Brain Imaging and Behavior
https://doi.org/10.1007/s11682-022-00692-z

ORIGINAL RESEARCH

Mediating role of the default mode network on parental acceptance/warmth and psychopathology in youth

Kaley Davis[1] · Emily Hirsch[2] · Dylan Gee[3] · Margaret Andover[2] · Amy Krain Roy[2]

Accepted: 24 May 2022

Abstract

Humans are reliant on their caregivers for an extended period of time, offering numerous opportunities for environmental factors, such as parental attitudes and behaviors, to impact brain development. The default mode network is a neural system encompassing the medial prefrontal cortex, posterior cingulate cortex, precuneus, and temporo-parietal junction, which is implicated in aspects of cognition and psychopathology. Delayed default mode network maturation in children and adolescents has been associated with greater general dimensional psychopathology, and positive parenting behaviors have been suggested to serve as protective mechanisms against atypical default mode network development. The current study aimed to extend the existing research by examining whether within- default mode network resting-state functional connectivity would mediate the relation between parental acceptance/warmth and youth psychopathology. Data from the Adolescent Brain and Cognitive Development study, which included a community sample of 9,366 children ages 8.9–10.9 years, were analyzed to test this prediction. Results demonstrated a significant mediation, where greater parental acceptance/warmth predicted greater within- default mode network resting-state functional connectivity, which in turn predicted lower externalizing, but not internalizing symptoms, at baseline and 1-year later. Our study provides preliminary support for the notion that positive parenting behaviors may reduce the risk for psychopathology in youth through their influence on the default mode network.

Keywords Default mode network · Parenting · Parent–child relationship · Psychopathology · Neural development

Introduction

Humans rely on their caregivers for a prolonged time, from infancy to young adulthood. Due to this protracted development, numerous opportunities exist for parenting practices to affect diverse systems (Bogin, 1997), including psychosocial, executive functioning, and emotion regulation processes (Beyers & Goossens, 1999; Morris et al., 2017; Steinberg et al., 1989). Consequently, parenting behaviors have been studied for the impact they have on the neural mechanisms underlying these systems (Callaghan & Tottenham, 2016; Farber et al., 2020; Glynn & Baram, 2019). The default mode network (DMN) serves a crucial role in cognitive and social functions (Andrews-Hanna, 2012). Atypical DMN connectivity patterns have been linked with psychopathology across the lifespan (Kim et al., 2016; Uddin et al., 2008; Umbach & Tottenham, 2020; Wise et al., 2017; Zhao et al., 2007). While parental factors and altered DMN connectivity have independently been associated with the emergence of psychopathology, no studies have investigated both factors and their association with child symptoms.

Parental acceptance-rejection theory (PARTheory; Rohner, 1980) highlights the impact of parental warmth on child development. Consistent with this theory, child perceptions of parental warmth and affection are associated with positive psychological outcomes, including greater self-esteem and emotional stability (Khaleque, 2013). Longitudinal studies

✉ Kaley Davis
kaley.davis@marquette.edu

Emily Hirsch
ehirsch4@fordham.edu

Dylan Gee
dylan.gee@yale.edu

Margaret Andover
andover@fordham.edu

Amy Krain Roy
aroy3@fordham.edu

[1] Marquette University, Milwaukee, WI, USA

[2] Fordham University, New York, NY, USA

[3] Yale University, New Haven, CT, USA

Published online: 01 June 2022

show that greater parental warmth is associated with fewer psychopathology symptoms and may attenuate anxiety and depression (Rothenberg et al., 2020; Butterfield et al., 2021). Additionally, lower parental warmth is associated with increased internalizing and externalizing psychopathology (Hipwell et al., 2008; Waller et al., 2018).

Childhood is characterized by periods of high neural plasticity resulting in significant changes and reorganization of neural systems (Huttenlocher & Dabholkar, 1997; Perrin et al., 2008). DMN, which encompasses the medial prefrontal cortex, posterior cingulate cortex, precuneus, and temporal parietal junction, is one such network that matures over the course of development (Wang et al., 2020, Fair et al., 2008; Sato et al., 2014; Uddin et al., 2011). Specifically, these regions demonstrate very low resting-state functional connectivity (RSFC) until ages 7–9 years, increasing with age into young adulthood (Fair et al., 2008; Fan et al., 2021; Sato et al., 2014; Uddin et al., 2011). Delayed DMN maturation, assessed using a resting-state measure of fractional amplitude of low frequency fluctuations, has been associated with greater psychopathology in children and adolescents, as rated on the Child Behavior Checklist (Achenbach & Rescorla, 2014; Sato et al., 2016). Further, a recent study using cross-sectional data from the Adolescent Brain Cognitive Development (ABCD) study found reduced DMN connectivity, suggesting a less mature pattern, associated with greater callous-unemotional traits (Umbach & Tottenham, 2020).

Genetic studies suggest that only an estimated 23% of the functional connectivity of the DMN is heritable, which is lower than other neural networks (Yang et al., 2016). Thus, development of the DMN may be particularly susceptible to environmental factors (Dégeilh et al., 2018; Rebello et al., 2018; Zeev-Wolf et al., 2019). Several studies have examined the effects of early life adversity (e.g., abuse, neglect) on DMN connectivity (Graham et al., 2015; Philip et al., 2013), but these are limited in generalizability because most children do not experience such extreme stressors. All children experience varying levels of both positive and negative parenting behavior. Therefore, examining the impact of normative parenting practices on brain development and youth outcomes has the potential to have a broader impact (Bhanot et al., 2021). Initial evidence supports such associations between normative variations in parenting and the development of DMN connectivity. Adenzato et al. (2019) found that adult participants who reported greater dysfunctional parenting as children showed weaker within-DMN electroencephalography connectivity. Longitudinal work has shown that when maternal parenting during early childhood supports child autonomy, a more mature connectivity pattern, evidenced by stronger negative connectivity between the DMN and salience network, is observed at age 10 (Dégeilh et al., 2018).

