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The longitudinal role of family conflict and neural reward sensitivity in youth's internalizing symptoms

Beiming Yang,[1] Zachary Anderson,[2] Zexi Zhou,[3] Sihong Liu,[4] Claudia M. Haase,[1] and Yang Qu[1]

[1]School of Education and Social Policy, Northwestern University, Evanston, IL 60208, USA
[2]Department of Psychology, Northwestern University, Evanston, IL 60208, USA
[3]Department of Human Development and Family Sciences, The University of Texas at Austin, Austin, TX 78712, USA
[4]Stanford Center on Early Childhood, Stanford University, Stanford, CA 94305, USA
Correspondence should be addressed to Yang Qu, School of Education and Social Policy, Northwestern University, 2120 Campus Dr, Evanston, IL 60208, USA.
E-mail: yangqu@northwestern.edu

Abstract

Adolescence is often associated with an increase in psychopathology. Although previous studies have examined how family environments and neural reward sensitivity separately play a role in youth's emotional development, it remains unknown how they interact with each other in predicting youth's internalizing symptoms. Therefore, the current research took a biopsychosocial approach to examine this question using two-wave longitudinal data of 9353 preadolescents (mean age = 9.93 years at T1; 51% boys) from the Adolescent Brain Cognitive Development study. Using mixed-effects models, results showed that higher family conflict predicted youth's increased internalizing symptoms 1 year later, whereas greater ventral striatum (VS) activity during reward receipt predicted reduced internalizing symptoms over time. Importantly, there was an interaction effect between family conflict and VS activity. For youth who showed greater VS activation during reward receipt, high family conflict was more likely to predict increased internalizing symptoms. In contrast, youth with low VS activation during reward receipt showed high levels of internalizing symptoms regardless of family conflict. The findings suggest that youth's neural reward sensitivity is a marker of susceptibility to adverse family environments and highlight the importance of cultivating supportive family environments where youth experience less general conflict within the family.

Keywords: adolescence; family conflict; internalizing symptoms; neurobiological susceptibility; ventral striatum

Introduction

Given that transition to adolescence often marks the onset of mental health problems such as depressive and anxious symptoms (Dunn and Goodyer, 2006; Jonsson *et al.*, 2011; Lee *et al.*, 2014; de Lijster *et al.*, 2017), it is crucial to identify contextual and neurobiological factors that play a role in the development of psychopathology during the preadolescent years (10–12 years old). Previous studies have demonstrated the roles of family conflict (Juang *et al.*, 2012; Delgado *et al.*, 2019; Weymouth *et al.*, 2019) and neural reward sensitivity (Hanson *et al.*, 2015; Toenders *et al.*, 2019; Rappaport *et al.*, 2020) in youth's well-being and mental health. At the same time, there is enormous variability in how adolescents respond to different environments (Monroe and Simons, 1991; Belsky and Pluess, 2009; Pluess and Belsky, 2013), and theories on adolescent neurobiological susceptibility suggest that individual differences in the developing brain may serve as a marker of susceptibility to social contexts (Schriber and Guyer, 2016). Recent research has examined the moderating role of neural reward sensitivity in the link between family conflict and youth's externalizing symptoms (Turpyn *et al.*, 2021). However, less is known about the unique and interactive effects of family conflict and neural sensitivity to reward on youth's internalizing symptoms, especially using a longitudinal approach. Therefore, using longitudinal data from the Adolescent Brain Cognitive Development (ABCD) study (Casey *et al.*, 2018; ABCD Human Subjects Study, 2021), the current study aimed to fill this gap and investigate the roles of family conflict and neural reward sensitivity in preadolescent development of internalizing symptoms.

Family context plays an important role in youth's well-being and mental health (for a review, see Buehler, 2020). Family conflict (e.g. interparental conflict and parent–child conflict), in particular, is a stressor that can undermine youth's emotional functioning and lead to the development of internalizing symptoms (e.g. Cummings *et al.*, 2015). Interparental conflict is associated with lower psychological adjustment among youth (e.g. loneliness, negative mood and emotional dysregulation; Zhou and Buehler, 2017; Fosco and Lydon-Staley, 2019; Weymouth *et al.*, 2019). Similarly, everyday conflict between parents and youth (i.e. conflicts over minor issues such as schoolwork, home chores and attire, Smetana, 2002) predicts increased internalizing symptoms such

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as depression and anxiety over time (Juang *et al.*, 2012; Derlan *et al.*, 2015; Delgado *et al.*, 2019).

Given that adolescence is an important period of neurobiological changes, it is important to investigate the role of youth's brain development in their mental health. In particular, the ventral striatum (VS), a subcortical brain region key to reward processing, is related to multiple aspects of youth's development including their emotional functioning, psychological well-being and behavioral adjustment (for a review, see Telzer, 2016). VS responses to reward are often measured by reward-related tasks such as the monetary incentive delay (MID) task (Knutson *et al.*, 2001; Forbes *et al.*, 2006; Luking *et al.*, 2017) and the reward guessing task (Carlson *et al.*, 2011; Foti *et al.*, 2011). Previous studies suggest that higher or increased VS responses to reward can be a risk factor for developing externalizing problems such as risk-taking behaviors (e.g. Galvan *et al.*, 2006, 2007; Chein *et al.*, 2011; Qu *et al.*, 2015a, 2015b, 2016). However, heightened ventral responses to reward may also promote youth's adaptability to the environment by motivating them to learn from the environment and work toward goals (Spear, 2000; Wahlstrom *et al.*, 2010). Such adaptability may alleviate youth's stress in response to physical and emotional changes during adolescence, which ultimately protects them from mental illness (Telzer, 2016). Indeed, concurrent and longitudinal studies with pre- and early adolescent samples consistently suggest that blunted VS activation during reward processing is a risk factor for depression (Bress *et al.*, 2012; Morgan *et al.*, 2013, 2022; Hanson *et al.*, 2015; Toenders *et al.*, 2019; Rappaport *et al.*, 2020). Additional work notes that blunted response in the VS to reward may also be a risk factor for anxiety (Aupperle and Paulus, 2010; Auerbach *et al.*, 2022); however, such findings are mixed as other studies found that anxiety-related disorders are also associated with heightened VS responses to reward (e.g. Maresh *et al.*, 2014; Gorka *et al.*, 2018; Lahat *et al.*, 2018). Although the associations between reward sensitivity and specific mental health symptoms can be complicated, given the important role of reward circuits in stress resilience (Dutcher, 2023), dysregulated reward circuits may lead to transdiagnostic features of mental health symptoms such as the general intensity of negative affect (Burkhouse *et al.*, 2017). As such, VS responses during reward processing may play a more consistent role in youth's internalizing symptoms in general compared with more specific symptoms of depression and anxiety.

