Journal of Abnormal Child Psychology (2020) 48:1325–1336
https://doi.org/10.1007/s10802-020-00679-8

Sustained Attention and Individual Differences in Adolescents' Mood and Physiological Reactivity to Stress

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Abstract

Biased attention to sad faces is associated with depression in adults and is hypothesized to increase depression risk specifically in the presence, but not absence, of stress by modulating stress reactivity. However, few studies have tested this hypothesis, and no studies have examined the relation between attentional biases and stress reactivity during adolescence, despite evidence that this developmental window is marked by changes in depression risk, stress, and the function of attention. Seeking to address these limitations, the current study examined the impact of adolescents' sustained attention to facial displays of emotion on individual differences in both mood reactivity to real-world stress and physiological (i.e., respiratory sinus arrhythmia [RSA]) reactivity to a laboratory-based stressor. Consistent with vulnerability-stress models of attention, greater sustained attention to sad faces was associated with greater depressive reactions to real-world stress. In addition, there was preliminary evidence from exploratory analyses that the impact of sustained attention on mood and/or physiological reactivity may be moderated by adolescents' age and sex such that relations are stronger for older adolescents and girls. The results of this study contribute to the current body of research on the role of attention in stress reactivity and depression risk and highlight the importance of considering age differences when examining these relations.

Keywords Attentional biases · Stress reactivity · Respiratory sinus arrhythmia · Depression risk · Adolescents

Introduction

According to cognitive theories, the way in which an individual attends to, interprets, and remembers negative information in their environment can increase risk for depression (Disner et al., 2011). Specifically, depression is thought to be characterized by increased sustained attention for, and difficulties disengaging from, depression-relevant stimuli (e.g., sad faces; for reviews, see Gibb et al., 2016; Gotlib & Joormann, 2010). Supporting cognitive models of depression, there is growing evidence that currently depressed adolescents and adults exhibit attentional biases, specifically biases in sustained attention, toward depression-relevant stimuli (for reviews, see Gibb et al., 2016; Gotlib & Joormann, 2010).

Despite the strengths of this research, there are two major limitations that need to be addressed. First, studies of attentional biases in psychopathology have historically relied on reaction times as an index of attentional bias (cf. MacLeod et al., 1986). However, there are increasing concerns about the psychometric properties of these reaction time indices based on data suggesting that they have very low, or even negative, split-half reliability (for a review, see Gibb et al., 2016). More recently, therefore, studies have begun to utilize eye-tracking, which allows a direct measure of patterns of gaze and provides indices with stronger psychometric properties (Armstrong & Olatunji, 2012; Gibb et al., 2016).

A second major limitation of previous work is that the majority has been cross-sectional and has largely not accounted for how attentional biases impact stress reactivity. Cross-sectional designs do not allow for an examination of whether attentional biases are associated with future risk for depression rather than simply being correlates of current depression. Furthermore, attentional biases by themselves are not believed to increase depression risk, but rather, cognitive models of depression are explicitly vulnerability-stress models of risk, such that attentional biases are thought to increase risk for the development of depression in the presence, but not

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10802-020-00679-8) contains supplementary material, which is available to authorized users.

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absence, of stress. Specifically, theorists have proposed that greater sustained attention to negative stimuli may contribute to increased emotional responding when faced with a stressful life event (Joormann & Vanderlind, 2014). Thus, depression-relevant attentional biases are hypothesized to increase a person's risk for depression by modulating their reactivity to stress. However, although cognitive models highlight the vital role of stress in contributing to risk for depression, few studies have actually examined attentional biases within a vulnerability-stress model of risk to test whether greater sustained attention to depression-relevant stimuli increases stress reactivity.

This said, there is initial support that attentional biases modulate stress reactivity. One study found that greater time to disengage attention from sad faces was associated with a more sustained negative mood reaction to a laboratory-based stressor (Sanchez et al., 2013). Additionally, two studies have prospectively tested vulnerability-stress models of attentional biases within the context of real-world stress, showing that the largest depressive reactions to stress were observed among adults with greater sustained attention to negative stimuli (Beevers et al., 2011; Beevers & Carver, 2003). Perhaps importantly, one prospective study that only examined the main effect of attentional biases on depressive symptom change, without taking into account the role of stress within a vulnerability-stress model, did not find evidence of attentional biases predicting increases in depression (Elgersma et al., 2019). Taken together, these studies provide preliminary support that greater sustained attention to sad faces is associated with mood reactivity to stress in adults.