There is still much to be explored regarding the effects of positive parenting on within-DMN RSFC and its putative role in mediating the relation between parenting behaviors and emotional and behavioral outcomes in late childhood. The ABCD study offers a unique opportunity to explore these relations in a large, longitudinal, multi-cultural dataset. Here, we predicted that parental acceptance and warmth would be associated with fewer emotional and behavioral problems at baseline and one year later, and that these associations would be mediated by within-DMN RSFC. As connectivity amongst regions in the DMN does not begin until middle childhood (Fair et al., 2008), the age range of the baseline ABCD sample (9–10 years) offers an ideal time to study this network as it is undergoing developmental changes susceptible to environmental factors such as parenting. Child psychological and behavioral problems were assessed broadly based on previous studies showing associations with DMN connectivity (Sato et al., 2016); specific associations with externalizing and internalizing domains were examined. As recommended by a recent review examining associations between DMN development and environmental experiences in childhood, sex differences were also assessed (Rebello et al., 2018).

Methods

Participants

This study utilized baseline and 1-year follow-up data from the publicly available ABCD study (Data Release 4.0; October 2021; http://dx.doi.org/10.15154/1523041). ABCD is a longitudinal, observational study of neuroimaging, environmental, psychological, and biological variables throughout adolescence in over 11,000 individuals nationwide across 22 data collection sites. Comprehensive descriptions of the aims (Jernigan et al., 2018; Volkow et al., 2018), recruitment strategies (Garavan et al., 2018), and procedures (Auchter et al., 2018) have been published elsewhere. All protocols, procedures, and documents across sites have been approved by, and are compliant with, human research protection programs and institutional review board regulations.

To explore the relations among the variables of interest with a dimensional approach, we did not exclude for psychiatric diagnoses, consistent with previous work (Sato et al., 2016). Participants were excluded if they did not have complete neuroimaging ($n = 856$) or survey data ($n = 297$), and siblings were removed at random to ensure the independence of individual observations ($n = 1{,}924$). Following these exclusions, our sample size was reduced from 11,877

to 9,366 youth ages 8.9–10.9 years at baseline and 8,811 youth ages 9.7–12.4 years at 1-year follow-up.

Phenotypic measures

Parental acceptance/warmth were assessed using the Acceptance subscale of the Child's Report of Parent Behavior Inventory (CRPBI-Acceptance), which was shortened from ten to five items for the ABCD study ($\alpha = 0.71$; Barber et al., 1994; Barber, 1997; Schaefer, 1965). Items are scored on a three-point scale, and then averaged for a total score (Range: 1- 3); higher scores indicate greater parental acceptance/warmth. For this project, we analyzed child reports on the study caregiver.

Parents completed the Child Behavior Checklist (CBCL), which assesses emotional and behavioral problems and is normed for sex and age (Achenbach & Rescorla, 2014). Primary analyses used Total Problems T-scores ($\alpha = 0.95$), and exploratory analyses used the Internalizing (i.e., anxiety, depression, and somatic complaints; $\alpha = 0.87$) and Externalizing Problems (i.e., rule-breaking and aggressive behavior; $\alpha = 0.90$) T-scores. For all scales, T-scores below 60 are considered to be in the Normal range, those between 60–63 are considered to be in the Borderline Clinical range, and those above 63 are considered to be in the Clinical range (Achenbach & Rescorla, 2014).

Neuroimaging acquisition and preprocessing

Participants completed the magnetic resonance imaging (MRI) portion of the baseline visits for the ABCD study across sites using one of three 3.0 Tesla scanners (Siemens Prisma, General Electric [GE] 750 and Philips) that utilized multi-channel coils allowing for multiband echo planar imaging acquisitions. Details of the ABCD imaging protocol are discussed elsewhere (Casey et al., 2018; Hagler et al., 2019). Prior to scanning, participants completed MR screening to confirm safety for MRI. The present study utilized data from resting state functional MRI scans, described in detail in Supplementary Materials.

DMN functional connectivity was measured using the average of the correlations computed for every pair of Fisher Z-transformed regions of interest (ROI) within the DMN, defined using Gordon parcellations (Gordon et al., 2016; Van Dijk et al., 2010). Visualizations of Gordon parcellations for the DMN may be found elsewhere (Gordon et al., 2020).

Statistical analyses

Data were cleaned and analyzed using IBM SPSS Statistics, Version 28.0 and PROCESS version 4.0 (Hayes, 2018). Mediation analyses employed a bootstrap procedure with 10,000 bootstrap samples (Model 4, Hayes, 2018). Moderating effects of sex were assessed with a moderated-mediation model using a bootstrap procedure with 10,000 bootstrap samples (Model 8; Hayes, 2018).

Given evidence suggesting atypical DMN connectivity patterns are associated with autism (Jann et al., 2015), we repeated analyses excluding participants with a diagnosis of autism spectrum disorder (ASD) according to parent report to confirm this was not driving findings. To ensure that our findings were not random due to a large sample and high statistical power, we repeated analyses using RSFC of the sensorimotor hand network (SMHN), a neural network not predicted to relate to our variables of interest.

Exploratory analyses were conducted to test the putative effects of demographic factors, child race and household income, on the mediation analysis and to investigate differential effects in maternal and paternal study caregivers.

Results

Sample characteristics

The final sample for the current study ($n = 9{,}366$) was 48.4% female, and ages ranged from 8.92–11.00 years ($M = 9.91$ years, $SD = 0.62$). See Table 1 for sample characteristics. Mean CBCL T-scores were in the Normal range at baseline and 1-year follow up. See Table 2 for descriptive statistics regarding the primary variables of interest.

Mediation analyses

Mediation analyses were conducted to test whether within-DMN RSFC at baseline mediates the relation between CRPBI-Acceptance baseline scores (see Fig. 1) and CBCL T-scores at baseline and 1-year follow-up (see Fig. 2).