Theories on adolescent brain development suggest that individual differences in youth's neurobiological susceptibility may moderate the effects of social contexts (e.g. cultural, parental, and peer factors) on developmental outcomes ranging from psychological and behavioral to academic adjustment (Schriber and Guyer, 2016; Guyer, 2020). Previous studies using structural, resting-state and task-based neuroimaging demonstrate that individual differences in brain structure and functioning may moderate the associations between social contexts and youth's internalizing symptoms (Schriber *et al.*, 2017; Sequeira *et al.*, 2019; Rudolph *et al.*, 2020; Ip *et al.*, 2022). In this vein, neural sensitivity to reward may serve as an important marker of susceptibility to the family environment. Recent research has shown that neural reward sensitivity exacerbated the association between family conflict and youth's externalizing symptoms, suggesting that youth with heightened neural reward sensitivity were more likely to perceive rewards and punishment in social contexts and thus develop externalizing symptoms as an adaptation in correspondence to environmental influences (Turpyn *et al.*, 2021). However, no study to date has examined the unique and interactive effects of family conflict and neural sensitivity to reward in youth's internalizing symptoms, especially using a longitudinal approach. Given the heightened neural reward sensitivity during adolescence compared to childhood and adulthood (Casey *et al.*, 2008, 2019; Crone and Dahl, 2012) and the link between reward sensitivity and internalizing symptoms (Hanson *et al.*, 2015; Toenders *et al.*, 2019), it is important to investigate how VS activation during reward processing interacts with family conflict to predict youth's emotional development over time. For youth who show high neural reward sensitivity, family conflict may be more likely to predict increased internalizing symptoms among them over time. However, for youth with dampened neural reward sensitivity, family conflict may not significantly affect developmental adjustment because of low levels of susceptibility to environmental influences; rather, this neural risk factor itself may contribute to increased internalizing symptoms over time.

The current study

Using longitudinal data from the ABCD study, the current study aimed to examine the role of family conflict and VS activity during reward processing in predicting adolescents' internalizing symptoms over time. The hypotheses and analyses were pre-registered (https://aspredicted.org/W12_FRL). Guided by prior research, we had the following hypotheses: first, we hypothesized that greater family conflict would predict increased internalizing symptoms among youth 1 year later. Second, we hypothesized that lower reward sensitivity, indicated by lower VS activity during reward processing in the MID task (Knutson *et al.*, 2001; Yau *et al.*, 2012; Knutson and Heinz, 2015), would predict increased internalizing symptoms among youth 1 year later. Third, we expected an interaction effect between family conflict and neural reward sensitivity in youth's internalizing symptoms over time, such that the effect of family conflict on the development of youth's internalizing symptoms over time would be amplified among those who showed higher VS activation during reward processing.

In addition to the main analyses described in the preregistration, the current study examined whether the main and interaction effects on youth's internalizing symptoms were specific to VS activity during reward processing. Specifically, the current study also investigated whether the activities in (I) dorsal striatal regions (i.e. caudate and putamen) during reward processing, (II) lateral and medial orbitofrontal cortex (OFC) during reward processing, and (III) VS during loss processing have main or interaction effects (with family conflict) on youth's internalizing symptoms over time. While the analyses focusing on dorsal striatum activity during reward processing were included in the preregistration, the analyses focusing on OFC during reward processing and VS during loss processing were exploratory and were not included in the preregistration.

Materials and methods

Participants

Data were obtained from baseline (T1) and 1-year follow-up (T2) of the ABCD study (data release 4.0). All the data included in the current study are available on the National Institute of Mental Health (NIMH) Data Archive (https://nda.nih.gov/abcd). The ABCD study is a massive multisite study that currently examines approximately 11 876 youth aged from 9 to 10 years in the baseline sample (Karcher and Barch, 2021). Previous work documents a variety of measures that were used for this study, including task-based functional magnetic resonance imaging (fMRI) and behavioral outcomes (Casey *et al.*, 2018). Among the full sample of 11 876 participants at T1, a total of 9353 participants (mean

age = 9.93 years, s.d. = 0.63 years; 51% boys and 49% girls) were included in the analyses. The current research included subjects based on the inclusion criteria provided by the ABCD team (i.e. participants with variable 'imgincl_mid_include' = 1), which are the recommended quality control criteria of the MID task in ABCD data release note 4.0 (e.g. passing MID behavior, passing FreeSurfer quality control, and pass fMRI manual post-processing quality control; for detailed criteria, see ABCD Human Subjects Study, 2021).

