Rumination in Early Adolescent Girls: An EEG Study of Cognitive Control and Emotional Responding in an Emotional Go/NoGo Task

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Abstract

Although there is a substantial literature on rumination and depression, research examining neurocognitive processes related to rumination is just emerging, and few studies have examined such processes in relation to depression-risk in early adolescence. This study examined the associations between neurocognitive processes and trait-rumination in relation to familial risk for depression in nondepressed girls in early adolescence. Neurocognitive processes were assessed via EEG recording during an emotional Go/NoGo task, and analyses examined two Event-Related Potential components, including the Go and NoGo N2, reflecting attentional engagement and cognitive control processes respectively, and the Go and NoGo P3, reflecting motivated attention and inhibitory motor processes. In higher-risk youth, rumination was associated with specific alterations in both N2 and P3 amplitudes to nonemotional faces when required to enact a response, suggesting disrupted behavioral flexibility in adjusting responses to meet task demands. In lower-risk youth, however, greater rumination was associated with diminished engagement of top-down attention and cognitive control resources (i.e., attenuated N2 amplitudes), and enhanced activation of inhibitory motor control processes (i.e., enhanced P3 amplitudes). Results provide novel information regarding the association between depression-risk, rumination, and emotional processing in early adolescence that may have implications for risk-identification and prevention.

Keywords Rumination · Affective Go/NoGo · N2 · P3 · Depression

Rumination reflects the tendency to engage in repetitive negative thinking regarding stressful or aversive events and has been consistently associated with depression and anxiety disorders in adolescence and adulthood (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). Indeed, a tendency to engage in ruminative thinking has been postulated as a central risk factor for the development of internalizing disorders in early adolescence (Kuyken, Watkins, Holden, & Cook, 2006), particularly for girls (Jose & Brown, 2008). Relatively few studies, however, have examined such processes in relation to depression risk in early adolescence. The current study employed a high-risk design to examine cognitive processes linked to rumination, assessed via EEG recording during an emotional Go/NoGo task, in relation to maternal depression in a sample of nondepressed girls in early adolescence (aged 10–14 years). Parental depression is a well-documented risk factor for

depression in offspring, particularly depression in mothers (e.g., Connell & Goodman, 2002). While there are multiple paths through which parental depression is related to depression in offspring, including genetic, neurodevelopmental, and social-interactional processes, the development of cognitive vulnerability is thought to represent a central mechanism for depression transmission across generations (Goodman, 2007). High-risk designs can provide important information regarding ruminative processes related to depression-risk before depression onset and may ultimately have important prevention implications.

Cognitive models of rumination

Several cognitive processes have been suggested as underpinnings of depressive rumination in adults. In particular, cognitive control difficulties, including challenges inhibiting previously relevant thoughts (e.g., about past events), may be associated with the perseverative thinking that characterizes depressive rumination (Whitmer & Banich, 2007). Depressive rumination also has been linked, more narrowly, to a negative

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processing bias, including difficulty disengaging processing of negative emotional information (Whitmer & Gotlib, 2013). Such inhibitory control deficits in relation to negative emotional stimuli may ultimately increase the accessibility of negative thoughts and memories, which then guide interpretations of current situations, foster pessimistic thinking, and undermine effective problem solving and coping, in line with response styles theory (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008).

The attentional scope model (Whitmer & Gotlib, 2013), however, suggests that inhibitory control deficits and biased attention toward negative stimuli may be secondary to a constricted scope of attention associated with rumination. Of particular relevance to the current study, the model suggests the narrowed attentional scope may carry advantages or disadvantages, depending on the context. When rumination occurs in the absence of depression, the narrowed attentional scope may lead to improved ability to ignore distracting information and facilitate enhanced processing of information at the center of attention (Whitmer & Gotlib, 2013). For instance, Zetsche and Joormann (2011) found that trait rumination in an unselected college student sample was associated with enhanced ability to ignore distracting negative emotional information in an emotional flanker task. However, depressive mood states lead to further narrowing of attentional scope and a biasing of attention towards negative information, which may lead to cognitive control impairments (Whitmer & Gotlib, 2013). Indeed, in depressed adults, high trait rumination has been associated with deficits in inhibiting previous mental sets in a task-switching paradigm (Whitmer & Banich, 2007), with diminished accuracy on a letter-naming task requiring rapid goal shifting (Atamirano, Myake, & Whitmer, 2010), and with impaired inhibition in an antisaccade task (De Lissnyder, Derakshan, De Raedt, & Koster, 2011). Thus, at least in depressed adults, rumination appears to be associated with significant cognitive control impairments that may disrupt adaptive functioning.

Rumination in youth.

Relatively few studies have examined rumination in relation to cognitive control processes or negative emotional biases in youth. In line with evidence from adults, behavioral studies in late childhood and adolescence have found that high trait rumination is associated with difficulty inhibiting responses to negatively valenced stimuli, particularly when switching from negative to positive blocks in an emotional Go/NoGo task (Hilt, Leitzke, & Pollak, 2014) and with longer gaze-time to negative faces in an emotional dot-probe task (Hilt, Leitzke, & Pollak, 2017). Further, Wagner, Alloy, and Abramson (2015) found that, in adolescent boys with elevated depressive symptoms, rumination predicted worse sustained attention on a

counting task. Of note, however, among boys with lower depressive symptoms, rumination predicted better sustained attention and enhanced set-shifting on a task requiring alterations in counting forwards and backwards. These findings are in line with the attentional scope model, suggesting differential rumination effects across depressed and nondepressed youth. Given the small body of available research, additional work is needed to extend our understanding of ruminative processes in childhood and adolescence.

Rumination and neurocognitive processes

In particular, research employing EEG/event-related potential (ERP) techniques may be helpful in extending our understanding of specific neurocognitive processes related to rumination in youth, given their high temporal resolution. Indeed, several recent studies have adopted this approach, primarily with adult samples, although inconsistent results have been observed across studies. Two studies have found that high trait-rumination is associated with impaired cognitive control (i.e., less negative N2 amplitudes in a flanker task; Alderman et al., 2015) and inhibitory responding (i.e., diminished P3 amplitude differences between successful and unsuccessful stop trials in a stop-signal task; Palmwood, Krompinger, & Simons, 2017), consistent with inhibitory control deficit accounts of rumination.

