Adolescent Depressive Symptoms: The Role of Late Childhood Frontal EEG Asymmetry, Executive Function, and Adolescent Cognitive Reappraisal

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Abstract

Cognitive reappraisal is adaptive for decreasing symptoms of depression; however, a gap in the research is understanding the childhood processes that contribute to cognitive reappraisal in adolescence. This study examined executive function and frontal electroencephalogram (EEG) asymmetry during late childhood as predictors of adolescent cognitive reappraisal and depressive symptoms. Data were from 123 participants in late childhood (age 10) and adolescence (age 14.5). A moderated mediation model was fit to the data to examine frontal EEG asymmetry as a moderator in the relation between late childhood inhibitory control and adolescent cognitive reappraisal as well as adolescent cognitive reappraisal and adolescent depressive symptoms. Results indicated lower inhibitory control was associated with lower cognitive reappraisal when children had right frontal EEG asymmetry. Lower cognitive reappraisal in turn was associated with higher depressive symptoms for children with right frontal EEG asymmetry. Working memory and cognitive flexibility were also examined but were not significant indicators. Results suggest the potential for targeting inhibitory control and cognitive reappraisal to diminish depressive symptoms particularly among adolescents with right frontal EEG asymmetry.

Keywords Adolescence · Late childhood · Cognitive reappraisal · Depressive symptoms · Inhibitory control · Frontal EEG asymmetry

Introduction

Emotion regulation continues to develop through adolescence, with strategies becoming more complex by implementing greater cognitive abilities as children develop (Pons et al., 2004). Two strategies that have received much attention in the literature are antecedent and response-focused strategies associated with the process model of emotion regulation (Gross & Thompson, 2007; Gross, 1998a). Antecedent focused strategies modify the emotional input by engaging in cognitive reframing, such as cognitive reappraisal (CR), which is believed to be adaptive to individual functioning (Gross, 1998b; McRae, 2016). Response-focused strategies, like expressive suppression, modify the

behavioral response following an emotion and have been considered maladaptive (Gross, 1998b).

The process model has been used extensively in adulthood research; more recently the process model has been applied to childhood and adolescent research (Chen et al., 2019; Parsafar & Davis, 2019). We incorporated the process model to examine whether executive function and frontal electroencephalogram (EEG) asymmetry (FA) may be important for CR and depressive symptoms among adolescents.

Executive Function and Depressive Symptoms

Executive functions are higher order cognitive processes, including inhibition, working memory, and cognitive flexibility, linked to the prefrontal cortex and associated with goal directed behavior (Diamond, 2013). In adults, executive function impairment is associated with depression (Cotrena et al., 2016; Fossati et al., 2002). As well, adult patients diagnosed with depressive disorder show marked deficits in executive function tasks when compared to control groups

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(Alves et al., 2014). After adults show improvements in depression, they subsequently show improvements in executive function (Biringer et al., 2005). The association between executive function and depression symptoms in childhood and adolescence show similar associations. Lower executive function is observed among clinically referred adolescents with depressive disorder (Holler et al., 2014). Adolescents of parents diagnosed with a depressive disorder, and thus at risk of developing depression themselves, have fewer depressive symptoms when they have better inhibitory control and cognitive flexibility (Davidovich et al., 2016). Emotion regulation may serve as a mechanism in the association between executive function and depressive symptoms. For instance, adults with attentional control deficits are more likely to engage in rumination as an emotion regulation strategy, which is subsequently associated with increasing levels of depression (DeJong et al., 2019).

Cognitive Reappraisal as a Mediator

Research indicates that adolescent emotion regulation strategies are important for minimizing adolescent depression (Shapero et al., 2019). CR may be one emotion regulation strategy that may help to mitigate these effects in adolescence. CR involves changes to thoughts about an emotional event by using positive reframing to alter the emotional experience and change the emotional impact (Lazarus & Alfert, 1964). Among adolescents, less adaptive use of CR is linked to greater clinical levels of anxiety and depression (Dryman & Heimberg, 2018; Young et al., 2019). Similarly, CR offsets the association between depressive symptoms and emotional responses to stress in adolescents (Shapero et al., 2019). In adults, being unable to inhibit negative emotions is linked to lower CR use compared to those who are more capable of inhibiting negative emotion; less use of CR is consequently linked to more depression (Joormann & Gotlib, 2010).

In children and adolescents, research indicates some association between executive function and depression (Vilgis et al., 2015), but there is little research examining potential mechanisms of this association in these age groups. Some research indicates that maladaptive and adaptive emotion regulation strategies mediate the association between executive function and depression in adolescents. Adolescents with greater executive function impairment show more maladaptive and less adaptive emotion regulation, which in turn is associated with depressive symptoms. Adolescents with more adaptive emotion regulation show fewer depressive symptoms (Wante et al., 2017). Among young adults, both CR and expressive suppression mediate the relation between executive function and depressive symptoms, with CR being associated with lower depressive symptoms (Hui et al., 2021). Both of these studies collected executive function

through questionnaires, all variables were collected during one time-point, and the studies were conducted with clinically referred samples. Our study extends previous research by examining these relations longitudinally and using task-specific executive function measures among a community sample.

Executive function during late childhood may be an important factor that contributes to CR ability during adolescence which then impacts depressive symptoms. In adults the research examining associations between executive function, CR, and maladaptive outcomes is well-established, but this research is minimal in childhood and adolescence (Cotrena et al., 2016; Opitz et al., 2012; Schmeichel & Tang, 2015). Research examining associations between executive function and CR in 9- to 12-year-old children indicates that executive function ability precedes CR (Andrés et al., 2016). Specifically, when adolescents self-report better executive function, they indicate higher CR. Other research shows that adolescents who indicate greater reliance on emotion suppression, rather than CR, report more difficulties with working memory (Lantrip et al., 2016). Among adulthood research which examines executive function and CR links, the specific executive function measures which are associated to CR ability vary; thus, creating executive function composite scores may not be appropriate. Hence, our study examines executive function factors separately (i.e., inhibition, cognitive flexibility, and working memory), similar to previous adulthood research (Hendricks & Buchanan, 2016; McRae et al., 2012; Schmeichel & Tang, 2014). Further, we focused on executive function during late childhood as this is a time when maturation of neural circuits occurs and children become more capable of engaging multiple executive function, this is also a time when we see children's ability to understand that changing thoughts can change emotions, a key component of CR (Best & Miller, 2010; Nagy et al., 2004; Pons et al., 2004).