Physiological Stress Reactivity

Beyond self-reported mood reactivity to stressors, physiological reactivity to stress may also be an important marker of depression risk, as the study of physiological reactivity may provide important insights into individual differences in real-world stress reactivity (Obradović, 2012). To this end, researchers have examined respiratory sinus arrhythmia (RSA), which is a peripheral measure of parasympathetic nervous system (PNS) regulatory influence on the heart, as an objective marker of stress reactivity. Higher levels of resting RSA are proposed to reflect increased capacity to adaptively respond to stress (Thayer & Lane, 2000), and adaptive stress responses are marked by moderate levels of PNS withdrawal (i.e., decreases in RSA) (Beauchaine, 2001). Therefore, as seen in the depression literature, both blunted and excessive decreases in RSA may be indicative of maladaptive stress reactivity. Blunted RSA reactivity is consistently observed in depressed adults (Schiweck et al., 2019), but results are mixed for youth. There is some evidence that greater RSA reactivity is associated with elevated levels of internalizing symptoms in children (Boyce et al., 2001; Obradović et al., 2011). However, within the context of elevated stress, both greater (Gray et al., 2017) and blunted (Mclaughlin et al., 2014) RSA reactivity have been found to predict depressive symptoms in youth.

Just as attentional biases are hypothesized to be associated with mood reactivity to stress, attentional biases may also be associated with RSA reactivity to stress, given that both involve disruptions in prefrontal-limbic circuitry. Specifically, diminished inhibitory control of the prefrontal cortex over amygdala reactivity is associated with difficulties directing attention away from dysphoric stimuli in depression (Disner et al., 2011) and with increased RSA reactivity (Beauchaine, 2015). Given their similar neurological underpinnings, one would expect that depressogenic attentional biases would also be associated with increased RSA stress reactivity. However, paralleling the paucity of research on attentional biases and mood reactivity to stress, only two studies to date have examined whether attentional biases associated with risk for depression are associated with RSA stress reactivity. Although one study failed to find a relation between attentional biases for sad faces and RSA reactivity to a standardized stressor in adults (Sanchez et al., 2017), another study in children found that greater sustained attention to emotional faces broadly was associated with greater RSA reactivity during a conflictual discussion (Woody et al., 2019). Clearly, more research is needed to delineate the relation between attentional biases and RSA stress reactivity, though evidence of abnormalities in RSA reactivity to stress in depression more broadly gives credence to the proposition that the impact of attentional biases on stress reactivity may also be observed at the physiological level.

The Current Study

It is clear that many questions remain as to how attentional biases may increase risk for depression. Further, although the majority of research to date has focused on adults, adolescence is a particularly important developmental window in which to examine the relation between attentional biases and stress reactivity, given that the transition to adolescence is marked by dramatic increases in negative life events (Ge et al., 1994) and emotional reactivity to stress (Larson & Ham, 1993). Therefore, the goal of the current study was to utilize a multiple-units-of-analysis approach to address limitations of previous research by examining sustained attention to emotional stimuli as a predictor of individual differences in adolescent stress reactivity, operationalized as both greater mood and physiological reactivity. The study had three primary aims. First, we examined whether greater sustained attention to sad faces would predict greater depressive symptom increases following life stress during a short-term multi-wave follow-up across an 8-week period. Of note, although there are limitations to the amount of variation in stress and depressive symptoms observed across an 8-week window, we chose a short-term follow-up as the multiple assessments of stress and depressive symptoms across this time frame allowed for a more nuanced examination of changes in depressive symptoms directly following the experience of stress. Second, we examined whether greater sustained attention to sad faces would predict greater physiological reactivity (i.e., greater RSA withdrawal) to a laboratory-based stressor in adolescents. Finally, although it has been proposed that physiological reactivity to stressors should reflect real-world stress reactivity (Obradović, 2012), no studies to date have examined whether laboratory-assessed RSA stress reactivity predicts which adolescents exhibit the greatest mood reactivity to stress in their daily lives. Therefore, we also examined whether greater RSA reactivity to stress would predict greater increases in depressive symptoms following life stress during the follow-up.