Several recent studies have examined rumination more specifically in relation to emotional processing, including in relation to Late Positive Potential (LPP) amplitudes, an ERP component reflecting elaborative processing of emotional versus neutral stimuli. Rumination has been associated with enhanced LPP responses to affective words in a counting task by nondepressed college students (Lo, Lau, Cheung, & Allen, 2012) and with stronger elaborative processing of losses versus gains in a gambling-task in adolescents (Webb et al., 2017). Furthermore, experimentally induced rumination predicted stronger elaborative processing of negative (versus positive or neutral) images in an unselected college-student sample (Lewis, Taubitz, Duke, Steuer, & Larson, 2015). Collectively, these studies are consistent with cognitive models suggesting both trait and state rumination are associated with enhanced affective processing, particularly for negative emotional stimuli. Finally, while anxiety has been associated with enhanced performance monitoring (indexed by more negative error-related negativity (ERN) amplitudes in response to performance errors), brooding rumination was associated with less negative ERN amplitudes in response to errors on a Flanker task in a college-student sample (Tanovic, Hajcak, & Sanislow, 2017). Results suggest that rumination may “normalize” error monitoring in anxious individuals, providing short-term relief, in line with the attentional scope model of possible benefits of rumination in some contexts.

Current Study

The current study examined neurocognitive processes related to rumination in nondepressed girls in early adolescence. We focused on girls due to the gender differences in both rumination and depression that emerge in adolescence (Hyde et al., 2008) and employed a high-risk design, examining ruminative processes in relation to maternal depression histories and symptom severity, to identify risk-related processes in the absence of diagnosed depression in youth. We examined ERP components reflecting inhibitory control processes (NoGo N2 and NoGo P3), as well as emotion-driven attentional engagement (Go N2 and Go P3) during an emotional Go/NoGo task (Schulz et al., 2007) that included calm, happy, and sad facial images. In emotional Go/NoGo tasks, participants are presented with a series of facial images displaying different emotions and are instructed to respond (via button press) to some emotions but to inhibit responding to others. This widely used task provides robust information regarding both inhibitory control and emotional responding (including possible emotional interference, reflecting performance decrements in relation to specific emotional stimuli; Hare et al., 2008). Although prior research has employed angry or fearful faces as negative emotional stimuli, we examined sad faces (along with calm and happy faces), because biased processing of sad faces (i.e., increased attentional engagement) has been suggested as a specific marker of depression susceptibility (Bistricky, Atchley, Ingram, & O'Hare, 2014).

Within emotional Go/NoGo tasks, N2 and P3 components to Go versus NoGo trials reflect distinct cognitive processes of potential relevance to possible negative processing biases and inhibitory control problems related to depressive rumination. The NoGo N2 and P3 components reflect different aspects of inhibitory control processes. The NoGo N2 reflects cognitive control processes, including the monitoring and detection of conflict between response execution and inhibition related to trial demands, with enhanced (i.e., more negative) N2 amplitudes found on NoGo versus Go trials (Folstein & Van Petten, 2008). The NoGo P3 reflects later inhibitory motor control, with P3 amplitudes generally more positive on NoGo versus Go trials (Smith, Johnstone, & Barry, 2008). In Emotional Go/NoGo tasks, more negative NoGo N2 amplitudes have been found for negative versus positive or neutral emotional stimuli in healthy participants, suggesting that negative emotional stimuli interfere with cognitive control processing, requiring the recruitment of greater cognitive control resources for successful performance (Buodo et al., 2017). Of relevance to the current study, depression has been associated with attenuated (i.e., less-negative) NoGo N2 amplitudes in nonemotional tasks (Kaiser et al., 2003) and with attenuated NoGo N2 amplitudes to negative versus positive trials in emotional Go/NoGo tasks (Krompinger & Simons, 2009), suggesting that negative emotional interference effects cognitive control may

be particularly pronounced in depressed individuals. Conversely, in an adolescent sample, enhanced NoGo P3 amplitudes to negative faces were associated with elevated depression (Zhang et al., 2016), suggesting greater processing resources were needed to inhibit motor responding. Therefore, the NoGo N2 and P3 are of relevance to the examination of ruminative processes in at-risk youth, because they serve as an emotionally sensitive indicator of inhibitory control at distinct stages of processing, which may enhance understanding of depressive rumination processes in at-risk adolescents.

While NoGo N2 and P3 responses index aspects of inhibitory control, Go N2 and P3 responses index different stages of emotion-driven attentional processes. In particular, the Go N2 reflects top-down attention towards emotions, such that the examination of Go N2 amplitudes provides an index of negative attentional biases related to rumination. In particular, more negative Go N2 amplitudes to neutral versus positive or negative emotional images (Zhang & Lu, 2012) and words (Chiu, Holmes, & Pizzagalli, 2008) in affective Go/NoGo tasks suggests that while emotional stimuli engage early attention via bottom-up processes, neutral stimuli require greater top-down engagement of attention to enact responses (Zhang & Lu, 2012). The Go P3 appears to reflect the motivational significance of stimuli (Zhang & Lu, 2012). As described, emotional images appear to engage early bottom-up attentional processes, leading to less negative Go N2 amplitudes for emotional versus neutral stimuli. Because attention has already been engaged for emotional Go trials via bottom-up processes, top-down attentional resources are available to enhance to Go P3 amplitude, in line with their motivational significance (Zhang & Lu, 2012). In line with this account, larger Go P3 amplitudes have been observed for emotional versus neutral stimuli in several studies (Chiu et al., 2008; Zhang & Lu, 2012). With respect to depression, attenuated Go N2 amplitudes to negative versus positive trials in emotional Go/NoGo were found for dysphoric versus nondysphoric adults, suggesting greater bottom-up attentional engagement (Krompinger & Simons, 2009). Similarly, enhanced P3 amplitudes for negative versus positive images were observed in dysphoric adults (Krompinger & Simons, 2009), suggesting greater motivational relevance of negative images in relation to depression. P3 amplitudes in emotional Go/NoGo tasks do not appear to have been examined in relation to trait rumination in adults or youth.