The direct effect of CRPBI-Acceptance scores on CBCL-Total T-scores, and the indirect effect were found to be statistically significant. Within-DMN RSFC significantly mediated the relation between CRPBI-Acceptance scores and CBCL-Total T-scores. Upon further investigation, within-DMN RSFC significantly mediated the relation between CRPBI-Acceptance scores and CBCL-Externalizing, but not CBCL-Internalizing, T-scores. See Table 3.

Analyses were repeated with CBCL scores at 1-year follow-up. The relations remained the same; within-DMN RSFC significantly mediating the relation between CRPBI-Acceptance scores and CBCL-Total and CBCL-Externalizing scores, but not CBCL-Internalizing scores. See Table 3.

Sex effects. As shown in Table 4, sex did not significantly moderate relations with baseline or 1-year follow-up CBCL T-scores. The direct effects of CRPBI-Acceptance on all CBCL T-scores at baseline and 1-year follow-up were

Table 1 Sample characteristics

Characteristic	Count (Percentage)
Age in Years – M(SD)	9.91 (0.62)
Female	4447 (47.5%)
Ethnicity	
Hispanic	2005 (21.4%)
Non-Hispanic	7360 (78.58%)
No Answer	1 (0.0%)
Race	
White	5906 (63.1%)
Black	1456 (15.5%)
American Indian/Alaska Native or Native	62 (0.7%)
Hawaiian or other Pacific Islander	234 (2.5%)
Asian	440 (4.7%)
Other Race	1134 (12.1%)
Mixed	133 (1.4%)
No Answer	
Study Caregiver Type	
Biological Mother	7972 (85.1%)
Biological Father	947 (10.1%)
Adoptive Parent	229 (2.4%)
Custodial Parent	91 (1.0%)
Other	127 (1.4%)
Parent Highest Level of Education:	
5th grade or less	15 (0.16%)
6-8th grade	117 (1.25%)
Some High School	494 (5.27%)
High School Graduate/GED	998 (10.66%)
Some College	1,548 (16.5%)
Associate's Degree	1,213 (12.95%)
Bachelor's Degree	2,576 (27.5%)
Master's Degree	1,804 (19.3%)
Professional School Degree	272 (2.9%)
Doctoral Degree	315 (3.4%)
No answer	14 (0.1%)
Parent Current Marital Status:	
Married	6261 (66.8%)
Widowed	75 (0.8%)
Divorced	863 (9.2%)
Separated	366 (3.9%)
Never Married	1172 (12.5%)
Living With Partner	55 (5.9%)
Refused to Answer	79 (0.8%)
Household Income	
Less than $5,000	320 (3.4%)
$5,000-$11,999	331 (3.5%)
$12,000-$15,999	226 (2.4%)
$16,000-$24,999	418 (4.5%)
$25,000-$34,999	538 (5.7%)
$35,000-$49,999	734 (7.8%)
$50,000-$74,999	1179 (12.6%)
$75,000-$99,999	1251 (13.4%)
$100,000–199,999	2582 (27.6%)
$200,000 and greater	976 (10.4%)
No answer	811 (8.7%)

significant for boys and girls; the index of moderated-mediation was not significant in any of the models.

Table 2 Descriptive statistics of variables of interest

Measure	Mean (Standard Deviation)
CRPBI-Acceptance Score Baseline	2.78 (0.31)
CBCL T-Scores	
Baseline	
Total Problems	46.09 (11.34)
Externalizing Problems	45.83 (10.33)
Internalizing Problems	48.68 (10.67)
1-Year Follow-Up	
Total Problems	45.75 (11.24)
Externalizing Problems	45.32 (10.15)
Internalizing Problems	48.92 (10.65)
Within-DMN RSFC Baseline	0.24 (0.06)

Secondary analyses: neurodevelopmental disorders

To confirm results were not driven by individuals with ASD, analyses were repeated excluding youth with ASD diagnoses. In the remaining sample (baseline: $n = 9,195$; 1-year follow-up: $n = 8,651$), the relations amongst these variables remained the same, suggesting that ASD symptoms were not driving the association. See Supplementary Table 1.

Control analyses: sensorimotor hand network

Mediation analyses were repeated to assess whether within-SMHN RSFC would mediate the relation between CRPBI-Acceptance scores and CBCL-Total, CBCL-Externalizing, and CBCL-Internalizing T-scores. Within-SMHN RSFC did not significantly mediate the relation between CRPBI-Acceptance scores and any of the CBCL T-scores. See Supplementary Table 2.

Exploratory analyses: demographics

First, mediations were repeated controlling for child race and combined household income. The CBCL-Total T-score mediation remained significant, but the CBCL-Externalizing T-score results did not. See Supplementary Material for more details. Second, analyses were conducted separately for maternal (baseline: $n = 7,972$; 1-year follow-up: $n = 7,518$) and paternal (baseline: $n = 947$; 1-year follow-up: $n = 881$) study caregivers from separate families. In mothers alone, mediations remained significant for CBCL-Total and CBCL-Externalizing T-scores. These mediation analyses were not significant in fathers.