The MID task

The current study used tabulated and region of interest–based results of the MID task that were publicly shared (Casey *et al.*, 2018; Hagler *et al.*, 2019; Chaarani *et al.*, 2021). In the MID task (Knutson *et al.*, 2001; Yau *et al.*, 2012), the participant attempted to win money by rapidly pressing a button following a series of prompts throughout the course of scanning. There were three types of trials that the participant experienced. Each trial included three relevant epochs including an anticipation phase, where the participant was informed if the current trial was a 'win' or 'lose' trial, a motor period, where the participant rapidly pressed a button in response to a prompt, and an outcome phase, where the participant was informed how they performed. On 'win' trials, the participant can win money ($5.00 or $0.20) or fail to win money depending on their performance. On 'lose' trials, the participant can avoid losing money if they press the button quickly enough or loses $5.00 or $0.20. Finally, on 'neutral' trials, the participant responded in a similar way, but no money was involved. Success on all trial types depended on response time during the motor period when the participant was instructed to press a button as quickly as possible following a prompt.

The task had an event-related design. First, a cue signaled whether the trial was a 'win' or 'lose' trial and the amount of money that was involved. 'Win' trials were represented by a pink circle, 'lose' trials involved a yellow square and neutral trials were represented by a blue triangle. This cue remained on the screen for 2 s. The participant then saw a fixation cross (jittered duration of 1.5–4 s), before attempting to respond to a signal that appeared on the screen for 0.15–0.5 s. The initial time allowed to respond at the beginning of the task was determined by the participant's performance during a practice session before scanning. The time was then adjusted depending on the participant's performance. If the participant's accuracy rose above a set limit, the amount of time the signal was on the screen was reduced. If the participant's overall accuracy was below a set cutoff, the amount of time the signal was on the screen was increased.

fMRI data acquisition and preprocessing

The ABCD study used a harmonized neuroimaging protocol across 21 sites. Three 3T scanner platforms (i.e. Siemens Prisma [Siemens Healthineers], GE 750 [GE Healthcare] and Philips [Philips Healthcare]) were used. For Siemens scanners, the following scanning parameters were used for T1 structural image acquisition: matrix = 256 × 256, 176 slices, field of view (FOV) = 256 × 256, resolution (mm) = 1.0 × 1.0 × 1.0, repetition time (T_R) = 2500 ms, echo time (T_E) = 2.88 ms, inversion time (T_I) = 1060 ms and flip angle = 8°. For Phillips scanners, the following scanning parameters were used for T1 structural image acquisition: matrix = 256 × 256, 225 slices, FOV = 256 × 240, resolution (mm) = 1.0 × 1.0 × 1.0, T_R = 6.31 ms, T_E = 2.9 ms, T_I = 1060 ms and flip angle = 8°. For GE scanners, the following scanning parameters were used for T1 structural image acquisition: matrix = 256 × 256, 208 slices, FOV = 256 × 256, resolution (mm) = 1.0 × 1.0 × 1.0, T_R = 2500 ms, T_E = 2 ms, T_I = 1060 ms and flip angle = 8°. Across all scanners, the following scanning parameters were used for T2*-weighted functional images associated with the MID task: matrix = 90 × 90, 60 slices, FOV = 216 × 216, T_E/T_R (ms) = 800/30, flip angle = 52°, resolution (mm) = 2.4 × 2.4 × 2.4 and multiband acceleration factor = 6. Each scanner used a standard head coil for the initial time point of fMRI data acquisition.

The MID task was presented to participants in a random order along with other functional tasks included in the study. Automated and manual methods were used to assess the quality of raw fMRI images, which looked for problems with acquisition, artifacts, motion or file corruption. Subsequent preprocessing of these images removed initial frames of functional images. The pipeline estimated within-volume head motion and performed rigid body motion correction in each individual. Data were processed for image distortions resulting from B0 field inhomogeneity. Isotropic resampling (2.4 mm) aligned fMRI data across participants from all sites. Functional data were registered to each individual's T1w structural image. Following preprocessing, images are sampled onto the cortical surface of each individual subject using FreeSurfer functions (Hagler *et al.*, 2019). Additional processing details can be found in previous publications (Casey *et al.*, 2018; Hagler *et al.*, 2019; Chaarani *et al.*, 2021).

General linear modeling using AFNI's 3dDeconvolve (Cox, 1996) was used to determine individual-level models. Baseline and quadratic trends in time series data were included in all first-level analyses. Motion estimates and their derivatives were also included in individual-level models as regressors of no interest (Power *et al.*, 2014). In cases where a single time point was associated with a framewise displacement (FD) of > 0.9, this volume was censored. Estimates were filtered with an infinite impulse response notch filter, which attenuates signals in the range of 0.31 to 0.43 Hz. This filtering is thought to result in motion estimates and FD values that more accurately reflect head motion (Fair *et al.*, 2020). A two-parameter gamma basis function was convolved with onsets of each MID task event during the anticipation and outcome phases of the task.

The current study focused on the reward anticipation and receipt epochs of the MID task. Previous research has highlighted the VS as a key neural correlate of anticipation and receipt of reward in the MID task (Knutson *et al.*, 2001; Beck *et al.*, 2009; Knutson and Heinz, 2015; Casey *et al.*, 2018; Cao *et al.*, 2019). Therefore, the current study employed a region-of-interest approach by examining the VS activation during reward anticipation and reward receipt. Estimations of VS activation were derived by applying FreeSurfer's anatomically defined parcellations to each individual's cortical surface space (Fischl *et al.*, 2002). Reward anticipation included the contrast of VS activation during the anticipation of a reward *vs* the anticipation of a neutral outcome. Reward receipt included the contrast of VS activation following positive reward feedback *vs* negative reward feedback. Estimates of VS activation related to each of these contrasts were used in subsequent analyses.