Frontal Asymmetry as a Moderator

FA is measured through the use of EEG, which measures electrical activity from the scalp. FA provides information on individuals' trait and state neurological correlates in emotion focused contexts. FA is the increased activation of either the right or left frontal hemisphere in relation to the other hemisphere and is associated with the behavioral expression and regulation of emotions (Fox, 1994; Fox et al., 1996). The approach/withdrawal model of resting state EEG proposes that greater left FA is associated with approach behavioral responses and positive affect, whereas greater right FA is associated with withdrawal behavioral responses and negative affect (Fox, 1994). We focused on trait FA as a moderator in our model because examining trait FA (i.e., during rest or baseline) provides information regarding the individual's

capacity to engage and recruit cognitive and affective processes specific to the individual (Reznik & Allen, 2018). In addition, greater right FA during baseline or resting state is linked with depression in adults and their children (e.g., Thibodeau et al., 2006).

Research examining direct links between FA and CR indicate that both state and trait left FA is associated with greater CR ability (Choi et al., 2016; Papousek et al., 2017; Wang et al., 2015). In a sample of 54 adolescents instructed to engage in a CR task, adolescents who engaged habitual CR showed greater left FA during the emotional tasks (Yang et al., 2021). Adulthood research that has examined the link between FA and CR indicates that left FA during resting state is greater among habitual cognitive reappraisers who are male, but not female. When individuals were instructed to engage CR, they displayed greater task left FA regardless of sex (Choi et al., 2016). In a study of adults ages 18 to 35, those who had a higher capacity for generating CR displayed greater left FA during the CR generation task (Papousek et al., 2017). Although FA has not been examined as a moderator between executive function and CR, executive function informs us of children's ability to adequately face cognitive challenges. If children are incapable of recruiting adequate cognitive processes for successful emotion regulation strategies, then left FA may provide children with the capacity to engage brain electrical processes necessary for the successful implementation of CR for diminishing depressive symptoms in adolescence (Sudikoff et al., 2015).

Furthermore, we are unaware of any research that has examined whether FA moderates CR outcomes, although FA has been used extensively in emotion regulation research as a moderator of emotional outcomes (Reznik & Allen, 2018). Research in children who are at an increased risk of depression indicates that left FA and CR diminish depressive outcomes (Kudinova et al., 2018; Lopez-Duran et al., 2012). Cognitive reappraisal and FA may also interact to predict differences in depressive symptoms. When comparing emotion regulation and FA among a sample of maltreated and nonmaltreated children, results indicated that among the nonmaltreated group, resilience scores increased as a function of emotion regulation and not FA. Among the maltreated group only, trait FA had a direct effect on resilience scores after accounting for emotion regulation; specifically, children with trait left FA showed higher resilience scores than children with right FA (Curtis & Cicchetti, 2007). Hence, trait left FA may serve as a protective factor for adolescent depressive symptoms.

Current Study

We examined individual difference factors that have previously been associated with both CR and depressive symptoms in the adulthood literature and examined them in a sample of community adolescents. We tested our model through moderated mediation and hypothesized that FA would moderate the association between executive function and CR, such that greater executive function (i.e., inhibitory control, working memory, cognitive flexibility) would be associated with greater CR ability only for adolescents with left FA. Higher CR ability would in turn be associated with lower depressive symptoms for adolescents with left FA. Individual executive function factor differences were not hypothesized due to previous research having mixed findings (Andrés et al., 2016; McRae et al., 2012; Tabibnia et al., 2011).

Method

Participants

Participants were cohort 1 and cohort 2 of a longitudinal study examining the integration of emotion and cognition across early development. Participants were recruited during infancy using flyers, word of mouth, and mailing lists. The two cohorts participating in the current study represent half of the original sample. Cohort 3 was recruited by a university research lab in another state and ended the longitudinal study in middle childhood, with no adolescent follow-up visit. The current study examines data from cohort 1 and cohort 2, from the late childhood and adolescent visits.

In late childhood, cohort 1 visited the research lab during 2013 (n = 81) and cohort 2 visited the lab in 2016 (n = 80). In addition, 31 questionnaires were completed and mailed back to us for cohort 1 (n = 11) and cohort 2 (n = 20) from families who were unable to visit the research lab. Thus, the late childhood sample consisted of 192 children (range 9 – 12 years; $M = 9.92$, $SD = 0.74$) and their mothers. The sample was 85% White, 4% Hispanic, 9% Multi-racial/other, 1.5% Asian, and 0.5% Black. Only participants who contributed data during the late childhood visit were recruited for the adolescent visit.

The adolescent visit consisted of 78 in-lab participants and 45 questionnaire-only participants, for a total of 123 adolescents (51% girls) and their mothers. Due to COVID-19, in-lab visits for tasks and questionnaires (mid-August 2019 through mid-March 2020) were halted and data collection resumed online (late August through early October 2020) with questionnaires. There were 79 dyads who completed data pre-COVID-19, with 78 in-lab and one questionnaire-only family. During COVID-19, 44 questionnaire-only participants provided data. Adolescent age range (range 12 – 18 years; $M = 14.64$, $SD = 1.94$) at the time of participation was wide due to the mean 3-year age difference between cohorts 1 and 2. Thus, the adolescent visit consisted of cohort 1 (n = 57; range 15 – 18 years; $M = 16.6$, SD = 0.72) and cohort

2 (n = 66; range 12 – 14.5 years; $M = 12.95$, $SD = 0.63$). For the combined adolescent participants, 88% identified as White/Caucasian, 6% Multi-racial/other, 5% Hispanic, and 1% Asian. Mothers were highly educated (85% had a college degree or advanced degree).

We examined whether differences emerged on late childhood FA, late childhood executive function measures, sex, and maternal education for those participants who did and did not contribute data during adolescence. ANOVA revealed no significant differences for FA, executive function measures, and maternal education (all p's > 0.30). To further examine whether differences in sex were observed for those adolescents who came into the research lab during the adolescent visit, a chi square test was conducted, no significant differences emerged ($p = 0.14$).

Procedures

Families visited the research lab (or completed and mailed in questionnaire packets) during late childhood and during adolescence. For both visits, participants entered the research lab with their parent, parents provided their written consent, and children/adolescents provided their written assent prior to starting the study. For both visits, mothers observed from an adjacent room while completing questionnaires. Institutional Review Board approval was obtained from the Virginia Tech IRB, protocol number 12-947 titled "Psychobiology of Cognitive Development in Middle Childhood" for the age 9 visit and by the Biomedical Research Alliance of New York (BRANY) IRB protocol numbers 19-030-568/19-352 titled "Psychobiology of Cognitive Development in Early Adolescence" for the adolescent visit.