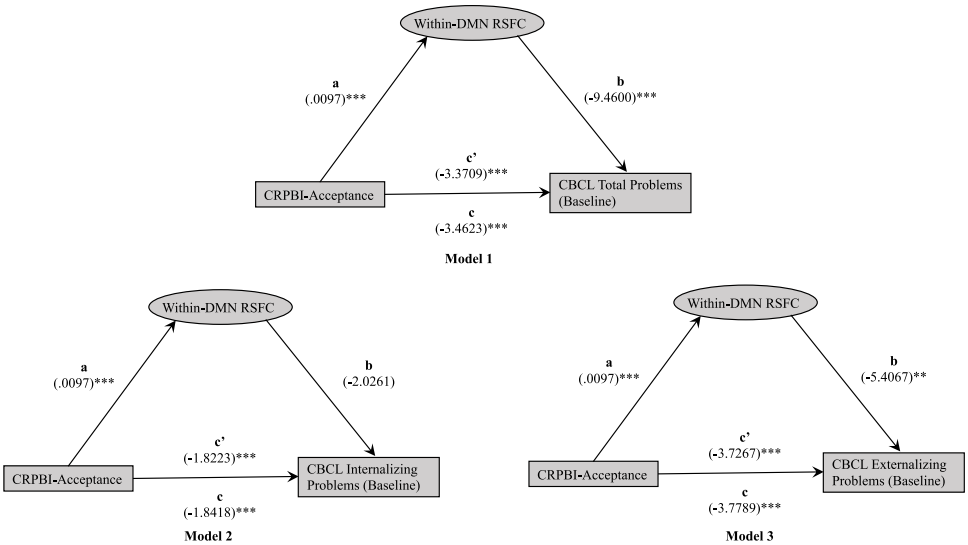

Fig. 1 Mediation model for baseline analyses. Standardized regression coefficients for the relationship between CRPBI parental acceptance/warmth and CBCL Total (Model 1), Internalizing (Model 2), and Externalizing (Model 3) Problems T-scores at baseline mediated by within-DMN RSFC. ** $p < .01$, *** $p < .001$

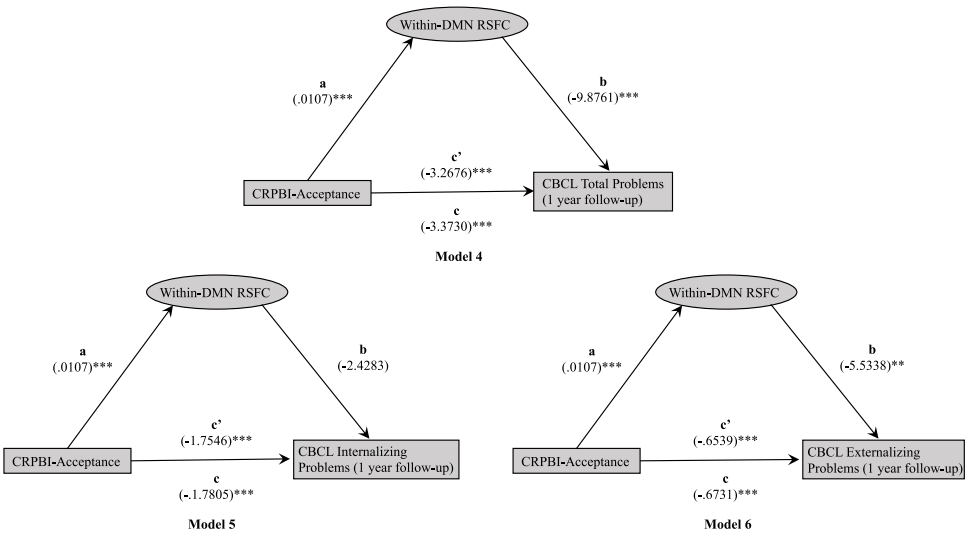

Fig. 2 Mediation model for 1-year follow-up analyses. Standardized regression coefficients for the relationship between CRPBI parental acceptance/warmth and CBCL Total (Model 4), Internalizing (Model 5), and Externalizing (Model 6) Problems T-scores at 1-year follow-up mediated by within-DMN RSFC. ** $p < .01$, *** $p < .001$

Table 3 Mediation analyses

Model	Outcome	Total Effect	Direct Effect	Indirect Effect [CI 95%]	P_M
I	CBCL Total Problems (Baseline)	-3.46***	-3.37***	-0.09 [-0.15, -0.04]	0.03
II	CBCL Internalizing Problems (Baseline)	-1.84***	-1.82***	-0.02 [-0.06, 0.02]	0.01
III	CBCL Externalizing Problems (Baseline)	-3.78***	-3.73***	-0.05 [-0.10, -0.02]	0.01
IV	CBCL Total Problems (1 year follow-up)	-3.37***	-3.27***	-0.11 [-0.17, -0.05]	0.03
V	CBCL Internalizing Problems (1 year follow-up)	-1.78***	-1.75***	-0.03 [-0.07, 0.01]	0.01
VI	CBCL Externalizing Problems (1 year follow-up)	-3.68***	-3.62***	-0.06 [-0.11, -0.02]	0.02

All mediation models used CRPBI-Acceptance baseline scores as the independent variable and within-DMN RSFC at baseline as the mediating variable. *** p-value $< .001$

Table 4 Moderated-mediation analyses

Boys	Model	Outcome	Direct Effect	Indirect Effect [CI 95%]
	I	CBCL Total Problems (Baseline)	-3.49***	-0.05 [-0.11, -0.01]
	II	CBCL Internalizing Problems (Baseline)	-1.99***	0.00 [-0.03, 0.03]
	III	CBCL Externalizing Problems (Baseline)	-3.66***	-0.03 [-0.08, 0.00]
	IV	CBCL Total Problems (1 year follow-up)	-3.51***	-0.06 [-0.13, -0.01]
	V	CBCL Internalizing Problems (1 year follow-up)	-1.80***	-0.01 [-0.04, 0.03]
	VI	CBCL Externalizing Problems (1 year follow-up)	-3.69***	-0.03 [-0.08, -0.00]
Girls	Model	Outcome	Direct Effect	Indirect Effect [CI 95%]
	I	CBCL Total Problems (Baseline)	-2.87***	-0.06 [-0.13, -0.01]
	II	CBCL Internalizing Problems (Baseline)	-1.26*	0.00 [-0.03, 0.04]
	III	CBCL Externalizing Problems (Baseline)	-3.53***	-0.03 [-0.08, 0.00]
	IV	CBCL Total Problems (1 year follow-up)	-2.73***	-0.08 [-0.16, -0.02]
	V	CBCL Internalizing Problems (1 year follow-up)	-1.47**	-0.01 [-0.05, 0.03]
	VI	CBCL Externalizing Problems (1 year follow-up)	-3.33***	-0.04 [-0.09, -0.00]
Index of Moderated-Mediation	Model	Outcome		Index [CI 95%]
	I	CBCL Total Problems (Baseline)		-0.01 [-0.07, 0.06]
	II	CBCL Internalizing Problems (Baseline)		0.00 [-0.03, 0.02]
	III	CBCL Externalizing Problems (Baseline)		-0.00 [-0.04, 0.03]
	IV	CBCL Total Problems (1 year follow-up)		-0.02 [-0.10, 0.06]
	V	CBCL Internalizing Problems (1 year follow-up)		-0.00 [-0.03, 0.02]
	VI	CBCL Externalizing Problems (1 year follow-up)		-0.01 [-0.06, 0.03]