Questionnaire measures

Family conflict

Family conflict was measured with the youth-reported family conflict subscale of the Family Environment Scale (Moos and Moos, 1981). At T1, youth reported on incidents of family conflict (nine items; e.g. 'family members often criticize each other' and 'family members sometimes get so angry they throw things') on a two-point scale (0 = false and 1 = true). Following the practices of previous studies (Donohue *et al.*, 2020; Gong *et al.*, 2021;

Table 1. Descriptive statistics and correlations among key variables

	1	2	3	4	5	6	7
1. T1 left VS during reward anticipation							
2. T1 right VS during reward anticipation	0.61***						
3. T1 left VS during reward receipt	0.02*	0.03*					
4. T1 right VS during reward receipt	−0.01	0.01	0.59***				
5. T1 family conflict	0.01	0.01	0.02	0.00			
6. T1 internalizing symptoms	−0.00	−0.00	−0.01	−0.01	0.08***		
7. T2 internalizing symptoms	0.00	0.01	−0.02	−0.01	0.07***	0.70***	
Mean	0.07	0.06	0.15	0.14	1.98	4.96	5.04
s.d.	0.27	0.28	0.33	0.33	1.92	5.43	5.46

*$P < 0.05$.
***$P < 0.001$.

Liu *et al.*, 2021), the current study used the sum score of family conflict. For participants who have valid answers to all the items, a sum score was calculated by the ABCD team, with a higher number indicating greater conflict within the family. This measure of family conflict showed acceptable internal consistency ($\alpha = 0.68$). Moreover, confirmatory factor analysis indicated that this measure had good structural validity, comparative fit index (CFI) = 0.98, Tucker-Lewis index (TLI) = 0.97, root mean square error of approximation (RMSEA) = 0.02, and standardized root mean squared residual (SRMR) = 0.01.

Youth's internalizing symptoms

Internalizing symptoms were measured with the parent-reported Child Behavior Checklist (Achenbach, 2001). At both T1 and T2, parents reported on the youth's internalizing symptoms (32 items; e.g. 'unhappy, sad or depressed' and 'feels worthless or inferior'). Following the practices of previous studies (Gong *et al.*, 2021; Liu *et al.*, 2021; Steegers *et al.*, 2021), the current study used the sum score of internalizing symptoms. For participants who have valid answers to all the items, a sum score was calculated by the ABCD team, with a higher number indicating more internalizing symptoms. This measure of internalizing symptoms showed good internal consistency ($\alpha = 0.86$ at both T1 and T2) and test–retest reliability ($r = 0.70$). Moreover, confirmatory factor analysis indicated that this measure had good structural validity at both T1 (CFI = 0.96, TLI = 0.95, RMSEA = 0.03 and SRMR = 0.02) and T2 (CFI = 0.97, TLI = 0.95, RMSEA = 0.02 and SRMR = 0.02).

Demographic covariates.

The current study controlled for youth's age, biological sex, race/ethnicity, household financial adversity, parents' educational attainment and marital status. Biological sex was coded into 0 = male and 1 = female. Race/ethnicity was coded into five binary variables: White, Black, Latino, Asian and other races (including multiracial). Household financial adversity was assessed using the Parent-Reported Financial Adversity Questionnaire (Diemer *et al.*, 2013), which was the sum score on experiences of financial difficulties in the past 12 months (7 items, 0 = no and 1 = yes, range = 0–7; e.g. 'in the past 12 months, has there been a time when you and your immediate family needed food but couldn't afford to buy it or couldn't afford to go out to get it?') reported by the primary caregiver of the youth. Parents' educational attainment was the highest educational attainment of the primary and secondary caregivers of the youth, ranging from 1 = less than a high school diploma to 5 = postgraduate degree. Parents' marital status was coded into 0 = not married or living together with a partner and 1 = married or living together with a partner.

Analytical plan

Analyses were conducted using mixed-effect models from the lme4 package (Bates *et al.*, 2015) in R version 4.0.2 (R Core Team, 2022). For all the models, participants' site and family were included as random intercepts, demographic variables were included as fixed-effect covariates and propensity scores were included as sampling weights. The attrition rate from T1 to T2 was ∼9%. Results in Little's test (chi-square = 388.448, $P < 0.001$) suggested that missing cases were not missing completely at random (Little, 1988). Multiple imputation was employed to address the missing data using the mice package in R (van Buuren and Groothuis-Oudshoorn, 2011). In addition, analyses using listwise deletion were also included as Supplementary Analyses section to ensure the robustness of the results.

In the first set of analyses, youth's internalizing symptoms at T2 were predicted by (I) family conflict at T1 and (II) youth's BOLD response in the VS during reward anticipation and reward receipt at T1 in mixed-effect models, controlling for youth's internalizing symptoms at T1 and other demographic covariates. Each predictor was examined in a separate model. Then, the second set of analyses was conducted to test the moderation effect of youth's BOLD response during reward processing (T1) on the association between family conflict (T1) and internalizing symptoms (T2), also controlling for youth's internalizing symptoms at T1 and other demographic covariates. For moderation analyses, predictor and moderator variables were mean-centered. The interaction effects were probed using the simple slope technique (Bauer and Curran, 2005), which estimates and presents the associations between family conflict and internalizing symptoms among youth with a low level (i.e. 1 s.d. below the mean) and a high level (1 s.d. above the mean) of VS activity during reward processing. Additional analyses with (I) dorsal striatal regions (i.e. caudate and putamen) during reward processing, (II) lateral and medial OFC during reward processing and (III) VS during loss processing were also conducted to examine whether the unique and interactive effects of neural activation on youth's internalizing symptoms are specific to the VS during reward processing.