During the late childhood visit, children were compensated with a $20 gift card and mothers with a $75 gift card for in-lab visits. Families who only completed questionnaires received two $20 gift cards, one for the child and one for the parent. During the adolescent visit, in-lab participants were compensated $50 cash for the adolescent and $50 cash for the mother. For the questionnaire only families, adolescent and the mother received a $20 gift card.

Measures Collected During Late Childhood

Frontal EEG Asymmetry Baseline EEG was collected during a two-minute video (opening scene from *The Lion King*). Children were capped using a stretch cap (Electro-Cap, Inc.; Eaton, OH; E1-series cap) with electrodes in a modified 10/20 system pattern. EEG recordings were collected from 26 left, right, and midline scalp sites evenly distributed across the scalp. After the cap was positioned, abrasive gel was placed and gently rubbed at each electrode site.

Conductive gel was then added at each electrode site. Electrode impedances were measured and accepted below 10Ω. EEG electrical activity was amplified from each lead using separate James Long Company Bioamps and bandpassed from 0.1 to 100 Hz. EEG signal was digitized on-line at 512 samples per second for each channel so that the data would not be affected by aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp., Southfield, MI) and EEG Analysis software developed by the James Long Company (Caroga Lake, NY) was used for EEG processing. The data were re-referenced via software to an average reference configuration and then artifact scored for eye movements and gross motor artifact. Artifacted epochs were eliminated from all subsequent analyses. The EEG data was analyzed using a discrete Fourier Transform (*DF*T) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 8-10 Hz frequency band. This frequency band has been used by others publishing FA research with children in late childhood (Forbes et al., 2008; Vuga et al., 2008). Data were log (ln) transformed to normalize EEG values. FA values were created by subtracting ln EEG power in the left hemisphere (F3) from ln EEG power in the right hemisphere (F4). Because of the inverse association between power values and activation, positive values indicate greater relative left frontal activation compared to the right (i.e., left FA) and negative values indicate greater relative right frontal activation compared to the left (i.e., right FA).

Working Memory Working memory was measured through the Backward digit span task. In this task, the experimenter read a series of random single-digit numbers to participants. Children were asked to repeat out loud the numbers in reverse order, with practice trial of two sets of two digits. After children passed the practice trial, the test trials were collected. Test trials included two different three-digit sequences, increasing one single-digit for both trials in the sequence until participants failed to correctly repeat the digits in both trials of the sequence. The variable of interest was the last correct trial as an indicator of backward digit span score.

Cognitive Flexibility Cognitive flexibility was measured using the Wisconsin Card Sorting Test (WCST; Heaton & Staff, 2003). For this computerized task, children were instructed to match a card of 64 total cards to one of four key cards. Images on the cards varied from shape, color, and quantity, children were asked to sort the cards according to one of three rules (e.g., by shape, by color, or by number) that they had to determine based on feedback from the computer. The sorting rules changed several times throughout the task, with computer feedback informing children of their errors. The age-standardized percentile score associated with conceptual level was the measure of interest.

Inhibitory Control We measured inhibitory control through the Number Stroop (Ruffman et al., 2001). Three conditions were administered. During the letter or control condition, trials consisted of a string of letters on the computer screen. Children were instructed to count the number of letters as quickly and accurately as possible and press the corresponding keyboard number. For the incongruent condition, children were presented with a series of numbers and asked to select the number that corresponded with the total number of items on the screen (e.g., 5555 would be 4). In the mixed condition, children were presented with either strings of letters or strings of numbers and asked to count the items in the string. The measure of interest was reaction time in the mixed condition, with faster reaction times (i.e., lower values) indicative of better inhibitory control.

Measures Collected During Adolescence

Cognitive Reappraisal Adolescents were asked to complete the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003). The ERQ is a 10-item self-report questionnaire that asks respondents to rate their use of different emotion regulation strategies from 1 (*strongly disagree*) to 7 (*strongly agree*) with two subscales, cognitive reappraisal (CR) and expressive suppression. The CR subscale was used. Cronbach's alpha for the CR subscale was 0.75.

Depressive Symptoms Adolescents self-reported depressive symptoms on the Revised Children's Anxiety and Depression Scale (RCADS). The questionnaire consists of 47 items, asking participants to rate how often certain things happen to them from 1 (*never*) to 4 (*always*). The RCADS consists of these subscales: separation anxiety disorder, social phobia, generalized anxiety disorder, panic disorder, obsessive compulsive disorder, and low mood (major depressive disorder). The low mood subscale raw score was used. Cronbach's alpha was 0.96.

Pubertal Status Adolescents self-reported pubertal status via the Pubertal Developmental Scale (PDS; Petersen et al., 1988). Participants rate growth on height, pubic hair, and skin changes. Both sexes then responded to two additional questions which asked boys to rate voice and facial hair changes, girls rated breast growth and onset of menarche. Ratings were reported using a 4-point Likert scale of 1 (*has not yet begun*) to 4 (*seems completed*), menarche was rated as a dichotomous 1 – "Yes" or 2 – "No". A response of Yes was recoded as 4, No was recoded as 1. The pubertal status score was averaged across the five corresponding items for both boys and girls. Cronbach's alpha for girls is 0.89 and for boys 0.94.

Analysis Plan

Analyses were conducted using MPlus version 8.3 (Muthén & Muthén, 1998-2017) with maximum likelihood estimation method. Data were missing completely at random using Little's missing completely at random (MCAR) test on study variables: $\chi^2 = 39.26$, df = 27, $p = 0.06$. To account for missing data, we used full information maximum likelihood estimation (FIML). Moderated mediation analysis was examined using 10000 bootstrap samples and 95% confidence intervals (CI); a CI that does not include zero indicates statistical significance of the parameter. We followed codes developed by Stride et al. (2015) to examine moderated mediation analyses using Model 58. Fit indices of root mean square error of approximation (RMSEA; McDonald & Ho, 2002), confirmatory fit index (CFI), standardized root mean square residual (SRMR), chi square (χ^2) were used to determine the fit of the model to the data for each hypothesis. The following cut offs were used; RMSEA < 0.08, SRMR < 0.08, CFI $\geq$ 0.95 (Hu & Bentler, 1999). We probed interaction terms if p values were 0.10 and lower given the difficulties in detecting interactions in non-experimental studies (McClelland & Judd, 1993; Whisman & McClelland, 2005). The index of moderated mediation was not used as it cannot be used when the indirect effect is not linear, such as when the predictor's effect on the mediator and the mediator's effect on the outcomes are both moderated by the same continuous variable (Edwards & Lambert, 2007; Hayes, 2015). All predictor and moderator variables were centered in order to minimize multicollinearity among the main effect and interaction effect variables.