All mediation models used CRPBI-Acceptance baseline scores as the independent variable, within-DMN RSFC at baseline as the mediating variable, and sex at birth as the moderating variable. * p-value < .05, ** p-value < .01, *** p-value < .001

Discussion

This is the first study to examine associations among parental acceptance/warmth, within-DMN RSFC, and psychological outcomes during late childhood. Using a large, high-powered sample, we found direct effects of parental acceptance/warmth on within-DMN connectivity and youth psychological symptoms, and within-DMN connectivity on youth symptoms. These findings support our hypotheses based on findings from previous work (Sato et al., 2016). Prior to this study, no investigations examined whether within-DMN connectivity could explain the association between parental acceptance/warmth and youth psychological outcomes. Specifically, higher within-DMN RSFC, indicating a more mature connectivity pattern, mediated the relation between greater parental acceptance/warmth and lower overall psychopathology scores at baseline and one year later. This appears to be driven primarily by externalizing problems, as analyses of internalizing scores were not significant. This supports previous findings showing associations between externalizing symptoms in youth, including callous-unemotional traits and violent behavior, and abnormal DMN connectivity (Sun et al., 2021; Umbach & Tottenham, 2020). These results enrich our theoretical understanding of the relationship between parenting and youth outcomes, suggesting that connectivity within the DMN may be a mechanism by which parental behaviors can promote positive psychological outcomes. It is also important to note that direct effects between parenting and child outcomes remained significant, suggesting that other variables may contribute to this association.

These novel findings complement and expand on the PARTheory (Rohner, 1980) and studies linking greater levels of parental acceptance/warmth with fewer psychological problems (Khaleque, 2013; Miller-Graff et al., 2016; Romund et al., 2016), by suggesting a neural basis for the relation between parental acceptance/warmth and child outcomes. While previous research suggests that dysfunctional parenting can adversely impact within-DMN connectivity (Adenzato et al., 2019) and positive parenting may impact general resting state network maturation (Dégeilh et al., 2018; Pozzi et al., 2021), our results support and extend these findings by indicating that positive parenting behaviors might be related to within-DMN connectivity and, in turn, psychological outcomes. As such, the significant mediation findings provide support for the notion that positive parenting behaviors promote the normative development of this neural system, which may reduce the risk for externalizing psychopathology, providing a novel target for parent-focused interventions. Given the role that the DMN plays in

socioemotional processes (Li et al., 2014; Xie et al., 2016), it may serve as an important intermediary between parenting and youth outcomes. Though speculative, one potential explanation for these findings is that through warmth and acceptance behaviors, parents foster a positive relationship with their children, which may teach them how to establish their own positive relationships with others, impacting social and behavioral outcomes.

Though we did not have a priori hypotheses regarding the role of demographic variables, we did explore them. Sex was not found to be a significant moderator of the present analyses, despite previous research suggesting that sex differences may exist (Ernst et al., 2019; Rothbaum & Weisz, 1994). While within-DMN RSFC remained a significant mediator between CRPBI-Acceptance and CBCL-Total T-scores after controlling for income and child race, significant effects of income on within-DMN RSFC and CBCL-Total T-scores were also observed, such that higher income was associated with greater RSFC and reduced CBCL Total T-scores. The mediation results with CBCL-Externalizing T-scores were no longer significant after controlling for income and child race. This suggests that demographic variables may influence these relations in more complex ways than addressed here, establishing a foundation for future work. Finally, mediation analyses were found to be significant for maternal, but not paternal, study caregivers, which may reflect true differences between mothers and fathers, or a lack of power for the paternal caregiver analyses. Additional work is needed to understand these associations and specifically, how they may differ between mothers and fathers within the same families.

To address concerns that the large sample size might result in detection of erroneous, random statistically significant results, we tested this model with a neural network not predicted to be related to our independent or dependent variables: the SMHN. Results confirmed that it was not significantly related to parental acceptance/warmth or CBCL scores, nor did it significantly mediate the association between these variables. These findings increase the likelihood that our findings are not erroneous and may be unique to the DMN.

The effect sizes of our results would be classified as small per traditional effect size categorization (Cohen, 1988). Small effect sizes, even very small ones, are not an unusual occurrence in datasets as large and well-powered as ABCD and have been much discussed (Dick et al., 2021, Funder & Ozer, 2019). Our results are particularly meaningful since the DMN does not begin to show connectivity amongst all regions until ages 7–9 years and does not reach full maturity until well into young adulthood (Fair et al., 2008). This sample consisted of a narrow age range of 8.9–10.9 years, when DMN connectivity is typically in the early stages of development. Therefore, while the effect sizes were relatively small, the fact that significant brain connectivity associated with parenting and psychopathology at this young age were detected lends additional support to our results.

There are several limitations to consider. First, while the finding that significant effects remained when examining CBCL scores at 1-year follow up supports the direction of our proposed model, the relation between parenting and youth behavior is a reciprocal one (Burke et al., 2008; Serbin et al., 2015). Second, we used child report of parenting and parent report of child functioning; however, child-perceived parenting may be influenced by a child's current functioning and mood, and parents with less warmth and acceptance may perceive their children more negatively (Allmann et al., 2021). Future studies should utilize multi-method assessments to examine these relations. Third, though mediation typically involves three time points, using fewer time points is considered acceptable to lay the foundation for future more extensive, longitudinal analyses (Hayes, 2018). Fourth, although head motion was not expected to impact hypothesized mediation effects, and the ABCD study implements several protocols to minimize motion, this cannot be ruled out given known effects of motion on resting state functional MRI studies of children (Satterthwaite et al., 2012).