Our broad goal was to examine behavioral and ERP responses in relation to rumination and depression-risk. We examined competing hypotheses, in light of inhibitory-control deficit, negative emotional bias, and attentional scope models of rumination, because they lead to distinct hypotheses for behavioral and ERP response patterns. For behavioral performance, inhibitory-control-deficit models suggest specific response difficulties for NoGo trials (requiring response inhibition) across emotions. However, the negative bias model

would suggest more behavioral errors on sad (versus happy or calm) faces, for both Go and NoGo trials, suggesting interference effects for negatively-valenced stimuli. Finally, the attention scope model would suggest differential relations between rumination and response errors in relation to depression-risk status, with more rumination-linked errors in high-risk youth, but fewer errors in lower-risk youth (in line with performance benefits associated with a narrowed attentional scope).

For ERP results, based on inhibitory-control-deficit models, we predicted that greater rumination would be associated with attenuated (less-negative) NoGo N2 amplitudes and less positive NoGo P3 amplitudes across emotions, suggesting deficits in inhibitory cognitive and motor control processes. By contrast, negative bias accounts of rumination would predict that previously described NoGo N2 and P3 effects would be specific to sad faces and also that greater rumination would be associated with less negative Go N2 amplitudes to sad faces (suggesting greater bottom-up attentional engagement) but more positive Go P3 to negative stimuli (suggesting greater subsequent top-down attentional engagement). Finally, the attention scope model predicts differential relations between rumination and all ERP indices across low- and high-risk groups, with stronger response deficits (i.e., attenuated N2 and P3 Go and NoGo amplitudes) in high-risk youth. Finally, we examined both maternal diagnostic history and current symptoms as indices of depression-risk. Although this aspect of the study was exploratory, diagnoses and symptoms may capture distinct aspects of risk (i.e., broader history or current functioning). Indeed, stronger effects for maternal depression symptoms than diagnoses have been found in behavioral (MacNamara, Kotov, & Hajcak, 2016) and neurocognitive studies (Clawson, Clayson, & Larson, 2013).

Method

Participants

Participants included 60 mother-daughter dyads. Families with girls aged 10–14 years were recruited from local schools, community centers, and via online postings. Mean maternal age was 43.30 years ($SD = 5.28$), and mean daughter age was 12.15 years ($SD = 1.33$). Consistent with the ethnic distribution of the region, 41 participating youth were European American (68.3%), 12 were African American (20%), 4 were Hispanic (6.7%), and 3 were Asian American (5%). Parents were married or cohabitating in 36 families (69.2%), and the average household income was between \$70,000–\$79,999. Computer problems were experienced for five youth, and one girl failed to correctly complete study questionnaires. Participants were also excluded from analyses if they performed below chance or more than two thirds artifact-

rejected trials for more than one trial-type, resulting in excluding two youth. Additionally, 1 girl was diagnosed with current depression and was excluded from analyses, leaving a final analytic sample of 51 families, including 49 biological and 2 adoptive mothers (both girls were adopted in infancy).

Measures

Children's Depression Inventory (CDI) Youth completed this 27-item self-report measure of depressive symptoms in children and adolescents, with possible scores ranging from 0 to 54 (Kovacs, 2015). High reliability was observed in the current sample ($\alpha = 0.91$).

Center for Epidemiological Studies Depression Scale (CES-D) Mothers completed this well-validated, 20-item, self-report measure of depressive symptoms, with possible scores ranging from 0 to 60 (Radloff, 1977). High reliability was observed in the current sample ($\alpha = 0.92$).

Cognitive Emotion Regulation Questionnaire-Child version (CERQ) Youth completed the child version of the CERQ (Garnefski, Rieffe, Jellesma, Meerum Terwogt, & Kraaij, 2007), a 36-item measure assessing cognitive responses and emotion regulation strategies in response to negative events. Items reflect the frequency of responses to negative events on a 1 (almost never) to 5 (almost always) scale. The CERQ includes 9 subscales, although the current analyses only examined the Rumination scale, which includes 4 items reflecting the tendency to engage in perseverative thinking focused on one's own emotional state (e.g., "Again and again, I think of how I feel about it."). Possible scores range from 1 to 5. The CERQ has been well-validated in early adolescence (Garnefski et al., 2007), and the rumination subscale correlates highly with other validated rumination measures (Selby, Anestis, Bender, & Joiner, 2009). High reliability was observed for this scale in the current sample ($\alpha = 0.82$).

Diagnostic interviews Mothers and daughters completed separate diagnostic interviews for current or lifetime Major Depressive Disorder, using the Structured Clinical Interview for DSM-IV TR (SCID; First & Gibbon, 2002), and the Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997). Interviews were administered by trained masters-level graduate students, supervised by a licensed clinical psychologist. Interviewers completed didactic training, including the observation of interviews and structured practice with feedback, until they reached a high level of interrater reliability ($\kappa > 0.80$), with ongoing meetings to minimize interviewer drift.

Emotional Go/NoGo task The emotional Go/NoGo task included a brief instruction and practice block, and a total of 288 trials, in 3 blocks of 96 trials each (32 of each emotion category: happy, sad, and calm). We used facial images from the NimStim Face Stimulus Set (Tottenham et al., 2009), balanced for gender and ethnicity. Each block used a different emotion category (happy, sad, or calm) as the NoGo stimulus, whereas the other two emotions served as Go stimuli. Blocks included 64 Go trials (66.7%) and 32 NoGo trials (33.3%). Elements of the task design, including the number and ratio of Go and NoGo trials, and the inclusion of three emotion categories in each block were adapted from Hum, Manassis, and Lewis (2013). Participants were instructed to press a button for Go trials as quickly as possible but to refrain from pressing the button for NoGo trials. On the basis of pilot testing, each block included a reminder prompt for the NoGo category (e.g., “Don’t press: SAD”), which remained at the bottom of the screen throughout the block, to facilitate recall of the current NoGo emotion, as our goal was to examine emotion identification and inhibition, rather than memory. Block order was counterbalanced across participants, and images were randomized within blocks. As shown in Figure 1, trials included a 500-ms fixation cross, a 1,000-ms presentation of a facial expression, and a randomized inter-trial interval (ITI), ranging from 1,500 to 2,500 ms (average = 2,000 ms). Images were centered horizontally on the screen, approximately 5 cm x

5.5 cm in size. Behavioral responses were collected with a Cedrus RB-740 response pad. Visual stimuli were presented in color on a Dell Optiplex computer with a 19” LCD monitor using SuperLab software.