Power Analysis

Power analyses were conducted to determine the necessary sample size to detect an effect. A-priori sample size calculator for multiple regression was used (Soper, 2021). For a moderated mediation model with 6 predictors, the minimum sample size needed to detect a medium effect ($f^2 = 0.15$) would be n = 97 with $1 - \beta = 0.80$, $\alpha = 0.05$.

Results

Outliers were handled through Winsorization, such that values 3 SD above or below the mean were replaced by the next closest value. This technique was applied to one outlier for FA. Descriptive statistics for all variables of interest at each visit are shown in Table 1.

To determine whether differences in questionnaire responses were evident due to COVID-19, *t*-tests were conducted with a pre- and during-COVID-19 grouping variable for the questionnaire responses. No significant differences

Table 1 Correlations and descriptive statistics among variables

	1	2	3	4	5	6
1. Frontal Asymmetry	1.00					
2. Inhibitory Control Number Stroop Test (ms)	0.08	1.00				
3. Working Memory Backward Digit Span Test	-0.13	-0.36**	1.00			
4. Cognitive Flexibility WCST	-0.17	-0.15	0.13	1.00		
5. Adolescent Cognitive Reappraisal (ERQ)	0.05	-0.23**	0.06	0.06	1.00	
6. Adolescent Depressive Symptoms (RCADS)	-0.16	0.02	-0.04	0.14	-0.28**	1.00
N	110	110	113	109	122	122
Mean	-0.008	2234.91	4.12	55.71	4.53	17.81
SD	0.18	570.46	0.77	35.73	1.01	5.75
Range	-0.48 – 0.43	1234.18 – 4074.92	2 – 6	2 – 99	1.83 – 7	10 – 39
Skewness	-0.01	0.60	-0.25	-0.21	-0.11	0.90
Kurtosis	0.10	-0.01	0.26	-1.61	0.27	0.93

RCADS is raw score

ms milliseconds, *WCST* Wisconsin card sorting test, *ERQ* emotion regulation questionnaire, *RCADS* revised - children's anxiety and depression scale

$*p < 0.05$; $**p < 0.01$

emerged. Pre- and during-Covid-19 means on all questionnaires are presented in Table 2. Sex, cohort (as a proxy for age), and pubertal status differences in adolescent CR and adolescent depressive symptoms were examined as well (see Table 2). *T*-tests revealed that adolescent depressive symptoms were significantly different when cohort and pubertal status was considered ($p < 0.05$), but not sex ($p = 0.19$). Therefore, age and pubertal status were included as covariates for all analyses.

Associations between task specific executive function and CR are mixed among the adulthood research, with some findings indicating only associations among some executive function factors and not others, although all executive function factors have been significantly linked to CR and depression in previous research (Andrés et al., 2016; Davidovich et al., 2016; Holler et al., 2014; McRae et al., 2012; Tabibnia et al., 2011; see Schmeichel & Tang, 2014, 2015 for comprehensive reviews). Therefore, we chose to address the previous research findings by examining each of the three executive function factors in separate models. For each model, we tested our hypothesis that the executive function component would predict CR, with FA as a moderator of that association. CR in turn would be related to depressive symptoms, with FA moderating that association.

Table 2 Sex, Cohort, and COVID Differences on Cognitive Reappraisal and Depressive symptoms

		N	Mean	SD	t-test
Adolescent Cognitive Reappraisal	Female	59	4.50	0.98	$t(120) = -0.32, p = 0.75$
	Male	63	4.56	1.04	
Adolescent Cognitive Reappraisal	Cohort 1	56	4.54	1.00	$t(120) = 0.03, p = 0.98$
	Cohort 2	66	4.53	1.02	
Adolescent Cognitive Reappraisal	Pre COVID -19	79	4.57	1.02	$t(120) = 0.61, p = 0.54$
	During COVID -19	43	4.46	1.00	
Adolescent Depressive Symptoms	Female	59	17.10	4.44	$t(120) = -1.32, p = 0.19$
	Male	63	18.48	6.70	
Adolescent Depressive Symptoms	Cohort 1	56	19.16	5.68	$t(120) = 2.44, p = 0.02$
	Cohort 2	66	16.67	5.59	
Adolescent Depressive Symptoms	Pre COVID -19	79	17.37	6.02	$t(120) = -1.16, p = 0.25$
	During COVID -19	43	18.63	5.18	

Cognitive Flexibility

The model with cognitive flexibility (WCST) demonstrated a poor fit ($\chi2 = 70.10$, $df = 9$, N = 123, $p < 0.001$; CFI = 0.00; RMSEA = 0.24; SRMR = 0.12). Modification indices indicated adding a correlation between pubertal status and age; after this correlation was included, model fit improved ($\chi2 = 4.82$, $df = 4$, N = 123, $p = 0.31$; CFI = 0.96; RMSEA = 0.04; SRMR = 0.03). Age was not a significant indicator of adolescent depressive symptoms and thus was removed from the model ($\chi2 = 4.15$, $df = 3$, N = 123, $p = 0.25$; CFI = 0.95; RMSEA = 0.06; SRMR = 0.03). Modification indices further indicated adding a correlation between FA and CR; the resulting model fit was indicative of a good fitting model ($\chi2 = 1.93$, $df = 2$, N = 123, $p = 0.38$; CFI = 1.00; RMSEA = 0.00; SRMR = 0.02).

Within the model, higher CR was associated with lower depressive symptoms, b = -1.82 ($\beta = -0.32$, $SE = 0.08$, $p < 0.001$, 95% CI [-2.73, -0.87]). In addition, higher pubertal status was associated with higher depressive symptoms b = 1.73 ($\beta = 0.25$, $SE = 0.09$, $p < 0.01$, 95% CI [0.54, 3.11]; Supplement Fig. S1). No other paths were significant.

Working Memory

The model with working memory (backward digit span test) initially demonstrated a poor fit ($\chi2 = 59.51$, $df = 9$, N = 123, $p = 0.00$; CFI = 0.00; RMSEA = 0.21; SRMR = 0.11). Modification indices indicated adding a correlation between pubertal status and age; after this correlation was included, model fit improved ($\chi2 = 4.85$, $df = 4$, N = 123, $p = 0.30$; CFI = 0.97; RMSEA = 0.04; SRMR = 0.03). Age was not a significant indicator of adolescent depressive symptoms and thus was removed ($\chi2 = 4.39$, $df = 3$, N = 123, $p = 0.22$; CFI = 0.95; RMSEA = 0.06; SRMR = 0.03). Modification indices indicated adding a correlation between FA and CR; the resulting model fit was indicative of a good fitting model ($\chi2 = 1.25$, $df = 2$, N = 123, $p = 0.54$; CFI = 1.00; RMSEA = 0.00; SRMR = 0.02).

