fig. 1a). Similar behavioral measures in the children...
were significantly negatively correlated with the parental monitoring scores, that is, low CBCL measures in the children were correlated with high parental monitoring scores (Fig. 1b).

We then estimated the “raw” correlations between the two family environment scores (family conflict and parental monitoring) based on youth surveys, and calculated the correlations with other important parent-related variables based on parent surveys (see “Methods” section). The correlation between the family conflict scores and parental monitoring scores was $-0.23$ ($p = 4.5 \times 10^{-107}$). The correlation of the family conflict scores with the parents’ income was $-0.14$ ($p = 3.8 \times 10^{-25}$), with the parents’ years of education was $-0.11$ ($p = 5.7 \times 10^{-25}$), and with the fathers’ and mothers’ psychiatric history were $0.013$ ($p = 0.23$) and $0.023$ ($p = 0.03$). The correlations of the parental monitoring score with the parents’ income was $0.12$ ($p = 6.5 \times 10^{-28}$), with the parents’ years of education was $0.10$ ($p = 1.3 \times 10^{-19}$), and with the fathers’ and mothers’ psychiatric history were $-0.007$ ($p = 0.51$) and $-0.028$ ($p = 0.01$).
Association between family conflict and parental monitoring scores with child cognitive and behavioral scores. Next, we correlated both family conflict and parental monitoring scores with cognitive scores, and behavioral problems measured with the CBCL, with potential confounds regressed out (see “Methods” section).

The family conflict scores were negatively correlated with all the cognitive scores (Fig. 1c). The range of correlations between the family conflict scores and the cognitive measurements was between −0.02 and −0.08 (Fig. 1c). Thus, children in families with a high family conflict score had poorer cognitive performance. Further, the family conflict scores were positively correlated with all the individual behavioral problems scores in the children with r values ranging from 0.05 to 0.15 (Fig. 1c). Scores for aggressive (r = 0.15), external (r = 0.15), conduct (r = 0.14), and opposition behaviors (r = 0.14) were most significantly correlated with the family conflict scores (Bonferroni corrected, p < 0.05). Children in families with high family conflict scores tended to have higher total behavioral problems scores (r = 0.13, Bonferroni corrected p < 0.05).

The parental monitoring scores were positively correlated with all of the cognitive scores (Fig. 1c). The range of correlations between the parental monitoring scores and cognitive measurements was between 0.03 and 0.09 (Fig. 1c). Thus, children in families with a high parental monitoring score have high cognitive scores. Further correlation analysis also showed that all the behavioral problem scores were negatively correlated with the parental monitoring scores with r values ranging from −0.01 to −0.13 (Fig. 1c). The attention (r = −0.13) and depressive (r = −0.11) problems scores were those most significantly negatively correlated with the parental monitoring scores (Bonferroni corrected, p < 0.05). The children in families with high parental monitoring scores had significantly lower total behavioral problems scores (r = −0.10, Bonferroni corrected p < 0.05).

Family conflict score is associated with lower cortical area, and parental monitoring score is associated with higher cortical area in children. We performed vertex-wise association analysis of cortical areas in the children with both the family conflict scores and parental monitoring scores, with potential confounds regressed out (see “Methods” section).

The total cortical area was significantly negatively correlated with the family conflict scores (r = −0.048, p = 6.2 × 10−6). Specifically, in children with high family conflict scores, vertex-wise analysis showed that the cortical areas were lower of the orbitofrontal cortex, middle temporal gyrus, supratemporal anterior cingulate cortex, and superior prefrontal cortex (FDR corrected, p < 0.05, Fig. 2a).

Total cortical area was significantly positively correlated with the parental monitoring scores (r = 0.038, p = 4.3 × 10−4). Specifically, in children with high parental monitoring scores, vertex-wise analysis showed that the cortical areas were higher of the anterior and posterior cingulate cortex, middle temporal gyrus, angular/supramarginal gyrus, and supplementary motor areas (FDR corrected, p < 0.05, Fig. 2b).

The brain areas correlated with both family conflict and parental monitoring scores are shown in Fig. 2c in yellow, and included the anterior and posterior cingulate cortex, the middle and inferior temporal gyri, and some postcentral and related areas.