Results

Bivariate correlations

Table 1 shows correlations between key variables examined in the current study. Youth's VS activation during reward anticipation was only weakly correlated or not correlated with such activation during reward receipt (left VS: $r = 0.02$, $P = 0.03$; right VS: $r = 0.01$,

Table 2. Moderation effects of youth's VS activation during reward receipt on the link between family conflict and internalizing symptoms

	Predicting youth's internalizing symptoms at T2					
	Model 1: left VS			Model 2: right VS		
	B	SE	β	B	SE	β
Youth's age	0.06	0.07	0.00	0.07	0.07	0.00
Youth's sex	0.23	0.09	0.02*	0.23	0.09	0.02*
Black	−0.61	0.17	−0.03***	−0.58	0.18	−0.03**
Hispanic	−0.06	0.14	−0.00	−0.03	0.14	−0.00
Asian	−0.31	0.29	−0.01	−0.29	0.28	−0.01
Others	−0.09	0.18	−0.00	−0.09	0.17	−0.00
Parents' educational attainment	0.07	0.05	0.01	0.07	0.05	0.01
Parents' marital status	−0.16	0.14	−0.01	−0.17	0.14	−0.01
Family financial adversity	0.06	0.04	0.01	0.07	0.05	0.01
Prior internalizing symptoms	0.67	0.01	0.67***	0.67	0.01	0.67***
Family conflict	0.06	0.02	0.02**	0.06	0.02	0.02**
VS activation	−0.33	−0.12	−0.02**	−0.22	0.13	−0.01
VS activation × family conflict	0.14	0.06	0.02*	0.17	0.06	0.02**

Note: For youth's sex, 0 = male and 1 = female; for race/ethnicity, Black, Hispanic, Asian and Others represent the contrast *vs* White; parents' educational attainment ranges from 1 = less than a high school diploma to 5 = postgraduate degree; for parents' marital status, 0 = not married or living together with a partner, 1 = married or living together with a partner.
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

$P = 0.43$). Youth's VS activation during reward processing was generally not correlated with their internalizing at both timepoints. Family conflict was correlated with more internalizing symptoms among youth at both T1 and T2 ($r > 0.07$, $P < 0.001$). Girls experienced more internalizing symptoms than boys at T2 ($r = 0.03$, $P = 0.007$) but not T1 ($r = 0.01$, $P = 0.44$); parents' educational attainment ($r < -0.03$, $P < 0.01$), primary caregiver living together with a partner ($r < -0.05$, $P < 0.001$) and financial adversity ($r > 0.13$, $P < 0.001$) were correlated with youth's internalizing symptoms at both T1 and T2.

Family conflict, reward sensitivity and internalizing symptoms

The first set of analyses examined whether youth's internalizing symptoms at T2 were predicted by (I) family conflict and (II) youth's VS activation during reward anticipation and reward receipt at T1. Results showed that greater family conflict at T1 predicted increased internalizing symptoms at T2 ($\beta = 0.02$, $P = 0.007$), adjusting for internalizing symptoms and other demographic covariates. Moreover, youth's left VS activation during reward receipt at T1 predicted their reduced internalizing symptoms at T2 ($\beta = -0.02$, $P = 0.02$), adjusting for internalizing symptoms and other covariates. However, right VS activation during reward receipt at T1 was not significantly predictive of internalizing symptoms over time ($\beta = -0.01$, $P = 0.13$). In addition, VS activation during reward anticipation at T1 also did not predict internalizing symptoms over time (left VS: $\beta = 0.00$, $P = 0.81$; right VS: $\beta = 0.01$, $P = 0.23$).

The interaction between family conflict and reward sensitivity

The second set of analyses examined whether youth's neural activation during reward processing moderated the longitudinal association between family conflict and youth's internalizing symptoms. VS activation during reward anticipation did not moderate the link between family conflict and youth's internalizing symptoms (left VS × family conflict: $\beta = 0.00$, $P = 0.99$; right VS × family conflict: $\beta = 0.00$, $P = 0.83$). However, results showed that there was an interaction effect between family conflict and VS activation during reward receipt in predicting youth's internalizing symptoms over time. As shown in Table 2, youth's left and right VS activation during reward receipt moderated the link between family conflict and their internalizing symptoms over time (left VS × family conflict in Model 1: $\beta = 0.02$, $P = 0.02$; right VS × family conflict in Model 2: $\beta = 0.02$, $P = 0.004$). Then, two simple slopes of the longitudinal associations between family conflict and internalizing symptoms were estimated and plotted: one for youth with low VS activation (i.e. 1 s.d. below the mean) and the other for youth with high VS activation (i.e. 1 s.d. above the mean). *t*-tests were performed to estimate whether the unstandardized simple slopes were significantly different from zero. As shown in Figure 1, when youth's VS activation during reward receipt was high, there was a linear association between family conflict and youth internalizing symptoms, with greater family conflict predicting increased internalizing symptoms among youth over time (high left VS activation: unstandardized simple slope = 0.10, $P < 0.001$; high right VS activation: unstandardized simple slope = 0.11, $P < 0.001$). In contrast, when youth's VS activation during reward receipt was low, family conflict was not significantly associated with youth's internalizing symptoms over time (low left VS activation: unstandardized simple slope = 0.01, $P = 0.64$; low right VS activation: unstandardized simple slope = 0.00, $P = 0.88$), such that youth with low VS activation during reward receipt showed high levels of internalizing symptoms regardless of the family environment they lived in.