Conclusions

The current study provides evidence that parental acceptance/warmth fosters healthy psychological development by promoting RSFC of the DMN, a network implicated in important cognitive and socioemotional processes. This contributes to our understanding of the mechanisms by which positive parenting relates to favorable youth outcomes, specifically reduced externalizing symptoms. These results underscore the importance of parenting behavior during childhood and the notion that positive parenting supports healthy neural and psychological development in children.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11682-022-00692-z.

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 and follow them over 10 years into early adulthood. A listing of participating sites and a complete listing of the study investigators can be found at https://abcdstudy.org/consortium_members/. ABCD consortium investigators designed and implemented the study and/or provided data but did not necessarily participate in analysis 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.

Author contribution Author contributions included conception and project design (KD, AKR, and DG), statistical analysis (KD, AKR,

and MA), interpretation of results (KD, AKR, and MA), drafting the manuscript work and revising it critically for important intellectual content (KD, AKR, DG, MA, and EH), and approval of final version to be published and agreement to be accountable for the integrity and accuracy of all aspects of the work (all authors).

Funding The ABCD Study is supported by the National Institutes of Health and additional federal partners under award numbers U01DA041048, U01DA050989, U01DA051016, U01DA041022, U01DA051018, U01DA051037, U01DA050987, U01DA041174, U01DA041106, U01DA041117, U01DA041028, U01DA041134, U01DA050988, U01DA051039, U01DA041156, U01DA041025, U01DA041120, U01DA051038, U01DA041148, U01DA041093, U01DA041089, U24DA041123, U24DA041147. A full list of supporters is available at https://abcdstudy.org/federal-partners.html.

Data availability The dataset generated and analyzed for the current project are available in the NIMH Data Archive (NDA; https://nda.nih.gov/).

Code availability Not applicable.

Declarations

Ethics approval All procedures performed in this study that involved human participants were conducted in accordance with the ethical standards of the institutional research committee.

Consent to participate All participants in this study provided informed consent as approved by a central institutional review board. Caregivers provided full written consent and children provided verbal assent.

Consent for publication We provide consent to publication.

Conflicts of interest None of the authors have a conflict of interest to declare.

References

Achenbach, T. M., & Rescorla, L. A. (2014). The Achenbach system of empirically based assessment (ASEBA) for ages 1.5 to 18 years. In *The use of psychological testing for treatment planning and outcomes assessment* (pp. 179–214). Routledge.

Adenzato, M., Imperatori, C., Ardito, R. B., Valenti, E. M., Della Marca, G., D'Ari, S., … & Farina, B. (2019). Activating attachment memories affects default mode network in a non-clinical sample with perceived dysfunctional parenting: An EEG functional connectivity study. *Behavioural Brain Research*, *372*, 112059.

Allmann, A. E., Klein, D. N., & Kopala-Sibley, D. C. (2021). Bidirectional and transactional relationships between parenting styles and child symptoms of ADHD, ODD, depression, and anxiety over 6 years. *Development and Psychopathology*, 1–12.

Andrews-Hanna, J. R. (2012). The brain's default network and its adaptive role in internal mentation. *The Neuroscientist, 18*(3), 251–270.

Auchter, A. M., Mejia, M. H., Heyser, C. J., Shilling, P. D., Jernigan, T. L., Brown, S. A., … & Dowling, G. J. (2018). A description of the ABCD organizational structure and communication framework. *Developmental Cognitive Neuroscience*, 32, 8-15.

Barber, B. K. (1997). Adolescent socialization in context - the role of connection, regulation, and autonomy in the family. *Journal of Adolescent Research, 12*, 5–11.

Barber, B. K., Olsen, J. E., & Shagle, S. C. (1994). Associations between parental psychological and behavioral control and youth internalized and externalized behaviors. *Child Development, 65*(4), 1120–1136.

Beyers, W., & Goossens, L. U. C. (1999). Emotional autonomy, psychosocial adjustment and parenting: Interactions, moderating and mediating effects. *Journal of Adolescence, 22*(6), 753–769.

Bhanot, S., Bray, S., McGirr, A., Lee, K., & Kopala-Sibley, D. C. (2021). A Narrative Review of Methodological Considerations in Magnetic Resonance Imaging of Offspring Brain Development and the Influence of Parenting. *Frontiers in Human Neuroscience*, *15*.

Bogin, B. (1997). Evolutionary hypotheses for human childhood. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists, 104*(S25), 63–89.

Burke, J. D., Pardini, D. A., & Loeber, R. (2008). Reciprocal relationships between parenting behavior and disruptive psychopathology from childhood through adolescence. *Journal of Abnormal Child Psychology, 36*(5), 679–692.

Butterfield, R. D., Silk, J. S., Lee, K. H., Siegle, G. S., Dahl, R. E., Forbes, E. E., … Ladouceur, C. D. (2021). Parents still matter! Parental warmth predicts adolescent brain function and anxiety and depressive symptoms 2 years later. *Development and Psychopathology*, *33*(1), 226-239.

Callaghan, B. L., & Tottenham, N. (2016). The neuro-environmental loop of plasticity: A cross-species analysis of parental effects on emotion circuitry development following typical and adverse caregiving. *Neuropsychopharmacology, 41*(1), 163–176.

Casey, B. J., Cannonier, T., Conley, M. I., Cohen, A. O., Barch, D. M., Heitzeg, M. M., … & Orr, C. A. (2018). The adolescent brain cognitive development (ABCD) study: imaging acquisition across 21 sites. *Developmental Cognitive Neuroscience*, *32*, 43–54.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). L. Erlbaum Associates.

Dégeilh, F., Bernier, A., Leblanc, É., Daneault, V., & Beauchamp, M. H. (2018). Quality of maternal behaviour during infancy predicts functional connectivity between default mode network and salience network 9 years later. *Developmental Cognitive Neuroscience, 34*, 53–62.