In Fig. S1, we show that these associations are robust with respect to random choice of the siblings (see “Methods” section). In Fig. S2, we show the corresponding results for cortical volume, which are consistent with those for cortical area, though the significant regions are less extensive for volume. In Fig. S3, we show that the associations of cortical area and cortical volume with the family environment scores are high (r = 0.75, p < 10−10 for both scores) (Fig. S3A, B), and cortical area and volume themselves also have a high correlation (r = 0.84, p < 10−10), as
also found previously (Fig. S3C). Cortical thickness was not associated with the family conflict and parental monitoring scores (all FDR corrected \( p > 0.05 \)), and for brevity is not described further.

**Longitudinal association between the children’s behavioral problems scores, and the family conflict and parental monitoring scores.** We performed longitudinal association analyses between the children’s behavioral problems (CBCL) scores and the family conflict scores/parental monitoring scores. Structural equation modeling was used to analyze the changes of scores between the baseline ages and 1 year later, with potential confounds regressed out (see “Methods” section). The children’s total behavioral problems scores at the baseline age were significantly associated with increased family conflict (\( \beta = 0.089, p < 10^{-4} \)) and decreased parental monitoring (\( \beta = -0.087, p < 10^{-4} \)) at the 1-year follow-up (Fig. 3a, b). The reverse was less significant for family conflict (\( \beta = 0.025, p = 0.001 \)) and parental monitoring (\( \beta = -0.020, p = 0.013 \)). The permutation test showed that the effect of the association between the children’s behavioral problems scores at the baseline age, and family conflict and parental monitoring at the 1-year follow-up, was significantly higher than the reverse effect (\( p < 0.001 \)). The model accounted for 24% of the variance in the family conflict scores, and 40.4% of the variance in the parental monitoring scores at the 1-year follow-up, by taking into account the children’s total behavioral problems scores at baseline (i.e., 1 year earlier). Most of the individual behavioral problems subscores had significant longitudinal associations as shown in Tables S3 and S4.

### Mediation analysis
In the light of the longitudinal association analyses, which showed a bidirectional effect of child behavioral problems on family conflict, we performed a mediation analysis to test a first hypothesis that the behavioral problems mediated the association between the reduced cortical area and the increased family conflict score. It was found that the children’s behavioral problems total score (CBCL) did significantly mediate the relationship between the cortical areas (shown in Fig. 2a) and the family conflict scores (Fig. 3a, path AB, 14.7% of the total effect size, \( \beta = -0.01; p = 5.6 \times 10^{-11}; 95\% \text{ CI}, -0.014 \text{ to } -0.007 \)). The first hypothesis was thus supported by this analysis. Most of the behavioral problems subscores had significant mediation effects as shown in Table S5.

The second hypothesis was that the children’s behavioral problems scores mediate in part the associations between the increased cortical areas and the higher parental monitoring scores. It was found that the children’s behavioral problems total score did significantly mediate the relationship between the cortical areas (shown in Fig. 2b) and the parental monitoring scores (Fig. 3b, path AB, 12.1% of the total effect size, \( \beta = 0.008; p = 2.4 \times 10^{-9}; 95\% \text{ CI}, 0.006-0.011 \)). The second hypothesis was thus also supported by this analysis. Most of the behavioral problems subscores had significant mediation effects as shown in Table S6. Because the longitudinal analysis showed an effect in both directions between child behavioral problems and parental monitoring, we also tested a mediation model for whether the cortical areas mediate the association between the parental monitoring scores and behavioral problem scores. We found a significant effect as shown in Fig. S4.