Supplementary analyses

Additional analyses were conducted to examine if the aforementioned effects were specific to VS activation during reward processing. First, the same sets of main and interaction effects models were conducted with dorsal striatum (i.e. caudate and putamen) activation during reward processing. Left caudate, right caudate, left putamen and right putamen were included in separate models. Results indicated that youth's caudate and putamen activation during reward anticipation (caudate: $\beta < 0.01$, $P > 0.25$; putamen: $\beta < 0.01$, $P > 0.75$) and reward receipt (caudate: $\beta < 0.01$,

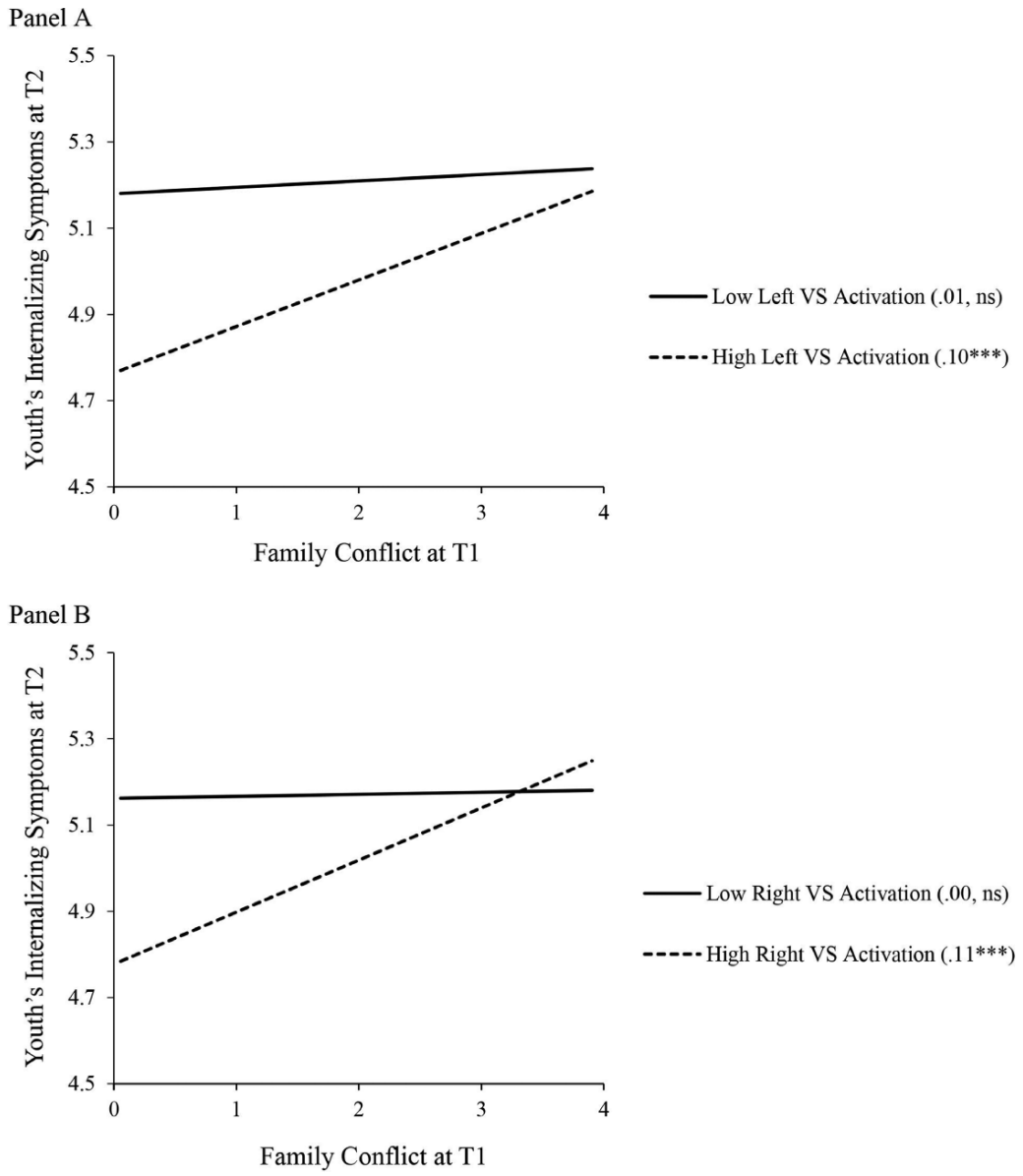

Fig. 1. The associations between family conflict and youth's later internalizing symptoms were moderated by left and right VS activation during reward receipt. *Note:* Youth's internalizing symptoms at TI, and other demographic covariates were controlled in the analyses. Low (or high) VS activation is 1 s.d. below (or above) the mean. The numbers in parentheses are unstandardized simple slopes. *** P<.001. Abbreviation: ns, not significant.

$P > 0.26$; putamen: $\beta < 0.01$, $P > 0.38$) did not predict their internalizing symptoms over time. Similarly, youth's caudate and putamen activation during reward anticipation (caudate: $\beta < 0.01$, $P > 0.51$; putamen: $\beta < 0.01$, $P > 0.66$) and reward receipt (caudate: $\beta < 0.01$, $P > 0.24$; putamen: $\beta < 0.01$, $P > 0.50$) did not moderate the longitudinal association between family conflict and youth's internalizing symptoms.