Dick, A. S., Lopez, D. A., Watts, A. L., Heeringa, S., Reuter, C., Bartsch, H., … & Thompson, W. K. (2021). Meaningful associations in the adolescent brain cognitive development study. *NeuroImage*, 118262.

Ernst, M., Benson, B., Artiges, E., Gorka, A. X., Lemaitre, H., Lago, T., … & Martinot, J. L. (2019). Pubertal maturation and sex effects on the default-mode network connectivity implicated in mood dysregulation. *Translational Psychiatry, 9*(1), 1–14.

Fair, D. A., Cohen, A. L., Dosenbach, N. U., Church, J. A., Miezin, F. M., Barch, D. M., … Schlaggar, B. L. (2008). The maturing architecture of the brain's default network. *Proceedings of the National Academy of Sciences, 105*(10), 4028–4032.

Fan, F., Liao, X., Lei, T., Zhao, T., Xia, M., Men, W., … He, Y. (2021). Development of the default-mode network during childhood and adolescence: A longitudinal resting-state fMRI study. *NeuroImage*, *226*, 117581.

Farber, M. J., Gee, D. G., & Hariri, A. R. (2020). Normative range parenting and the developing brain: A scoping review and recommendations for future research. *European Journal of Neuroscience*.

Funder, D. C., & Ozer, D. J. (2019). Evaluating effect size in psychological research: Sense and nonsense. *Advances in Methods and Practices in Psychological Science*, *2*(2), 156–168.

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R. Z., Heeringa, S., … Zahs, D. (2018). Recruiting the ABCD sample: design considerations and procedures. *Developmental Cognitive Neuroscience*, *32*, 16–22.

Glynn, L. M., & Baram, T. Z. (2019). The influence of unpredictable, fragmented parental signals on the developing brain. *Frontiers in Neuroendocrinology, 53*, 100736.

Gordon, E. M., Laumann, T. O., Adeyemo, B., Huckins, J. F., Kelley, W. M., & Petersen, S. E. (2016). Generation and evaluation of a cortical area parcellation from resting-state correlations. *Cerebral Cortex, 26*(1), 288–303.

Gordon, E. M., Laumann, T. O., Marek, S., Raut, R. V., Gratton, C., Newbold, D. J., … Nelson, S. M. (2020). Default-mode network streams for coupling to language and control systems. *Proceedings of the National Academy of Sciences*, *117*(29), 17308–17319.

Graham, A. M., Pfeifer, J. H., Fisher, P. A., Carpenter, S., & Fair, D. A. (2015). Early life stress is associated with default system integrity and emotionality during infancy. *Journal of Child Psychology and Psychiatry, 56*(11), 1212–1222.

Hagler Jr, D. J., Hatton, S., Cornejo, M. D., Makowski, C., Fair, D. A., Dick, A. S., … Watts, R. (2019). Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *NeuroImage*, *202*, 116091.

Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (2nd ed.). Guilford publications.

Hipwell, A., Keenan, K., Kasza, K., Loeber, R., Stouthamer-Loeber, M., & Bean, T. (2008). Reciprocal influences between girls' conduct problems and depression, and parental punishment and warmth: A six year prospective analysis. *Journal of Abnormal Child Psychology, 36*(5), 663–677.

Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology, 387*(2), 167–178.

Jann, K., Hernandez, L. M., Beck-Pancer, D., McCarron, R., Smith, R. X., Dapretto, M., & Wang, D. J. (2015). Altered resting perfusion and functional connectivity of default mode network in youth with autism spectrum disorder. *Brain and Behavior, 5*(9), e00358.

Jernigan, T. L., Brown, S. A., ABCD Consortium Coordinators. (2018). Introduction. *Developmental Cognitive Neuroscience, 32*, 1–3.

Khaleque, A. (2013). Perceived parental warmth, and children's psychological adjustment, and personality dispositions: A meta-analysis. *Journal of Child and Family Studies, 22*(2), 297–306.

Kim, S. M., Park, S. Y., Kim, Y. I., Son, Y. D., Chung, U. S., Min, K. J., & Han, D. H. (2016). Affective network and default mode network in depressive adolescents with disruptive behaviors. *Neuropsychiatric Disease and Treatment, 12*, 49.

Li, W., Mai, X., & Liu, C. (2014). The default mode network and social understanding of others: What do brain connectivity studies tell us. *Frontiers in Human Neuroscience, 8*, 74. https://doi.org/10.3389/fnhum.2014.00074

Miller-Graff, L. E., Cater, Å. K., Howell, K. H., & Graham-Bermann, S. A. (2016). Parent–child warmth as a potential mediator of childhood exposure to intimate partner violence and positive adulthood functioning. *Anxiety, Stress, & Coping, 29*(3), 259–273.

Morris, A. S., Criss, M. M., Silk, J. S., & Houltberg, B. J. (2017). The impact of parenting on emotion regulation during childhood and adolescence. *Child Development Perspectives, 11*(4), 233–238.

Perrin, J. S., Hervé, P. Y., Leonard, G., Perron, M., Pike, G. B., Pitiot, A., … Paus, T. (2008). Growth of white matter in the adolescent brain: role of testosterone and androgen receptor. *Journal of Neuroscience, 28*(38), 9519–9524.

Philip, N. S., Sweet, L. H., Tyrka, A. R., Price, L. H., Bloom, R. F., & Carpenter, L. L. (2013). Decreased default network connectivity is associated with early life stress in medication-free healthy adults. *European Neuropsychopharmacology, 23*(1), 24–32.

Pozzi, E., Vijayakumar, N., Byrne, M. L., Bray, K. O., Seal, M., Richmond, S., … Whittle, S. L. (2021). Maternal parenting behavior and functional connectivity development in children: A longitudinal fMRI study. *Developmental Cognitive Neuroscience*, *48*, 100946.

Rebello, K., Moura, L. M., Pinaya, W. H., Rohde, L. A., & Sato, J. R. (2018). Default mode network maturation and environmental adversities during childhood. *Chronic Stress, 2*, 1–10.