Within the model, higher CR was associated with lower depressive symptoms, b = -1.81 ($\beta = -0.32$, $SE = 0.08$, $p < 0.001$, 95% CI [-2.75, -0.88]; Supplement Fig. S2). The interaction between CR and FA was not significant, b = 5.65 ($\beta = 0.17$, $SE = 0.10$, $p = 0.08$, 95% CI [-0.52, 12.06]), however, we further probed this interaction effect, considering the known difficulties in detecting interaction effects in non-experimental studies (McClelland & Judd, 1993; Whisman & McClelland, 2005). Simple slopes analysis revealed the effect of CR was significant for right FA, b = -2.60, $SE = 0.74$, 95% CI [-4.00, -1.10] but not for left FA, b = -1.02, $SE = 0.56$, 95% CI [-2.12, 0.06] (see Supplement Fig. S3). In addition, higher pubertal status was associated with higher depressive

symptoms b = 1.91 ($\beta = 0.27$, $SE = 0.09$, $p < 0.01$, 95% CI [0.69, 3.34]). No other paths were significant.

Inhibitory Control

We first analyzed the final model with the number Stroop task (inhibitory control), but the model did not converge, likely due to high variance within the task. We log-transformed the number Stroop task to minimize variance. After controlling for age and pubertal status, the model with inhibitory control (number Stroop task) was analyzed and demonstrated poor fit (i.e., $\chi2 = 67.71$, $df = 49$, N = 123, $p < 0.001$; CFI = 0.00; RMSEA = 0.23; SRMR = 0.12). Modification indices indicated adding a correlation between pubertal status and age; after this correlation was included, model fit improved ($\chi2 = 6.72$, $df = 4$, N = 123, $p = 0.16$; CFI = 0.91; RMSEA = 0.07; SRMR = 0.04). Within the model, age was not a significant indicator of depressive symptoms; thus, the path was trimmed for parsimony. Resulting model fit had room for improvement ($\chi2 = 5.21$, $df = 3$, N = 123, $p = 0.16$; CFI = 0.93; RMSEA = 0.08; SRMR = 0.04). Modification indices indicated adding a correlation between CR and the interaction variable. The final model was analyzed and demonstrated good fit ($\chi2 = 1.81$, $df = 2$, N = 123, $p = 0.40$; CFI = 1.00; RMSEA = 0.00; SRMR = 0.02).

Mediating Effect of Cognitive Reappraisal Moderated mediation analysis was examined using 10000 bootstrap samples and 95% confidence intervals (CI). As shown in Table 3 and summarized in Fig. 1, the direct association between inhibitory control and depressive symptoms was not significant. Instead, inhibitory control was directly associated with CR, b = -0.90 ($\beta = -0.23$, $SE = 0.09$, $p = 0.01$, 95% CI [-0.39, -0.04]), which in turn was significantly associated with depressive symptoms, b = -1.90 ($\beta = -0.33$, $SE = 0.08$, $p < 0.001$, 95% CI [-0.48, -0.17]). Worse late childhood inhibitory control (i.e., slower reaction time) was associated with lower adolescent CR, and lower CR was associated with higher depressive symptoms. Additionally, higher pubertal status was associated with higher depressive symptoms, b = 1.87 ($\beta = 0.26$, $SE = 0.08$, $p = 0.002$, 95% CI [0.63, 3.27]).

Moderated Mediation Effects The interaction effect between FA and inhibitory control on adolescent CR was not statistically significant at $p < 0.05$ (b = 3.69, $\beta = 0.16$, $SE = 0.09$, $p = 0.08$, 95% CI [-0.66, 7.56]; see Table 3 and Fig. 2). However, we further probed this interaction effect, given the known difficulties in detecting interaction effects in non-experimental studies (McClelland & Judd, 1993; Whisman & McClelland, 2005). Simple slopes analysis revealed the direct effect of inhibitory control on the mediator (i.e., CR) was conditional, such that it was significant only at lower levels of FA (i.e., right FA), b = -1.42, $SE = 0.44$, 95% CI

Table 3 Moderated mediation results

Predictors	Cognitive Reappraisal (M) Coeff. (SE)	Depressive Symptoms (Y) Coeff. (SE)
Pubertal Status	–	1.87 (0.65)**
IC	-0.90 (0.37)*	-1.84 (2.08)
IC X FA	3.69 (2.06) +	–
CR	–	-1.90 (0.49)***
CR X FA	–	5.69 (3.26) +

Conditional indirect effects	IC CR Depressive Symptoms Coeff. (SE)	95% CI
Low (Right FA)	3.82 (1.88)	0.99, 8.41
High (Left FA)	0.42 (0.70)	-0.46, 2.44

Coefficients are unstandardized; parentheses indicate the standard errors

IC inhibitory control, *FA* frontal EEG asymmetry, *CR* cognitive reappraisal

*** p < 0.001, **p < 0.01, *p < 0.05, +p < 0.10

[-2.31, -0.55] and not at higher levels of FA (i.e., left FA), b = -0.38, *SE* = 0.49, 95% CI [-1.37, 0.57]. Figure 2 provides a visual representation of the interaction between inhibitory control and FA on the mediator (i.e., CR).

Results indicated the moderation effect of FA on the association between the mediator (i.e., CR) and depressive