Electroencephalogram (EEG) recording Continuous EEG data was recorded using a Biopac MP 150 system from 11 scalp sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, and O2) and the right-ear, with a common-ground sensor at FCz. Tin electrodes in an Electro-Cap International head-cap following the international 10/20 placement system was used to record EEG data. A left-ear reference was used during recording, and data were re-referenced offline to the average of the left and right ears. Vertical electro-oculogram (EOG) data was recorded with sensors below and above the right eye, and blink artifacts were removed through independent component analyses (ICA; Delorme, Sejnowski, & Makeig, 2007). Electrode impedances were below 5 k Ω . EEG data was recorded with a sampling rate of 500 Hz and gain of 2,000. EEG data was filtered with a half-amplitude bandpass filter (cutoffs = 0.1–30 Hz), and artifact-corrected and averaged offline using EEGLab (Delorme & Makeig, 2004; sscn.ucsd.edu/eeglab/) and ERP-Lab toolbox (Lopez-Calderon & Luck, 2014; www.erplab.org/erplab). Continuous data was epoched for the three affective face categories across a 200-ms baseline

Fig. 1 Illustration of emotional Go/NoGo task

(during the fixation-cross display) and 1,000-ms picture viewing window. Trials were excluded if EEG exceeded $\pm 75 \mu\text{V}$.

Procedures

Mothers were screened by phone to assess study eligibility (including a daughter in the age-range, mother/legal guardian willing to participate, and fluent English) and maternal and youth symptoms of depression (both by mother-report). Eligible dyads were invited to take part in a 90-minute lab visit. Before the lab visit, participants were asked to complete a series of questionnaires assessing demographic information, parenting styles, and history of depression. Consent and assent were obtained from both mother and daughter at the start of the lab visit. Mothers and daughters then completed individual diagnostic interviews regarding their own depression histories in separate rooms administered by trained research assistants. Following these interviews, daughters completed the Go/NoGo task, alone in a temperature controlled, sound-attenuated room, monitored via wall-mounted cameras in an adjacent control room. Families received a \$50 gift card for their participation in the study. All procedures were approved by the university's Institutional Review Board.

Data Analysis

Time-ranges and locations for ERP components N2 and P3 were determined via visual inspection of the grand-average, before segmenting across conditions, and comparison with prior studies (Hum, Manassis, & Lewis, 2013; Palmwood, Krompinger, & Simons, 2017). We averaged across the following electrodes for each component: N2 (average of Fz and Cz), and P3 (average of P3, Pz, and P4). The N2 was calculated from correct Go and NoGo trials as the average amplitude between 350–400 ms and the P3 between 400–450 ms following stimulus onset. Behavioral data included reaction times and error-rates, as well as the signal detection parameter d' , which reflects perceptual sensitivity to stimulus conditions independent of response biases (higher scores reflect greater sensitivity in identifying and correctly responding to emotions; Schulz, Fan, Magidina, Marks, Hahn, & Halperin, 2007). Correlational analyses examined associations between ERP and behavioral performance indices, as well as rumination.

Preliminary repeated measures ANOVAS examined task-effects for behavioral and ERP indices, without predictors or covariates. Analyses included trial-type (Go, NoGo) and emotion (happy, sad, calm) as within-subject variables. In subsequent repeated measures ANOVAs, rumination and maternal depression were added as between-subjects variables, as well as the interactions between rumination and maternal depression. Youth self-reported depressive symptoms and several

demographic variables were included as covariates in all of these analyses, including family income, ethnicity (a dichotomous score reflecting European American (EA) vs. non-EA status to simplify analyses), and maternal marital status (single vs. married/cohabiting). All analyses were performed using SPSS version 25.0 with Huynh-Feldt epsilon corrections and Bonferroni-corrected follow-up analyses. Significant interactions involving continuous variables (rumination or maternal symptoms) were examined using the *Johnson-Neyman approach to identifying regions of significance*. The study was adequately powered to detect moderate to large effects. To simplify reporting, only the significant highest-order interaction effects are reported, when the lower-order interactions were also significant.

Results

Descriptive Statistics

Descriptive statistics for rumination and depressive symptoms were as follows: Rumination ($M = 2.89$, $SD = 1.05$; range: 1–5); CDI ($M = 11.10$, $SD = 6.03$; range: 0–33); CES-D ($M = 11.50$, $SD = 10.64$; range: 0–40). Ten mothers reported clinically significant depressive symptoms on the CES-D (i.e., scores greater than 16; Radloff, 1977), and four girls reported clinically significant depressive symptoms on the CDI (i.e., scores above 19; Kovacs, 1992). Twenty-two mothers reported a history of depression diagnosis, seven of whom also endorsed a current diagnosis. Of mothers with depression histories, six reported a history of therapy, and nine reported a history of therapy and medication for depression. Youth rumination was significantly correlated with youth depressive symptoms ($r = 0.30$, $p < 0.05$) but not with maternal depressive symptoms or diagnoses. Furthermore, demographic factors (youth age, maternal marital status, SES, ethnicity (coded as 0 = European American, 1 = non-European American)) were not significantly associated with either youth rumination or maternal/youth depressive symptoms or maternal diagnostic history. Mothers with depression histories were more likely to receive medication or therapy for depression ($n = 15$) than mothers without depression diagnoses ($n = 7$; $\chi^2(1, N = 51) = 18.32$, $p < 0.05$), although treatment history was not significantly related to youth rumination/depressive symptoms or any demographic factor. Other descriptive statistics are shown in Table 1. Figure 1 shows ERPs for Go/NoGo trials by emotion category.