Second, the same sets of main and interaction effects models were conducted with lateral and medial OFC activation during reward processing. Left lateral OFC, right lateral OFC, left medial OFC and right medial OFC were included in separate models. Results indicated that youth's lateral and medial OFC activation during reward anticipation (lateral OFC: $\beta < 0.01$, $P > 0.43$; medial OFC: $\beta < 0.01$, $P > 0.92$) and reward receipt (lateral OFC: $\beta < 0.01$, $P > 0.68$; medial OFC: $\beta < 0.01$, $P > 0.56$) did not predict their internalizing symptoms over time. Similarly, youth's lateral and medial OFC activation during reward anticipation (lateral OFC: $\beta < 0.01$, $P > 0.58$; medial OFC: $\beta < 0.01$, $P > 0.27$) and reward receipt (lateral OFC: $\beta < 0.02$, $P > 0.07$; medial OFC: $\beta < 0.02$, $P > 0.07$) did not moderate the longitudinal association between family conflict and youth's internalizing symptoms.

Finally, the same sets of main and interaction effects models were conducted with VS activation during loss processing. Left VS and right VS were included in separate models. Results indicated that youth's VS activation during loss anticipation (left VS: $\beta = -0.00$, $P = 1.00$; right VS: $\beta = 0.01$, $P = 0.09$) and loss receipt (left VS: $\beta = 0.01$, $P = 0.06$; right VS: $\beta = 0.01$, $P = 0.17$) did not predict their internalizing symptoms over time. Similarly, youth's VS activation during loss anticipation (left VS: $\beta = 0.01$, $P = 0.10$; right VS: $\beta = 0.00$, $P = 0.98$) and loss receipt (left VS: $\beta = 0.00$, $P = 0.21$; right VS: $\beta = 0.01$, $P = 0.06$) did not moderate the longitudinal

association between family conflict and youth's internalizing symptoms.

All the models were also analyzed again using listwise deletion. No meaningful changes in results were found. More specifically, family conflict predicted increased internalizing symptoms over time ($\beta = 0.02$, $P = 0.01$). Left VS activation during reward receipt predicted reduced internalizing symptoms over time ($\beta = -0.02$, $P = 0.04$), whereas right VS activation during reward receipt was not significantly predictive of internalizing symptoms over time ($\beta = -0.01$, $P = 0.18$). VS activation during reward anticipation also did not predict internalizing symptoms over time ($\beta < 0.01$, $P > 0.24$). Moderation results remained the same as well. Youth's VS activation during reward receipt moderated the longitudinal associations between family conflict and their internalizing symptoms (left VS × family conflict in Model 1: $\beta = 0.02$, $P = 0.01$; right VS × family conflict in Model 2: $\beta = 0.02$, $P = 0.003$). The simple slopes analyses showed the same pattern that greater family conflict predicted increased internalizing symptoms over time when VS activation during reward receipt was high (unstandardized simple slopes > 0.10, $P < 0.001$) but did not when VS activation during reward receipt was low (unstandardized simple slopes < 0.01, $P > 0.87$).

Discussion

Adolescence is a time of psychological and emotional changes (Lee *et al.*, 2014; Maciejewski *et al.*, 2015). Previous studies found that high family conflict (Delgado *et al.*, 2019; Weymouth *et al.*, 2019) and low neural reward sensitivity (Bress *et al.*, 2012; Toenders *et al.*, 2019) can be risk factors for youth's mental health. However, it remains unknown how family conflict and reward sensitivity uniquely and interactively predict youth's psychological adjustment over time. Using a large-scale longitudinal sample from the ABCD study, the current research found that higher family conflict was predictive of increased internalizing symptoms, whereas higher VS activity during reward receipt was predictive of decreased internalizing symptoms over 1 year during preadolescence. Notably, there was an interaction effect between family conflict and VS in predicting internalizing symptoms over time. For youth with higher levels of VS activation to reward receipt, family conflict was associated with increased internalizing symptoms over time; in contrast, youth with lower levels of VS activation to reward receipt showed high levels of internalizing symptoms regardless of the levels of family conflict. Additional analyses examining the dorsal striatum regions and the OFC during reward processing and the VS during loss processing did not show similar main and moderation effects.

Consistent with prior research probing the link between family conflict and youth's mental health (e.g. Zhou and Buehler, 2017; Delgado *et al.*, 2019; Weymouth *et al.*, 2019), family conflict was longitudinally associated with increased internalizing symptoms over 1 year during preadolescence. Moreover, high VS activation during reward receipt was associated with reduced internalizing symptoms over time, also in line with findings of previous studies on depression (Hanson *et al.*, 2015; Toenders *et al.*, 2019). However, VS activation during reward anticipation was not predictive of youth's internalizing symptoms over time. This suggests that neural processes during reward anticipation and reward receipt are distinct from each other; while anticipation emphasizes the processing of potential reward opportunities, receipt emphasizes the processing of reward-related results (Oldham *et al.*, 2018). The difference in processing is also consistent with prior findings on how they develop differently during adolescence (Hoogendam *et al.*, 2013). Indeed, in the current study, VS activation during reward anticipation was not highly correlated with such activation during reward receipt (left VS: $r = 0.02$, $P = 0.03$; right VS: $r = 0.01$, $P = 0.43$), which is in line with prior studies that suggest the differences in neural response between anticipation and receipt of reward (Pornpattananangkul and Nusslock, 2015; Simon *et al.*, 2015).