symptoms was not significant, b = 5.69 (β = 0.17, *SE* = 0.10, *p* = 0.08, 95% CI [-0.70, 11.78]; Fig. 3), however we further probed this interaction effect given the known difficulties in detecting interaction effects in non-experimental studies (McClelland & Judd, 1993; Whisman & McClelland, 2005). Simple slopes analysis revealed that the effect of CR
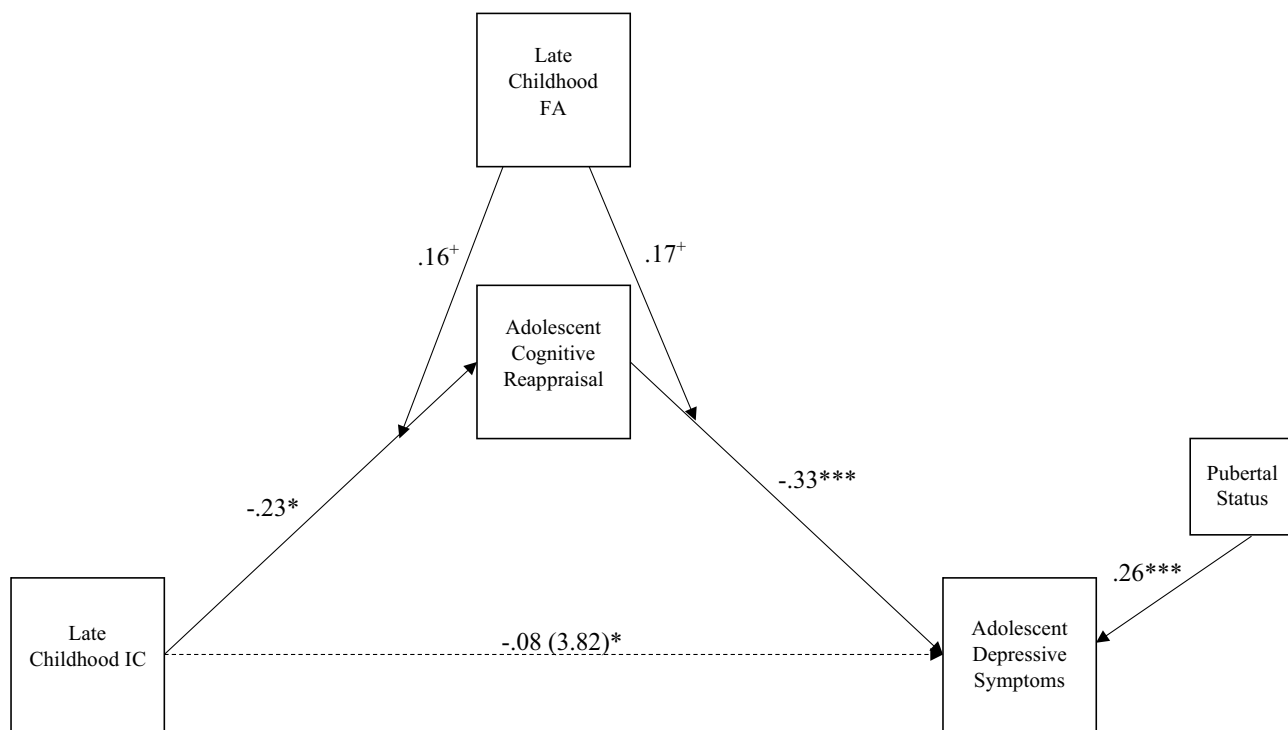

Fig. 1 Summarized model fitting results of associations among late childhood IC (inhibitory control), adolescent cognitive reappraisal, and adolescent depressive symptoms moderated by late childhood FA (frontal EEG asymmetry). Standardized estimates presented. Paren-

theses indicate the unstandardized indirect effect estimate of late childhood IC on adolescent depressive symptoms. **p < 0.01, *p < 0.05, +p < 0.10
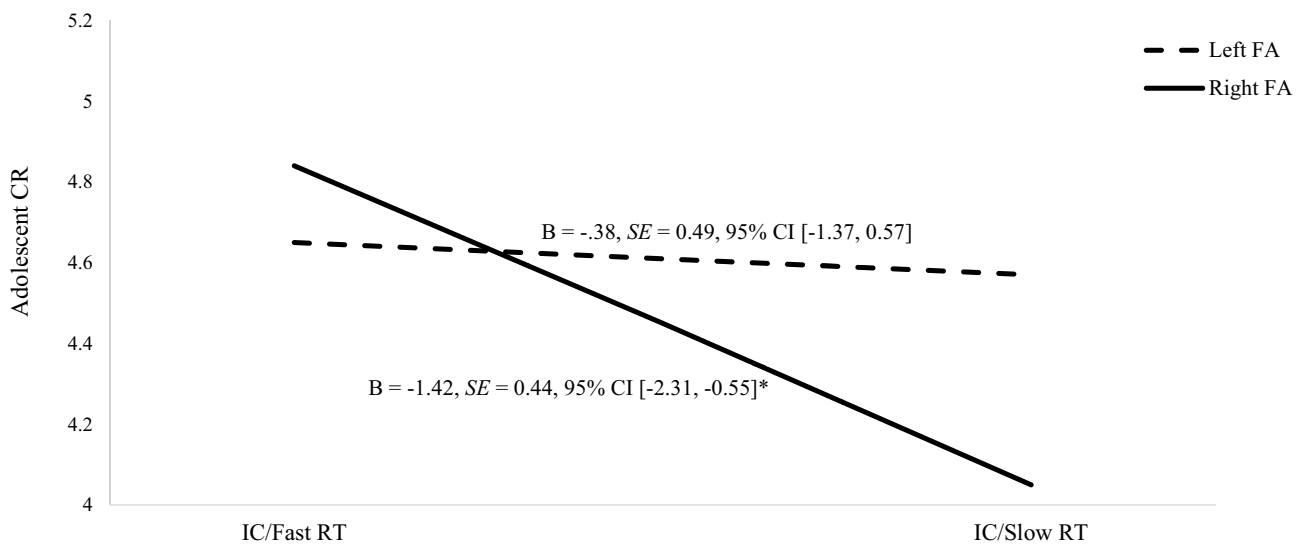
Fig. 2 CR (cognitive reappraisal) as a function of IC (inhibitory control) and FA (frontal EEG asymmetry). Slow reaction time (RT) is indicative of worse IC. Unstandardized estimates are presented

on depressive symptoms was dependent upon the levels of FA, such that the CR-depressive symptoms link was significantly only at lower levels of FA (i.e., right FA), b = -2.70, SE = 0.75, 95% CI [-4.15, -1.22] but not at higher levels of FA (i.e., left FA), b = -1.10, SE = 0.57, 95% CI [2.20, 0.004].

The conditional indirect effect of inhibitory control on depressive symptoms via CR was found for adolescents with lower levels of FA (i.e., right FA; see Table 3 and Fig. 4), b = 3.82, SE = 1.87, 95% CI [1.06, 8.55]. That is, for those with right FA during late childhood, adolescent CR mediated