Error rate

Task We first examined a 2 (trial-type: Go, NoGo) $\times$ 3 (emotion: happy, sad, calm) repeated measures ANOVA predicting error rates, which yielded a significant emotion effect,

Table 1. Descriptive statistics for emotional go NoGo trials

	Go Trials			NoGo Trials		
	Mean	SD	Range	Mean	SD	Range
Happy						
Error rate	0.10	0.10	0.02–0.44	0.20	0.14	0.00–0.44
Reaction Time	650.45	64.04	529.59–741.32	636.11	90.41	404.88–890.00
N2 amplitude	−4.56	6.07	−14.84 to 7.83	−4.36	6.33	−23.61 to 8.34
P3 amplitude	10.31	7.83	−4.62 to 28.63	9.17	8.10	−4.44 to 28.53
Sad						
Error rate	0.15	0.10	0.00–0.48	0.21	0.19	0.00–0.44
Reaction Time	674.32	58.82	560.49–832.43	663.78	125.71	456.40–941.00
N2 amplitude	−4.09	9.09	−28.17 to 15.44	−6.04	9.14	−22.39 to 15.49
P3 amplitude	11.74	8.74	−15.17 to 32.15	9.41	7.13	−8.03 to 25.64
Calm						
Error rate	0.25	0.14	0.00–0.56	0.27	0.19	0.00–0.59
Reaction Time	690.68	74.39	478.30–827.63	685.53	93.61	510.18–949.00
N2 amplitude	−6.14	6.08	−21.60 to 6.29	−2.71	8.20	−17.71 to 10.39
P3 amplitude	10.13	7.62	−6.66 to 34.12	11.34	8.57	−4.24 to 30.64

Note: Reaction time for NoGo trials denotes reaction time for commission errors. Error rates are reported as proportions of incorrect responses. Reaction times are reported in milliseconds. N2 and P3 amplitudes are reported in microvolts.

$F(2, 100) = 21.18, p < 0.05, \eta_p^2 = 0.35$, with higher error rates observed on calm versus sad or happy trials. A significant trial $\times$ emotion interaction was also observed, $F(2, 100) = 17.25, p < 0.05, \eta_p^2 = 0.07$. In follow-up analyses, Go error rates (e.g., omission errors) differed across all three emotions (calm > sad > happy), whereas NoGo error rates (e.g., commission errors) were highest in calm versus sad or happy trials (Table 1).

Maternal diagnosis A significant maternal depression $\times$ rumination interaction was observed, $F(1, 42) = 6.83, p = 0.01, \eta_p^2 = 0.14$. Follow-up analyses indicated that elevated rumination was associated with higher error rates in youth of mothers with depression histories (estimate = 0.06, SE = 0.02, $p = 0.003$) but was not significantly related to error rates in youth of mothers without depression histories (estimate = 0.00, SE = 0.02).

Maternal symptoms A significant rumination $\times$ maternal depressive symptoms interaction was observed, $F(1, 42) = 4.41, p = 0.04, \eta_p^2 = 0.09$. Follow-up analyses indicated that at lower maternal symptoms (CES-D scores below 6.82, including 38.30% of the sample), youth rumination was associated with fewer errors, overall (estimate = −0.05, SE = 0.02, at boundary).

D-prime

Task A 3-way (emotion: happy, sad, calm) repeated measures ANOVA for perceptual sensitivity, yielded a significant

emotion effect, $F(2, 100) = 18.71, p < 0.001, \eta_p^2 = 0.27$. In follow-up analyses, both happy and sad d-prime scores were not significantly different from one another but both were larger than d-prime scores for calm faces.

Maternal diagnoses A significant maternal depression $\times$ rumination interaction was observed, $F(1, 42) = 12.94, p = 0.001, \eta_p^2 = 0.23$. In follow-up analyses, higher rumination was associated with diminished perceptual sensitivity in youth of mothers with positive depression histories (estimate = −0.58, SE = 0.17, $p = 0.001$), but was not significantly related to perceptual sensitivity in youth of mothers without depression histories (estimate = 0.02, SE = 0.13).

Maternal symptoms A significant maternal depression $\times$ rumination interaction was observed, $F(1, 42) = 8.24, p = 0.006, \eta_p^2 = 0.16$. In follow-up analyses, greater rumination was related to diminished perceptual sensitivity across emotions at higher maternal symptoms (CES-D scores above 17.55, including 17.65% of the sample; estimate = −0.30, SE = 0.15, at boundary).

N2 amplitudes

Task A significant emotion $\times$ trial-interaction was observed, $F(2, 100) = 4.26, p = 0.02, \eta_p^2 = 0.08$. In follow-up analyses, Calm Go amplitudes (reflecting top-down attention engagement) were significantly more negative than Calm NoGo amplitudes (reflecting cognitive control

processes; Table 1). A trend-level effect for Sad faces was in the opposite direction.

Maternal Diagnosis In the analysis for maternal diagnostic history, no significant main or interactive effects associated with maternal depression were observed.

Maternal Symptoms The analysis for maternal symptoms yielded a significant trial $\times$ emotion $\times$ rumination $\times$ maternal symptoms interaction, $F(2, 84) = 8.22, p = 0.001, \eta_p^2 = 0.19$. Significant rumination $\times$ maternal symptoms interactions were observed for Calm Go (reflecting top-down attention engagement; estimate = $-0.24, SE = .09, p < 0.05$), Happy NoGo (reflecting cognitive control processes; estimate = $-0.30, SE = 0.10, p < 0.05$) and Sad NoGo trials (reflecting cognitive control; estimate = $-0.34, SE = 0.13, p < 0.05$). ERP effects are shown graphically in Figure 2. To unpack these interactions, separate moderated regression analyses were conducted for Calm Go, and Happy and Sad NoGo amplitudes. The nature of the interaction was the same across trials. For Calm Go trials, rumination was related to attenuated (i.e., less negative) N2 amplitudes at lower maternal symptoms (CES-D scores below 4.74, including 27.45% of the sample; rumination effect at critical region boundary = $2.22, SE = 1.10$). At high maternal symptoms, however, rumination was related to enhanced (i.e., more negative) N2 amplitudes (CES-D scores above 27.35, including 11.77% of the sample; rumination effect at critical region boundary = $-3.78, SE = 1.87$). For Sad NoGo trials, rumination was related to attenuated N2 amplitudes at lower maternal symptoms (CES-D scores below 7.25, including 50.98% of the sample; rumination effect at critical region boundary = $2.70, SE = 1.33$). At high maternal symptoms, rumination was related to more negative N2 amplitudes (CES-D scores above 33.29, including 5.88% of the sample; rumination effect at critical region boundary = $-6.49, SE = 3.22$).