### Fig. 3 The longitudinal association and mediation analyses

**a** The longitudinal association between the behavioral problems total score (TotProb CBCL Syndrome Scale) in the children and the family conflict score measured 1 year later using structural equation modeling. Higher behavioral total scores were associated with higher family conflict scores 1 year later (\( p < 10^{-4} \), \( n = 8836 \)), and higher family conflict scores were associated with higher behavioral problems total scores 1 year later (\( p = 0.001 \), \( n = 8836 \)), but less significantly. **b** The longitudinal association between the behavioral problems total score in the children and the parental monitoring score using structural equation modeling. Higher behavioral problems total scores were associated with lower parental monitoring scores 1 year later (\( p < 10^{-4} \), \( n = 8836 \)) (solid diagonal line), and higher parental monitoring scores were associated with lower behavioral problems total scores 1 year later (\( p = 0.013 \), \( n = 8836 \)), but less significantly. **c** Mediation analysis: the indirect path (A, AB, and B) shows that the behavioral problems total score in the children significantly mediates the association between the cortical area in the children and the family conflict scores (\( \beta = -0.01, p = 5.6 \times 10^{-11} \), \( n = 8756, 14.7\% \text{ variance explained} \)). **Path A:** Association between the independent variable (the cortical area) and the mediator (the behavioral problems total score). **Path B:** Association between the mediator (the behavioral problems total score) and the outcome (the family conflict score). **Path C** shows a significant reduction in the regression coefficient between the cortical area and the family conflict score when the mediator (the behavioral problems total score) is included in the model (\( p < 10^{-4} \), \( n = 8756, 14.7\% \text{ variance explained} \)). **Path D**: Association between the mediator (the behavioral problems total score) and the outcome (the family conflict score). **Path E** shows a significant reduction in the regression coefficient between the cortical area and the family conflict score when the mediator (the behavioral problems total score) is included in the model (\( p < 10^{-4} \), \( n = 8756, 14.7\% \text{ variance explained} \)). **Path F**: Association between the mediator (the behavioral problems total score) and the outcome (the family conflict score). **Path G** shows a significant reduction in the regression coefficient between the cortical area and the family conflict score when the mediator (the behavioral problems total score) is included in the model (\( p < 10^{-4} \), \( n = 8756, 14.7\% \text{ variance explained} \)). All statistical tests here are two-sided, and pass Bonferroni correction (\( p < 0.05 \)).
Both of these mediation analyses were performed with data at the baseline time. Potential confounds were regressed out (see “Methods” section). We also tested whether the mediation effect remained if the change of the parents’ psychiatric symptom total score (ABCD Parent Adult Self Report Scores Aseba, abed_assr01) was included as an additional covariate. The results in Fig. S5 show that the mediation models were still significant.

Discussion
This research demonstrates in a large sample the association between the area of certain cortical regions and scores related to family environment, including family conflict and parental monitoring, and shows that the children’s behavioral problems (assessed with the CBCL) mediate the associations between the structure of brain regions and the family problems. Moreover the behavioral problems in the children relate in part to the parental monitoring and the family conflict that are measured 1 year later. The associations involving the area of cortical regions such as the anterior cingulate and orbitofrontal cortex provide evidence about brain regions that are involved in the associations between the children’s behavioral problems and the family conflict and parental monitoring. The findings also raise the importance of measuring and assessing the effects of the children’s behavioral problems on the family, as well as the more traditional concepts of how the parents influence the children.

For clarity, we assess here what the results show about the family conflict scores. The behavioral problems scores of the 8756 children aged 9–11 years were positively correlated with the family conflict scores. The family conflict scores were also correlated with smaller areas of some cortical regions, including the orbitofrontal cortex, middle temporal gyrus, supracallosal anterior cingulate cortex, and superior prefrontal cortex (Fig. 2a). The longitudinal analysis showed that the children’s total behavioral problems scores at the baseline age were significantly associated with increased family conflict at the 1-year follow-up. The reverse was less significant. The childrens’ behavioral problems significantly mediated the association between the lower areas of cortical regions and the increased family conflict scores. The cognitive scores of the children were negatively correlated with the family conflict scores and positively correlated with the parental monitoring scores. Our interpretation of these findings is that behavioral problems mediate effects of reduced cortical areas of some key brain regions including the orbitofrontal and anterior cingulate cortices in the 9–11 years old children on the higher family conflict scores. There is evidence that these brain areas are associated with behavioral problems such as depression31–34. However, we cannot exclude mediation effects in the other direction, such as an effect of the higher family conflict and opposition scores on the children. The parental monitoring scores were positively correlated with low attention problems and low depressive problems scores. High areas of the pregenu anterior cingulate cortex are associated with high parental monitoring (Fig. 2b). This is the part of the cingulate cortex associated with punishment and nonreward, and has correlations with the unpleasantness of stimuli36–39. Low areas of the supracallosal anterior cingulate cortex (middle anterior and middle posterior part of the cingulate gyrus and sulcus) are associated with high family conflict (Fig. 2a). This is the part of the cingulate cortex associated with punishment and nonreward, and has correlations with the unpleasantness of stimuli36,37. We thus propose that these differences between the parental monitoring and the family conflict relate to the different functions of these different parts of the anterior cingulate cortex. Correspondingly, the medial orbitofrontal cortex (involved in reward10–42) had a low area (Fig. 2a) that was associated with family conflict which in turn was associated with behaviors that included aggressive and external behaviors.