the relation between late childhood inhibitory control and depressive symptoms, such that worse late childhood inhibitory control (i.e., slower reaction time) was associated with lower CR, and lower CR was in turn associated with higher depressive symptoms among adolescents, after controlling for pubertal status. Better late childhood inhibitory control (i.e., faster reaction time) was associated with higher CR, which was in turn associated with lower adolescent depressive symptoms, after controlling for pubertal status (see Table 3 and Fig. 4).
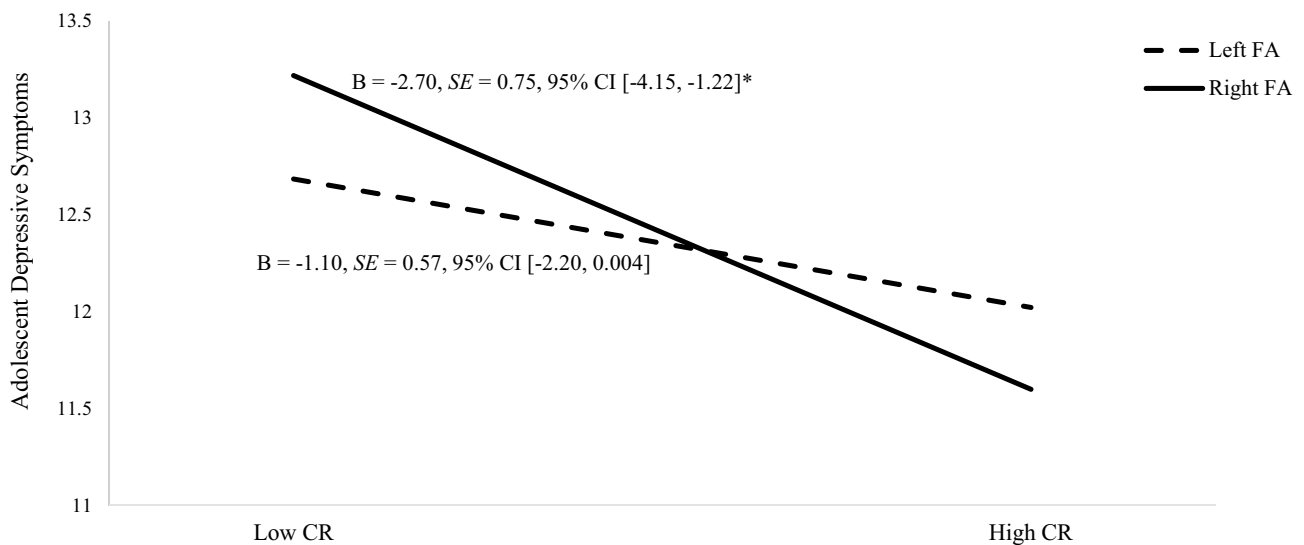

Fig. 3 Depressive Symptoms as a function of CR (cognitive reappraisal) and FA (frontal EEG asymmetry) for the model with inhibitory control. Unstandardized estimates are presented
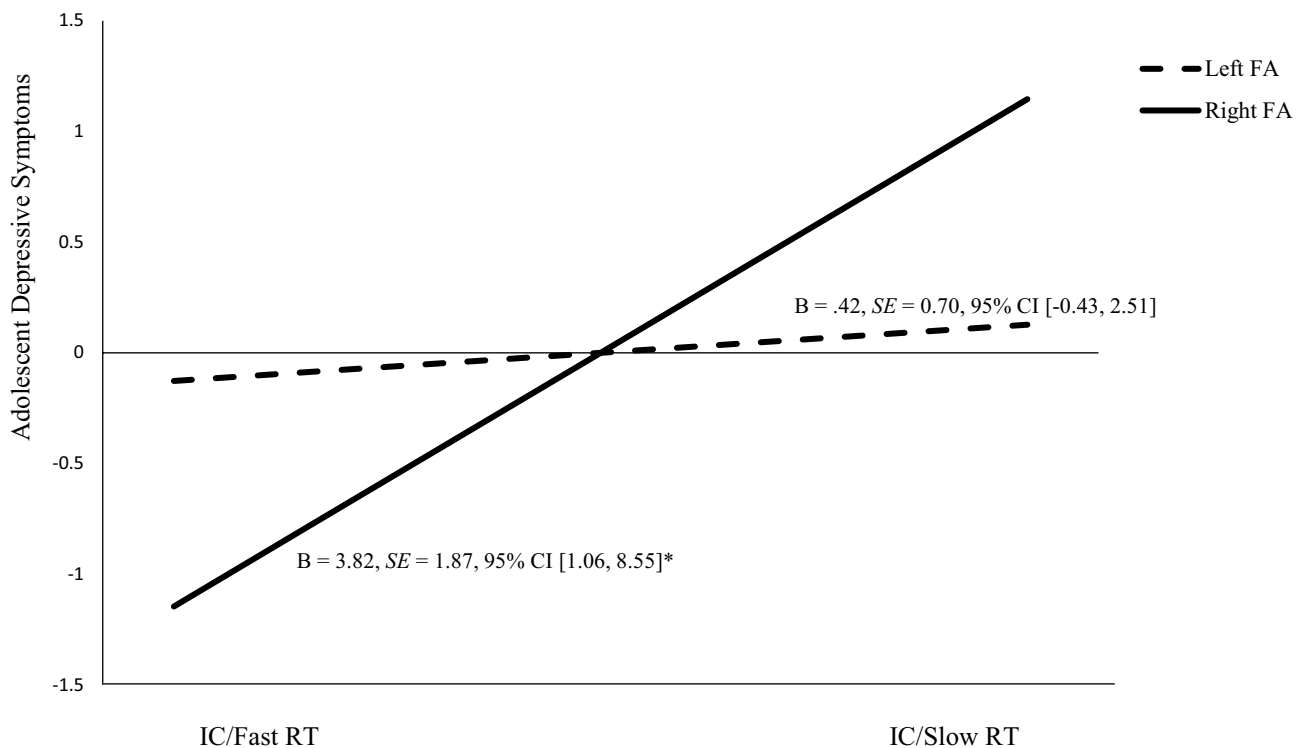
Fig. 4 Indirect effect of IC (inhibitory control) on adolescent depressive symptoms through CR (cognitive reappraisal) for right FA (frontal EEG asymmetry) and left FA. Slow RT (reaction time) is indica-tive of worse IC. Unstandardized estimates are presented. Values for adolescent depressive symptoms are standardized

Discussion

We examined whether adolescent CR mediates the association between executive function and adolescent depressive symptoms, and whether the indirect effect is further conditional on FA during late childhood. Our findings indicate that not all executive functions emerge as significant in this association; only the model with middle childhood inhibitory control emerged as significant. Cognitive flexibility and working memory during middle childhood were not significant predictors of adolescent CR or depressive symptoms. This was surprising, given previous research which finds that cognitive flexibility and working memory are also associated with CR ability and depressive symptoms in adolescence and adulthood (Andrés et al., 2016; Davidovich et al., 2016; Holler et al., 2014; McRae et al., 2012). Because our study is one of the first to examine these relations longitudinally, it may be that when considering the development of CR, inhibitory control during middle childhood plays an important role, but when considering simultaneous executive function, all three executive function factors may be important for concurrent CR. We also did not find direct effects between the executive function measures during late childhood and depressive symptoms in adolescence, it may be that concurrent EF is more strongly

associated directly with depressive symptoms in adolescence as opposed to indirect longitudinal relations (Han et al., 2016; Steinberger & Barch, 2021). Future research should continue to examine the developmental trajectory of more advanced cognitive strategies of emotion regulation as they relate to cognitive processes and subsequent depressive symptoms.