Finally, for Happy NoGo trials as well, rumination was related to attenuated N2 amplitudes at lower maternal symptoms (CES-D scores below 9.40, including 56.86% of the sample; rumination effect at critical region boundary = $1.84, SE = 0.91$). At high maternal symptoms, however, rumination was negatively related to N2 amplitudes (CES-D scores above 30.47, including 7.84% of the sample; rumination effect at critical region boundary = $-4.34, SE = 2.15$).

P3 amplitudes

Task A significant emotion $\times$ trial-interaction was observed, $F(2, 100) = 4.51, p = 0.01, \eta_p^2 = 0.08$. In follow-up analyses, P3 amplitudes were significantly larger on Sad Go (reflecting top-down attention and motivation) than Sad NoGo trials (reflecting inhibitory motor control; Table 1). A trend-level effect ($p = 0.08$) in the opposite direction was also observed for Calm faces, with larger amplitudes for Calm NoGo than Calm Go trials.

Maternal diagnoses A significant trial $\times$ emotion $\times$ rumination $\times$ maternal depression interaction was observed, $F(2, 84) = 3.12, p < 0.05, \eta_p^2 = 0.14$, with significant rumination $\times$ maternal diagnosis effects for Sad Go (estimate = $-5.03, SE = 2.50, p < 0.05$), and Calm Go trials (estimate = $6.35, SE = 2.18, p < 0.05$), with Go P3 amplitudes reflecting top-down attention and motivational salience. For Calm Go trials, rumination was significantly negatively associated with P3 amplitudes in mothers with depression histories, as shown in Figure 3a (effect = $-4.10, SE = 2.04, p < 0.05$). For Sad Go trials, however, rumination was significantly positively related to P3 amplitudes in girls of mothers without depression histories (effect = $4.56, SE = 1.76, p < 0.05$) but not in mothers with depression histories (effect = $-0.56, SE = 2.43, n.s.$; Figure 3b).

Fig. 2 Go/NoGo responses across emotions

Fig. 3 N2 amplitudes in relation to rumination and maternal depressive symptoms

Maternal Symptoms In the analysis for maternal depressive symptoms, a significant trial $\times$ emotion $\times$ rumination $\times$ maternal symptoms interaction was observed, $F(2, 84) = 3.77, p < 0.05, \eta_p^2 = 0.14$, with significant rumination $\times$ maternal symptoms interactions observed for Happy NoGo trials (estimate = -0.30 , $SE = 0.13, p = 0.02$) (and trend-level interaction for Sad NoGo trials (estimate = -0.20 , $SE = 0.11, p = 0.08$), with NoGo P3 amplitudes reflecting inhibitory motor control. A follow-up regression analysis for Happy NoGo trials indicated that rumination was significantly positively related to P3 amplitudes at lower maternal symptoms, as shown in Figure 3c (CES-D scores below 5.06, including 39.22% of the sample; effect at critical region boundary = 4.06, $SE = 2.01$). A comparable trend-level effect was observed for Sad NoGo trials.

Additional controls Analyses were re-run controlling for maternal anxiety symptoms and treatment history. There were no significant effects for either variable in relation to behavioral performance, or N2 and P3 amplitudes, and previously significant effects remained significant.

Correlations between ERP amplitudes and behavioral performance As shown in Table 2, more negative N2 amplitudes on sad Go trials were associated with more omission errors. On Calm Go trials, however, more negative N2 amplitudes were associated with fewer omission errors. More negative Calm Go N2 amplitudes also were associated with more frequent commission errors on sad and happy NoGo trials and lower perceptual sensitivity (d-prime scores) for happy and sad

faces. More positive P3 amplitudes on sad Go trials were associated with fewer sad commission errors. More positive calm Go P3 amplitudes were associated with fewer sad omission errors, whereas more positive P3 amplitudes for Sad NoGo trials were associated with greater perceptual sensitivity to sad faces.

Discussion

Rumination is a robust risk factor for depression onset and relapse, and an emerging body of research has identified a complex pattern of cognitive processing risks and benefits associated with the narrowed attentional scope related to rumination (Whitmer & Gotlib, 2013). The broad goal of the current study was to extend this emerging literature by employing a high-risk design to examine inhibitory control (e.g., NoGo N2 and P3 amplitudes) and attentional engagement processes (e.g., Go N2 and P3 amplitudes) during an emotional Go/NoGo task in relation to trait-rumination in early adolescent girls (aged 10–14 years). We examined competing hypotheses regarding rumination and depression-risk, derived from inhibitory-control deficit (e.g., specific behavioral and ERP deficits for NoGo trials across emotions), negative bias (e.g., specific behavioral and ERP deficits for sad faces across trials), and attention scope models (e.g., stronger behavioral and ERP deficits for high-risk vs. low-risk girls). Overall, our version of the emotional Go/NoGo task yielded behavioral and neurocognitive results that were in line with