We found that cortical thickness was not associated with the family conflict and parental monitoring scores. Consistent with this, it has been reported that cortical area rather than thickness in children is associated with sleep duration and associated cognitive and behavioral problems42, and with lead-exposure risk43. A possible explanation is that the overall regional pattern of cortical thickness is relatively stable from early postnatal life, while the changes of cortical area have more development and changes later46. Other possible explanations are that cortical surface area and cortical thickness have distinct sources of genetic influence44, and that cortical thickness is more polygenic than cortical area45.

The longitudinal analysis showed that the childrens’ behavioral problems score was associated with parental monitoring 1 year later (p < 1 × 10−4). The reverse association was also found, but it was less significant (p = 0.013). The mediation analysis provided evidence that the childrens’ behavioral problems scores mediate the association between increased cortical area in the children and the parental monitoring. Our large-scale longitudinal analysis with 8836 children suggests that high behavioral problems of the children are associated with the family conflict, and low behavioral problems in the children are associated with high parental monitoring. A precedent for thinking that there are at least some effects from the childrens’ behavior to the parents is that a “bidirectional” model may be appropriate, i.e., children influence...
parents and parents influence children\(^\text{46,47}\). For example, it has been suggested that children may deliberately intervene to change parental behaviors, beliefs, and attitudes\(^\text{42}\). We note that the longitudinal cross-lagged panel model (CLPM) accounts for temporal stability through the inclusion of autoregressive parameters and cannot separate effects within and between individuals, so our findings indicate the group average effect, not effects at the individual level\(^\text{48}\).

To further understand the associations described here between the children’s psychiatric problems and the family conflict and parental monitoring, we analyzed whether there are associations between the relatives’ psychiatric history and the behavioral problems in the children. We found that the relatives’ psychiatric history was significantly positively correlated (\(r = 0.14, p = 3 \times 10^{-4}\)) with the children’s total psychiatric problems score. This is consistent with the evidence that there is a genetic component to psychiatric problems in children\(^\text{49,50}\). A possible explanation for our findings is that there is a genetic contribution to brain structure in children that can affect their behavior and cognition, and that these behavioral/psychiatric and cognitive states can influence the family problems and parental monitoring of the family environment. However, we stress that the role of gene–environment interactions is complex\(^\text{51}\), and our study reports associations, and so is not able to assess causality. We also stress that associations between child behavioral problems and parenting or family conflict constructs could reflect a number of possibilities. For example, this could reflect either passive gene–environment interaction, where parents and children share genetic predispositions, or evocative gene–environment interaction, where children’s behavioral problems elicit family conflict. We do emphasize that in all the analyses described here, the parents’ psychiatric history was regressed out, so that possible contribution of genetic effects has been taken into account in the analyses.