We further extend previous research by examining indirect effects as being conditional on trait FA, which is associated with a tendency toward depressive symptoms (Thibodeau et al., 2006). We probed the interaction of FA within our model when the interaction term was statistically significant at $p < 0.10$ given that interaction terms are known to be difficult to detect using non-experimental data. Nevertheless, the relatively small interaction effects indicate the need for further replication. These findings are interesting nonetheless, considering that among adolescents, depressive symptoms have been increasing over the last few decades, research indicates worrisome increases among adolescents born between 1990 and 2000 (Keyes et al., 2019). One mechanism that may help to decrease depressive symptoms among adolescents is developing their emotion regulation strategies, specifically CR. Our results indicate that when children have better inhibitory control this is associated with lower adolescent depressive symptoms through CR. For adolescents with right

FA, targeting inhibitory control can be one way to reduce the risk for depressive symptoms (Thibodeau et al., 2006).

Within our sample we did not find any significant sex differences. This finding was surprising given previous research findings which indicate that girls are at an increased risk of developing depression, a drastic increase in depression is visible during the adolescent years, and is more chronic for girls (Breslau et al., 2017; Essau et al., 2010). In our sample, adolescents who self-reported higher pubertal status also self-reported higher depressive symptoms (Keyes et al., 2019). Our sample was not diverse, with the majority of participants being White and having highly educated parents. Recent literature that examines cultural, cognitive, and biological factors indicates these factors put girls at an increased risk of developing depression compared to boys (Gupta et al., 2013; Hamilton et al., 2015; Hyde et al., 2008; Shorey et al., 2022). Although we did not find sex differences within our sample, future research should continue to examine these associations further while also considering external factors which may differentially impact depressive outcomes for girls and boys.

For our sample, only the executive function of inhibitory control was a significant predictor of adolescent depressive symptoms mediated by CR. In particular, this association was significant when children displayed right FA during late childhood; specifically, better inhibitory control (i.e., faster reaction time) predicted higher adolescent CR. When children had worse inhibitory control (i.e., slower reaction time) and right FA during late childhood, they self-reported lower CR as adolescents. For those with right FA during late childhood, lower CR was then linked to a higher number of depressive symptoms in adolescence. Previous adulthood research indicates differences regarding the specific executive function variables that are linked to CR ability (McRae et al., 2012; Tabibnia et al., 2011). For our study, cognitive flexibility and working memory were not significantly associated with CR ability. We focused on habitual CR rather than task-specific CR, which was the focus of much of the previous work with adults. We may have found differences regarding direct links of working memory and cognitive flexibility if we had also used task-specific CR (Schmeichel & Tang, 2015) because asking adolescents to learn a new emotion regulation strategy and implement it during emotion elicitation may require other executive function, in addition to inhibitory control. By focusing on trait FA, we were able to examine FA as an individual difference factor that provides adolescents with the capability to engage CR and protect against depressive symptoms.

Among adults, depression is linked to deficits in working memory, inhibitory control, and cognitive flexibility, but these associations are not well understood during adolescence (Fossati et al., 2002; Vilgis et al., 2015). Childhood and adolescent research indicates that symptoms of depression are associated with slower reaction times on inhibitory control tasks (Cataldo et al., 2005; Vilgis et al., 2015). This association is also evident in children and adolescents with deficits in working memory and cognitive flexibility (Vilgis et al., 2015). Our results indicate that only inhibitory control is a significant contributor to adolescent depressive symptoms when both CR and FA are considered in the model. The indirect effect of inhibitory control on depressive symptoms through CR indicates that children with right FA are better capable of engaging CR when they are more effective inhibitors, and their higher CR is protective against depression. Based on previous literature indicating right FA as a risk factor being associated with more depressive symptoms, our findings indicate this association requires a consideration of other protective factors (Thibodeau et al., 2006) or a more complex model of adolescent FA and depressive symptoms. Our results highlight inhibitory control and CR serve as protective factors in the development of depressive symptoms among children and adolescents with right FA.

Our study had some limitations. The sample demographics were limited to primarily White youth with educated parents. Because adolescents from diverse ethnic and socioeconomic backgrounds are at an increased risk of depressive symptoms, it is imperative to ensure that future research is generalizable to a more diverse sample of adolescents (Merikangas et al., 2010; Wagstaff & Polo, 2012). For example, adolescents who perceive greater racial and ethnic discrimination are at an increased risk of more depression and internalizing symptoms (Benner et al., 2018). Less use of CR and greater expressive suppression among Latino and Asian heritage college students is associated with greater depressive symptoms (Juang et al., 2016). Adolescents from disadvantaged socioeconomic backgrounds are at an increased risk of stressors that negatively impact brain development, subsequently impacting cognitive and emotional abilities (Noble & Giebler, 2020; Noble et al., 2021). Therefore, incorporating a model focused on increasing these cognitive and affective regulatory skills in youth from disadvantaged backgrounds can have a substantial impact on subsequent development.

We examined habitual CR and not task-specific CR, as done in most of the adulthood research literature. Our findings may have been more aligned with adult research if we had used the same CR. Although we examined all three executive function factors associated with habitual CR, only one model indicated significant associations among the variables, the model with inhibitory control. Future research should continue to examine the association among various EFs and habitual and task-specific CR to further understand how and when interventions may be implemented to decrease symptoms of depression among adolescents (Luciana, 2016). A final limitation of our study

was that both CR and depressive symptoms were collected concurrently, therefore we cannot make directional inferences between these two variables.

Nevertheless, our findings may be of help in developing early CR interventions for adolescent depression focused on inhibitory control. Overall, our findings have the potential to inform future interventions that can be targeted toward inhibitory control during late childhood, as well as during early childhood. Inhibitory control development is critical for emotion regulation from early childhood (Whedon et al., 2021). For children with right FA, targeting inhibitory control could reduce the risk for depression symptoms during adolescence (Blair & Diamond, 2008; Carlson & Wang, 2007). This can be an easy and cost-effective intervention that could substantially impact adolescent depressive symptoms (Moilanen et al., 2010). Teaching young children to regulate their emotions by implementing these strategies into school curricula can be beneficial for the long-term effects of diminishing the rise of depressive symptoms in adolescence (Hoffmann et al., 2020).

Data Availability Data used in these analyses are available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

Ethics Approval This study was approved by the Virginia Tech IRB (late childhood protocol #12-947) and by the Biomedical Research Alliance of New York (BRANY) IRB (adolescent protocol-#19-030-568/19-352).

Consent to Participate Informed consent and child assent was obtained from all participants in this study.

Conflict of Interest The authors have no conflicts to disclose.

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