Fig. 4 P3 amplitudes in relation to rumination and maternal depression status

Table 2 Correlations

	N2 amplitudes						P3 amplitudes					
	Happy Go	Sad Go	Calm Go	Happy NoGo	Sad NoGo	Calm NoGo	Happy Go	Sad Go	Calm Go	Happy NoGo	Sad NoGo	Calm NoGo
Happy omission errors	−0.04	−0.14	−0.17	−0.11	−0.03	−0.09	−0.11	−0.24†	−0.25†	−0.11	−0.10	−0.10
Sad omission errors	−0.04	−0.28*	−0.11	−0.20	.05	−0.14	−0.12	−0.34*	−0.33*	−0.20	−0.16	−0.19
Calm omission errors	0.09	0.00	.29*	−0.12	0.04	−0.02	−0.03	−0.10	−0.02	−0.21	0.06	−0.15
Happy commission errors	0.00	−0.01	−0.26†	0.01	−0.13	−0.19	0.05	0.08	0.01	0.12	−0.02	0.05
Sad commission errors	−0.02	0.12	−0.34*	−0.16	−0.12	−0.10	0.01	0.16	0.00	0.06	−0.19	0.11
Neutral commission errors	0.06	−0.06	0.00	−0.14	0.06	−0.14	0.01	0.00	−0.01	−0.04	−0.05	−0.13
Happy d-prime	0.10	0.09	.43*	−0.01	0.18	0.22	0.05	0.03	0.18	−0.06	0.12	0.00
Sad d-prime	0.05	0.00	.39*	0.18	.19	0.17	0.11	0.00	0.23	0.07	.43*	0.11
Calm d-prime	−0.14	−0.04	−0.07	0.09	0.01	0.04	0.03	−0.03	0.10	0.16	0.05	0.14

those reported in prior studies employing this paradigm (Zhang & Lu, 2012), suggesting that it was effective in evoking the desired cognitive response processes. However, specific rumination-linked neurocognitive effects were more mixed with respect to hypotheses, although they were interpretable in light of theoretical accounts of ruminative processes.

Diagnostically focused analyses

In line with predictions from the inhibitory control and attentional scope models, greater rumination in girls of mothers with histories of depression was associated with less accurate behavioral performance, including difficulty adjusting behavioral responding to meet trial-demands. In contrast to negative emotional bias accounts, behavioral effects were not specific to sad faces. ERP results for at-risk girls were more complex with respect to hypotheses. In particular, greater rumination in high-risk girls was not associated with alterations in Go or NoGo N2 amplitudes, as we hypothesized from the inhibitory-control deficit model. This pattern of results may be consistent with a more nuanced version of the cognitive control deficit model, in which at-risk, ruminating girls failed to recruit additional cognitive control (via NoGo N2) or attentional resources (via Go N2), which contributed to performance decrements. Furthermore, rumination in high-risk girls was associated with attenuated (less positive) calm Go P3 amplitudes, suggesting diminished attentional engagement with calm faces on trials requiring the enactment of a response (Zhang et al., 2016). This specific attenuation was not hypothesized, but it is worth noting that calm trials were more challenging than emotional Go trials, and while calm Go P3 amplitudes were not directly associated with performance on

calm Go trials in the current study, lower P3 amplitudes have been associated with diminished performance accuracy in prior research (Zhang & Lu, 2012), and unexpectedly, less positive calm Go P3 amplitudes were associated with more omission errors on Sad Go trials, which occurred with calm Go trials in happy NoGo blocks (a similar trend-level association was observed for happy Go trials). It may be that, for at-risk girls, rumination was associated with disrupted engagement with the most challenging stimuli (calm faces), which then interfered with accurate responding to sad Go trials, or that responding to sad faces disrupted engagement with the more ambiguous calm Go faces. Future work examining such possibilities is needed. Although more complex than our hypotheses, the pattern of effects across trial types for high-risk girls is consistent with diminished capacity to update working memory and adjust to changing task demands observed, suggested by inhibitory-control and attentional scope models (Whitmer & Banich, 2007).

By contrast, in girls of mothers without histories of depression, greater rumination was unrelated to behavioral performance. However, rumination was associated with more positive P3 amplitudes on sad Go trials, suggesting that higher rumination was associated with greater motivational relevance of sad faces in low-risk girls (in line with negative-bias accounts). Furthermore, in correlational analyses, more positive P3 amplitudes were associated with more accurate responding to sad Go trials. Thus, although more complex than our hypotheses, the overall pattern of results was consistent with the attentional scope model, in suggesting some benefits of rumination in low-risk (compared with high-risk) girls, particularly when responding to sad faces. It is worth noting that the current study was cross-sectional, and rumination may not necessarily be benign in low-risk girls over the long-term. For

instance, Bistricky et al. (2014) found that depression was related to enhanced P3 amplitudes to sad faces in adults, and similar results were reported by Krompinger and Simons (2009). Thus, while rumination in daughters of nondepressed mothers may have some performance benefits, the enhanced sad Go P3 amplitude suggests possible reason for concern despite low family-risk, and longitudinal research should examine whether these short-term benefits associated with rumination in girls at low familial-risk may nonetheless be associated with future depression. Overall, the pattern of results from diagnostically focused analyses suggests distinct patterns of response alterations related to rumination across girls at high versus low-risk for depression, in a manner generally consistent with the attentional scope model (Whitmer & Gotlib, 2013).

Symptom-based analyses

Rumination also was associated with distinct patterns of neurocognitive responses in girls at higher versus lower depression-risk in analyses focused on maternal depressive symptoms. In girls of mothers reporting elevated depressive symptoms (i.e., high-risk girls), rumination was not directly associated with behavioral performance, although it was associated with more negative N2 amplitudes on happy and sad NoGo trials, as well as on calm Go trials. Coupled with the lack of behavioral effects of rumination in higher-risk girls, the NoGo ERP amplitude effects suggest that rumination was associated with the need to recruit additional cognitive control resources when required to inhibit responding to emotionally-evocative stimuli to match the performance of high-risk girls reporting lower rumination. In contrast to negative-bias accounts of rumination, these effects were not specific to negatively valenced stimuli. The direction of effects is contrary to our predictions of attenuated NoGo N2 amplitudes, from inhibitory-control deficit and attentional scope models. Given that these high-risk girls were screened for depression histories themselves, it is possible that such compensatory efforts may become less effective over time, as the girls progress further through the age of heightened risk for depression-onset, underscoring the need for longitudinal work in this area.