Despite these limitations we believe our study has a number of strengths. It includes voxel-level analysis, which allows the exact brain regions to be delineated, rather than large predefined regions as in many investigations of relations involving brain areas. This sample is large, and the ABCD dataset includes many behavioral measures. The children in this dataset are of almost the same age thereby controlling for age. The longitudinal design of the study has enabled us to analyze the relationship between the children’s psychiatric problems and parental monitoring in children were assessed by the ABCD CBCL scores (abcd_cbcls01) based on youth surveys. The first was the family conflict score (les_y_ss_fc_pr) estimated as the average of nine questions from the ABCD Parent Family Environment Scale-Family Conflict Subscale Modified from PhenX (FES, abcd_fes01), which reflects conflict between family members including the parents and children\(^\text{20}07\). A higher family conflict score indicates that there are more severe family conflicts in a child’s family. The second is the parental monitoring score (pmq_y_ss_mean), calculated as the average of the five questions from the ABCD Parental Monitoring Survey (pmq01), which reflects overall high parental monitoring behaviors\(^\text{52}\). The questions for these two scores and the ways they were calculated are included in Supplementary Material. The above two scores were collected at the ABCD baseline time, and the participants were followed up 1 year after the baseline time.

Cognitive scores. Cognitive function was assessed by the ABCD Youth NIH TB Summary Scores (abcd_tbs01) which consists of ten validated and reliable psychometric test scores: Picture Vocabulary Test Score (nihtubx_picvocab); Flanker Inhibitory Control and Attention Test Score (nihtubx_flanker); List Sorting Working Memory Score (nihtubx_list); Dimensional Change Card Sort Test Score (nihtubx_cardsort); Pattern Comparison Processing Speed Test Score (nihtubx_pattern); Picture Sequence Memory Test Score (nihtubx_picture); Oral Reading Recognition Test Score (nihtubx_reading); Cognition Fluid Composite Score (nihtubx_fluidcomp); Crystallized Composite Score (nihtubx_cryst); and Cognition Total Composite Score (nihtubx_totalcomp)\(^\text{57,58}\). A high score means higher cognitive function.

Behavioral problems scores. Dimensional psychopathology and adaptive functioning in children were assessed by the ABCD CBCL scores (abcd_cbcls01) based on parent surveys\(^\text{52}\). It contains 20 empirically based syndrome scales related to behavioral problems: Anxious/Depressed CBCL Syndrome Scale (cbcl_scr_anxdep); Withdrawn/Depressed CBCL Syndrome Scale (cbcl_scr_syn_withdep); Somatic Complaints CBCL Syndrome Scale (cbcl_scr_syn_somatic); Social Problems CBCL Syndrome Scale (cbcl_scr_syn_social); Thought CBCL Syndrome Scale (cbcl_scr_syn_thought); Attention Problems CBCL Syndrome Scale (cbcl_scr_syn_attention); Rule-Breaking Behavior CBCL Syndrome Scale (cbcl_scr_syn_rulebreak); Aggressive Behavior CBCL Syndrome Scale (cbcl_scr_syn_aggressive); Internalizing Problems CBCL Syndrome Scale (cbcl_scr_syn_internal); Externalizing Problems CBCL Syndrome Scale (cbcl_scr_syn_external); TotalProb CBCL Syndrome Scale (cbcl_scr_syn_totprob); Depressive Problems CBCL DSM5 Scale (cbcl_scr_dsm5_depress); Anxiety Problems CBCL DSM5 Scale (cbcl_scr_dsm5_anxiety); Somatic Problems CBCL DSM5 Scale (cbcl_scr_dsm5_somatic); ADHD CBCL DSM5 Scale (cbcl_scr_dsm5_adhd); Oppositional Defiant Problems CBCL DSM5 Scale (cbcl_scr_dsm5_odd); Conduct Problems CBCL DSM5 Scale (cbcl_scr_dsm5_conduct); Sleep Disturbance CBCL DSM5 Scale (cbcl_scr_dsm5_sleep); Social Problems CBCL DSM5 Scale (cbcl_scr_dsm5_social); Sluggish Cognitive Tempo CBCL Scale2007 Scale (cbcl_scr_07_stc); Obsessive–Compulsive Problems CBCL Scale2007 Scale (cbcl_scr_07_osc); and Stress CBCL Scale2007 Scale (cbcl_scr_07_stress). A high score indicates dimensional psychopathology and a more severe behavioral problem in 1/2 of the above 20 scores per 1 year of the baseline time and the participants were followed up 1 year after the baseline time. More details of the behavior assessments used in our analysis are provided in Supplementary Material (Table S1) and also can be found at the ABCD website (https://abcdstudy.org/scientists/protocols/).