Rohner, R. P. (1980). Worldwide tests of parental acceptance-rejection theory: An overview. *Behavior Science Research, 15*(1), 1–21.

Romund, L., Raufelder, D., Flemming, E., Lorenz, R. C., Pelz, P., Gleich, T., … Beck, A. (2016). Maternal parenting behavior and emotion processing in adolescents—An fMRI study. *Biological psychology*, *120*, 120–125.

Rothbaum, F., & Weisz, J. R. (1994). Parental caregiving and child externalizing behavior in nonclinical samples: A meta-analysis. *Psychological Bulletin, 116*(1), 55.

Rothenberg, W. A., Lansford, J. E., Bornstein, M. H., Chang, L., Deater-Deckard, K., Di Giunta, L., ... & Bacchini, D. (2020). Effects of parental warmth and behavioral control on adolescent externalizing and internalizing trajectories across cultures. *Journal of Research on Adolescence*, *30*(4), 835–855.

Sato, J. R., Salum, G. A., Gadelha, A., Picon, F. A., Pan, P. M., Vieira, G., … Del'Aquilla, M. A. G. (2014). Age effects on the default mode and control networks in typically developing children. *Journal of Psychiatric Research*, *58*, 89–95.

Sato, J. R., Salum, G. A., Gadelha, A., Crossley, N., Vieira, G., Manfro, G. G., … Anés, M. (2016). Default mode network maturation and psychopathology in children and adolescents. *Journal of Child Psychology and Psychiatry*, *57*(1), 55–64.

Satterthwaite, T. D., Wolf, D. H., Loughead, J., Ruparel, K., Elliott, M. A., Hakonarson, H., Gur, R. C., & Gur, R. E. (2012). Impact of in-scanner head motion on multiple measures of functional connectivity: Relevance for studies of neurodevelopment in youth. *NeuroImage, 60*(1), 623–632.

Schaefer, E. S. (1965). A configurational analysis of children's reports of parent behavior. *Journal of Consulting Psychology, 29*(6), 552.

Serbin, L. A., Kingdon, D., Ruttle, P. L., & Stack, D. M. (2015). The impact of children's internalizing and externalizing problems on parenting: Transactional processes and reciprocal change over time. *Development and Psychopathology, 27*(4pt1), 969–986.

Steinberg, L., Elmen, J. D., & Mounts, N. S. (1989). Authoritative parenting, psychosocial maturity, and academic success among adolescents. *Child development*, 1424–1436.

Sun, Q., Zhang, Y., Zhou, J., & Wang, X. (2021). Altered resting-state functional connectivity in the default mode network in male juvenile violent offenders. *Brain Imaging and Behavior*, 1–9.

Uddin, L. Q., Supekar, K. S., Ryali, S., & Menon, V. (2011). Dynamic reconfiguration of structural and functional connectivity across core neurocognitive brain networks with development. *Journal of Neuroscience, 31*(50), 18578–18589.

Uddin, L. Q., Kelly, A. C., Biswal, B. B., Margulies, D. S., Shehzad, Z., Shaw, D., … Milham, M. P. (2008). Network homogeneity reveals decreased integrity of default-mode network in ADHD. *Journal of Neuroscience Methods*, *169*(1), 249–254.

Umbach, R. H., & Tottenham, N. (2020). Callous-unemotional traits and reduced default mode network connectivity within a community sample of children. *Development and Psychopathology*, 1–14.

Van Dijk, K. R., Hedden, T., Venkataraman, A., Evans, K. C., Lazar, S. W., & Buckner, R. L. (2010). Intrinsic functional connectivity as a tool for human connectomics: Theory, properties, and optimization. *Journal of Neurophysiology, 103*(1), 297–321.

Volkow, N. D., Koob, G. F., Croyle, R. T., Bianchi, D. W., Gordon, J. A., Koroshetz, W. J., …. Deeds, B. G. (2018). The conception of the ABCD study: From substance use to a broad NIH collaboration. *Developmental Cognitive Neuroscience, 32*, 4–7.

Waller, R., Hyde, L. W., Klump, K. L., & Burt, S. A. (2018). Parenting is an environmental predictor of callous-unemotional traits and aggression: A monozygotic twin differences study. *Journal of the American Academy of Child & Adolescent Psychiatry, 57*(12), 955–963.

Wang, S., Tepfer, L. J., Taren, A. A., & Smith, D. V. (2020). Functional parcellation of the default mode network: a large-scale meta-analysis. *Scientific Reports*, *10*. https://doi.org/10.1038/s41598-020-72317-8

Wise, T., Marwood, L., Perkins, A. M., Herane-Vives, A., Joules, R., Lythgoe, D. J., … Arnone, D. (2017). Instability of default mode network connectivity in major depression: a two-sample confirmation study. *Translational Psychiatry*, *7*(4), e1105–e1105.

Xie, X., Bratec, S. M., Schmid, G., Meng, C., Doll, A., Wohlschläger, A., ... & Sorg, C. (2016). How do you make me feel better? Social cognitive emotion regulation and the default mode network. *NeuroImage, 134,* 270–280.

Yang, Z., Zuo, X. N., McMahon, K. L., Craddock, R. C., Kelly, C., De Zubicaray, G. I., … Wright, M. J. (2016). Genetic and environmental contributions to functional connectivity architecture of the human brain. *Cerebral cortex*, *26*(5), 2341–2352.

Zeev-Wolf, M., Levy, J., Goldstein, A., Zagoory-Sharon, O., & Feldman, R. (2019). Chronic early stress impairs default mode network connectivity in preadolescents and their mothers. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 4*(1), 72–80.

Zhao, X. H., Wang, P. J., Li, C. B., Hu, Z. H., Xi, Q., Wu, W. Y., & Tang, X. W. (2007). Altered default mode network activity in patient with anxiety disorders: An fMRI study. *European Journal of Radiology, 63*(3), 373–378.