The results for calm Go N2 amplitudes suggest diminished bottom-up attentional engagement with neutral stimuli, requiring greater engagement of top-down attentional processes to enact responses (Zhang & Lu, 2012). In correlational analyses, more negative calm Go N2 amplitudes were associated with more accurate performance on calm Go trials, suggesting some performance benefits. Unexpectedly, however, correlational analyses also indicated that more negative N2 amplitudes on calm Go trials were associated with more commission errors on happy and sad NoGo trials. Of note, calm Go trials occur in either sad NoGo or happy NoGo blocks, and rumination in high-risk girls also was associated with more

negative N2 amplitudes on sad and happy NoGo trials. It may be that rumination in high-risk girls is associated with failure to engage bottom-up processing toward calm faces in emotional NoGo blocks, requiring the recruitment of greater top-down attentional resources to enact responses (e.g., more negative calm Go N2 amplitudes). The recruitment of top-down resources may facilitate accurate responding to calm Go trials, but due to rumination-linked challenges, updating working memory and ignoring no-longer relevant information described in the attentional scope model ultimately may interfere with accurate responding to emotional trials in which behavioral inhibition is required, despite engaging stronger cognitive control resources on those trials (e.g., more negative N2 amplitudes to sad and happy NoGo trials). Of note, these rumination-effects were not specific to negatively valenced stimuli, in contrast to negative emotional bias accounts, but suggest a broader pattern of challenges adaptively responding across trials in higher-risk girls, in line with the attentional scope model. Possible emotional interference effects associated with neurocognitive responses during calm Go trials were observed across diagnostic and symptom-focused analyses, suggesting a potentially important component of ruminative processes in high-risk youth that merits further research.

In contrast to results for high-risk girls, elevated rumination in girls of mothers with lower depressive symptoms was associated with more accurate performance, regardless of emotional valence or trial-demands. Such enhanced performance associated with rumination in low-risk youth is generally consistent with the attentional scope model. Furthermore, in low-risk girls, elevated rumination was associated with attenuated (less negative) N2 amplitudes to the calm Go and happy/sad NoGo trials (the same trials for which rumination-linked alterations were observed for high-risk girls but in the opposite direction), suggesting diminished engagement of cognitive control resources (NoGo N2 to happy and sad faces) and diminished top-down attentional engagement with calm faces. Elevated rumination in lower-risk girls also was associated more positive P3 amplitudes to positively and negatively valenced NoGo trials, suggesting greater engagement of inhibitory motor control processes (Smith et al., 2008). In line with prior research (Zhang & Lu, 2012), larger P3 amplitudes to sad NoGo trials were associated with improved perceptual sensitivity to sad stimuli, indicating greater capacity to adjust response patterns to meet trial demands. Generally, the symptom-based results were not consistent with negative-bias accounts of rumination (as effects were not specific to negatively valenced stimuli). Although more complex than our hypotheses, results for low-risk girls were generally in-line with the attentional-scope model, suggesting rumination was associated with better behavioral performance, coupled with diminished need for early engagement of cognitive control resources but enhanced inhibitory motor control.

Limitations and future directions

As with any study, there are several limitations that may point to important directions for future research. First, we employed a cross-sectional design, and longitudinal work is needed to examine how the current results might change across adolescence or predict depression onset. We also employed a relatively small community-recruited sample. Although the study was adequately powered for moderate to large interaction effects, larger samples would provide greater statistical power to detect more modest interaction effects. Furthermore, we only included mothers and daughters in the current study, and future work including both fathers and sons is needed. For example, Wagner, Alloy, and Abramson (2015) found stronger effects of rumination on sustained attention in early adolescent boys with elevated depression compared with girls, highlighting the importance of future work on gender differences in ruminative effects.

Several measurement limitations are worth acknowledging. First, our diagnostic assessment was limited to depression, although depression and anxiety often co-occur. Of note, controlling for current symptoms of anxiety did not change the current results. While similar independent effects have been observed in other studies in this area (MacNamara et al., 2016), future work including broader diagnoses is warranted. Second, we employed a unidimensional measure of rumination. Recent studies that have examined subcomponents of rumination (e.g., brooding vs. reflective rumination) have yielded inconsistent results. In particular, Palmwood, Krompinger, and Simons (2017) found that reflective (but not brooding) rumination was associated with inhibitory control deficits in early adulthood, whereas Tanovic et al. (2017) found stronger effects for brooding versus reflective rumination in relation to ERN amplitudes. Given the sparse literature on subdimensions of rumination related to ERP amplitudes, further work is warranted. Third, in light of the age of participants, we employed a relatively simple three-category emotional Go/NoGo task. We also focused on sad stimuli (rather than anger or fear), as responses to sad faces have been proposed as a marker for depression risk (Bistricky et al., 2013), and future work examining a broader range of emotional stimuli is warranted. Finally, in diagnostically based analyses, rumination was associated with behavioral accuracy in high-risk youth. Because ERP averages were computed only from correct trials, this small-to-moderate effect may lead to differences in the reliability of ERP amplitudes across youth, which may attenuate between-group differences.

Despite limitations, this is the first high-risk study that we are aware of to employ EEG techniques to examine

rumination-linked emotional processing in healthy girls at varying familial risk for depression. Given that altered cognitive processing has been suggested as a central risk pathway from maternal to child depression, such high-risk studies can identify neurocognitive risk factors before depression onset and may have implications for early risk identification and prevention. Results were complex but generally consistent with attentional scope model accounts of differential effects of rumination related to depression-risk. Even in girls free from depression, the combination of maternal diagnostic history and elevated rumination was associated with a pattern of diminished motivational engagement with nonemotional stimuli when required to enact responses, which may interfere with adjusting responses to meet current response demands to emotional stimuli. A conceptually similar pattern of rumination-linked processing alterations were observed when depression-risk was defined by current maternal symptoms rather than diagnostic history, with results suggesting that greater rumination in high-risk girls was associated with a pattern of enhanced top-down attentional engagement toward calm faces when required to enact responses, which may disrupt accurate responding to emotional faces. Such interference effects are consistent with results for rumination in adults and suggest that rumination-linked difficulty adjusting responding to meet task demands may be an early risk-marker in relation to maternal depression. Longitudinal work is needed to examine whether such effects are predictive of future depression in high-risk youth or may disrupt family or peer relational functioning, which may depend in part on flexible responding in the face of negative or positive emotions. The current results also underscore the possible importance of targeting ruminative processes in prevention-focused work.

Open Practices Statement Data and task-related materials are available from the first author upon request. This study was not preregistered.

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