Association analysis. A general linear model (GLM) was used to test the associations of the family environment scores (family conflict and parental monitoring) with psychiatric phenotypes. Although a linear mixed effect model was recommended by the ABCD and was used in other studies\(^\text{46,61}\), in the analysis of vertex-wise brain imaging data, the linear mixed effect model was computationally
Mediation analysis. A standard mediation analysis was performed using the Mediation Toolbox developed by Tor Wager’s group (https://github.com/canlab/MediationToolbox), which has been widely used in many neuroimaging studies. A standard three-variable path model was used here, with the detailed methodology description in Supplementary Material of ref. 62. Briefly, mediation analysis tests whether the association between two variables can be explained by a third variable (the mediator). The hypothesis tested here was whether the behavioral problems total score (TotProb CBCL Syndrome Scale) mediated the association between surface areas of the brain and the family conflict score/parental monitoring score. Confounding variables as in the association analysis were regressed out in the mediation model. The significance of the mediation was estimated by the bias-corrected bootstrap approach (with 10,000 random samplings). In this analysis, all brain measurements and behavioral variables were collected at the ABCD baseline time.

Longitudinal association analysis. For the above-mentioned measurements, it was possible to perform a longitudinal analysis using the family conflict scores, or parental monitoring scores, and the behavioral problems total scores that were obtained in the follow-up 1 year after the baseline time. A classic two-wave CLPM based on structural equation modeling was implemented to investigate the longitudinal associations between the family conflict scores or parental monitoring scores and the behavioral problems total scores (66,67). Specifically, the relative strength of the cross-lagged relationships between the behavioral problems total scores and the family conflict scores or the parental monitoring scores all measured at the baseline time with the 1-year follow-up were evaluated by a cross-lagged panel structural model implemented by Mplus (version 7.4)68. Effects in both directions were considered. The model was estimated by using maximum likelihood estimation with robust standard errors that also takes clustering of cases into account. The standardized regression coefficients and standard errors are reported throughout. Confounding variables as in the association analysis were regressed out in the CLPM analysis.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability
Neuroimaging and behavioral data from ABCD dataset are obtained from https://nda.nib.gov/abcd with the approval of the ABCD consortium. A reporting summary for this article is available as a Supplementary Information file.

Code availability
The data preprocessing software FreeSurfer v6.0 can be obtained from https://surfer.nmr.mgh.harvard.edu. Qoola T v2.1 for automatic quality control can be obtained from: https://github.com/Qoola/T/QC. Matlab 2019a was used for the brain and behavioral association analysis. The scripts can be downloaded from a GitHub repository at: https://github.com/weikanggong/ABCD_family_environment. Software for the mediation analysis can be obtained from https://github.com/canlab/MediationToolbox. Software for the CLPM analysis can be obtained from https://www.statmodel.com.

Received: 17 October 2019; Accepted: 26 May 2021; Published online: 18 June 2021
Acknowledgements

Data used in the preparation of this article were obtained from the Adolescent Brain Cognitive Development (ABCD) Study (https://abcdstudy.org), held in the NIMH Data Archive (NDA). This is a multisite, longitudinal study designed to recruit more than 10,000 children age 9–10 years and follow them over 10 years into early adulthood. The ABCD study is supported by the National Institutes of Health and additional federal partners under award numbers U01DA041048, U01DA050987, U01DA041028, U01DA041106, U01DA041117, U01DA041025, U01DA041120, U01DA041022, U01DA051016, U01DA051018, U01DA051037, U01DA050988, U01DA051039, U01DA051038, U01DA051018, U01DA041093, and U01DA041089. 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/Investigators. The authors declare no competing interests.

W.G. and W.C. proposed the study and analyzed the data. All authors considered how to analyze the data and wrote and approved the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41467-021-23994-0.

Peer review information Nature Communications thanks the anonymous reviewer(s) for their contribution to the peer review of this work.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© The Author(s) 2021