Importantly, youth's VS activation to reward receipt (i.e. positive reward feedback minus negative reward feedback) moderated the longitudinal associations between family conflict and mental health, such that family conflict was associated with increased internalizing symptoms over time among youth with higher, but not lower, VS activation to reward receipt. These results suggest that youth who are highly sensitive to reward may be more susceptible to the influence of adverse family environments. The interactive roles of family conflict and neural reward sensitivity are in line with the theory of neurobiological susceptibility to social contexts (Schriber and Guyer, 2016). The results can also be interpreted as only youth who show higher neural reward sensitivity benefit from a low conflict family environment. The vantage sensitivity theory suggests that variations in response to positive experiences are a function of individual endogenous characteristics (Pluess and Belsky, 2013). In line with the vantage sensitivity theory, our results suggest that heightened neural reward sensitivity amplifies youth's positive response to nurturing and supportive environments (i.e. low family conflict). Moreover, there were no significant interaction effects between family conflict and youth's VS during loss receipt, which suggests that reward sensitivity but not the sensitivity to monetary feedback, in general, is an indicator of susceptibility to family conflict. Taken together, the findings of the current research extended prior empirical evidence on youth's externalizing symptoms (Turpyn *et al.*, 2021), demonstrating that VS activity during reward processing may be an indicator of neurobiological susceptibility and vantage sensitivity to family contexts on youth's internalizing symptoms.

Youth who show higher neural reward sensitivity are likely to be highly tuned to their interactions with other family members, because such interactions can be potentially rewarding in the forms of acceptance, approval and praise, especially in families with low levels of conflict. However, in families with high levels of conflict, interactions between family members tend to end up with disagreement or even criticism, which eventually lead to family-wide emotional insecurity (Cummings *et al.*, 2015). Therefore, youth who are highly tuned to social interactions in the family are more likely to be affected by maladaptive family contexts such as high family conflict. Given greater neural sensitivity to reward (Casey *et al.*, 2008; Crone and Dahl, 2012), adolescents may be especially sensitive to the influence of the family environment. Therefore, it is particularly important for parents, communities and the overall society to cultivate a supportive family environment for youth's healthy psychological development.

In contrast, youth who show lower neural reward sensitivity may be more resistant to influences of social contexts and thus less affected by the family environment. Results of the current study suggest that youth with lower neural sensitivity to reward show high levels of internalizing symptoms regardless of the family environment they lived in. Although youth with higher (*vs* lower) VS activation to reward receipt were under a greater influence of family conflict, their levels of internalizing symptoms did not exceed the levels of their counterparts with lower neural reward sensitivity even in families with high family conflict. These findings suggest that dampened neural reward sensitivity acts as a significant neural risk factor for internalizing symptoms

over time, rendering family conflict a lesser role to play in youth's psychological adjustment.

Limitations and future directions

There are several limitations in the current study that point to directions for future research. First, the findings of the current research were correlational. Therefore, causality should be interpreted with caution. Second, the present study was limited in what brain regions we could explore because we used the estimations of the regions of interest provided by the ABCD team. Alternative to the atlases used in the ABCD study, other specific anatomic atlases have been tailored to accommodate questions in clinical neuroscience (e.g. Rolls *et al.*, 2020). Therefore, it is necessary for future research to examine the link between family conflict and youth's internalizing symptoms using alternative atlases. Third, the effect sizes of the longitudinal associations of family conflict and neural reward sensitivity with internalizing symptoms were generally small, and thus, the clinical implications of the findings should be taken with caution. Fourth, the current research only focused on youth's neurobiological susceptibility to family context. Future research should examine other social contexts (e.g. peer, school and neighborhood) and how they interact with youth's reward sensitivity. Finally, the current study only examined neural reward sensitivity as a marker of susceptibility to adverse family environments among youth during preadolescence. It is important for future studies to examine the role of neural reward sensitivity in youth's psychological adjustment during other phases of adolescence and how such associations change over the course of adolescence potentially using data from future releases of the ABCD study.

Conclusions

Given the extensive emotion and mood changes during adolescence, it is important to identify protective and risk factors for youth's psychological adjustment. Using a large-scale longitudinal sample, our results suggest that family conflict predicts increased internalizing symptoms and neural reward sensitivity predicts decreased internalizing symptoms among youth over time. Notably, the current study provides evidence that the VS may serve as a marker of neurobiological susceptibility to the family environment in predicting youth's internalizing symptoms over time. Given that adolescents typically show heightened sensitivity to reward compared to other age groups, it is crucial to cultivate a supportive family environment where youth have less exposure to stress or conflict. In addition, family interventions on youth mental health should consider tailoring the content based on youth's neurobiological characteristics; while youth with heightened sensitivity may benefit more from reduced family conflict, youth with lower sensitivity may benefit from general support to provide more resources and directly target internalizing symptoms. Our findings on neural reward sensitivity as a marker of neurobiological susceptibility to the family environment can help future policies and interventions to uplift youth who may benefit the most in positive youth development.

Data availability

Data used in the preparation of this article were obtained from the ABCD[SM] Study (https://abcdstudy.org), held in the NIMH Data Archive. This is a multisite, longitudinal study designed to recruit more than 10 000 children aged 9–10 years and follow them over 10 years into early adulthood. The ABCD data repository grows and changes over time. The ABCD data used in this report came from http://dx.doi.org/10.15154/1523041.

Author contributions

Beiming Yang (Conceptualization [equal], Data curation [supporting], Formal Analysis [equal], Software [equal], Visualization [lead], Writing—original draft [equal], Writing—review & editing [supporting]), Zachary Anderson (Writing—original draft [equal], Writing—review & editing [supporting]), Zexi Zhou (Formal Analysis [equal], Software [equal], Writing—review & editing [supporting]), Sihong Liu (Data curation [supporting], Writing—review & editing [supporting]), Claudia M. Haase (Data curation [supporting], Writing—review & editing [supporting]), and Yang Qu (Conceptualization [equal], Methodology [lead], Writing—review & editing [supporting], Project administration [lead], Resources [lead], Supervision [lead], Funding acquisition [lead]).

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Conflict of interest

The authors declared that they had no conflict of interest with respect to their authorship or the publication of this article.

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