Exploratory Analyses

Importantly, no studies to-date have examined youth age or sex as moderators of depression-relevant attentional biases. These are important gaps in the current body of literature that need to be addressed for a number of reasons. Regarding developmental differences, the function of attention is proposed to change across development, with attentional avoidance of sad faces being associated with depression risk in children and preferential attention toward sad faces being associated with risk in adults (Gibb et al., 2016). If the relation between attention and depression risk does indeed "flip" during adolescence, the relation between attention and stress reactivity may change, and perhaps strengthen, across this developmental window. Though no studies have tested age differences in the relations between attention and depression risk or stress reactivity, studies within the depression literature more broadly illustrate increases in risk for depression onset (Hankin et al., 1998), mood reactivity to stress (Larson & Ham, 1993), and RSA reactivity to stress (Hollenstein et al., 2012) during adolescence, thereby potentially supporting hypotheses that impact of attention on stress reactivity may also increase during adolescence. Similarly, though no research has examined youth sex as a moderator of the impact of depression-relevant attentional biases, female, compared to male, adolescents also demonstrate greater risk for depression onset (Nolen-Hoeksema & Girgus, 1994) and greater mood and RSA stress reactivity (Hankin et al., 2007; Li et al., 2009).

Therefore, based on hypotheses that the function of attention may change across adolescence and given evidence for age and sex differences in depression risk and stress reactivity, exploratory analyses examined whether youth age or sex moderated any proposed relations between sustained attention and stress reactivity. Although we expected the relation between sustained attention to sad faces and stress reactivity would be strongest among older adolescents and females, it is important to note that these analyses were exploratory in nature, due to the paucity of research on age and sex differences in attentional biases.

Method

Participants

Participants included 95 adolescents from 81 families between the ages of 13 and 17 recruited from the community. Exclusion criteria included a history of intellectual or developmental disorders, as assessed via parent report. The average age was 14.95 (*SD* = 1.43; *Median* = 14.76) and 53.7% were female. In terms of race, 81.1% identified as Caucasian, 7.4% identified as African American, and 11.5% identified as biracial or another race.

Measures

Sustained Attention Attention was assessed using the attentional disengagement task, which allows for the assessment of patterns of attention for emotional faces via eye-tracking (Sanchez et al., 2013, 2017). The stimuli for this task consisted of pairs of pictures comprising an emotional (i.e., angry, sad, happy) and neutral facial expression of the same person. There were three different trial types throughout the task with 72 total trials, presented in random order (24 passive view, 24 engagement, 24 disengagement). Across the passive view, engagement, and disengagement trials, participants engaged in free viewing of the pair of faces for 3000 ms. Additionally, for the engagement and disengagement trials, after this free viewing phase, participants were prompted to move their gaze to either engage with or disengage from the emotional or the neutral faces via a frame placed around one of the faces in each pair. Gaze data were recorded during the 3000 ms free viewing segment across all three trial types, and average gaze duration was calculated for each emotion type by averaging the amount of time that participants spent looking at each emotion across trials. The split-half reliabilities for average gaze duration during passive viewing to angry, happy, and sad faces were .70, .74, and .65, respectively.[1]

Trier Social Stress Test Youth's physiological reactivity to stress was assessed during a modified version of the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), which is a commonly-used paradigm that has been shown to elicit RSA

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[1] Poor split-half reliability was observed for time to disengage from angry, happy, and sad faces (.46, .62, and .44, respectively) and time to engage with angry, happy, and sad faces (.75, .42, .50). Therefore, the current study only focused on average gaze duration across the 3000 ms of passive face viewing prior to each trial as a measure of sustained attention to emotional faces.

reactivity to stress in adolescents (Yim et al., 2015). During the TSST, participants were instructed that they would give a speech and do mental math in front of a panel of judges. For their speech, participants were told to imagine that they just moved to a new school and were told to talk about themselves and why they would be well-liked by their peers. For the math phase, adolescents were asked to count backwards out loud by 7's from 757. Youth were given 5 min to prepare their speeches, after which time two neutral judges (confederates) entered the room. The confederates sporadically took notes during the speech and provided negative feedback (e.g., "That is incorrect, begin again", "You need to be faster") during the math phase.

RSA RSA was calculated for a 5-min baseline period (rest), during which adolescents were asked to sit quietly, as well as for the anticipation phase of the TSST.[2] Electrocardiogram (ECG) data were obtained using Biopac BioNomadix wireless systems and recorded with Acqknowledge v4.2 software. ECG was recorded via a standard 3-electrode (lead II) set-up and ECG data were sampled at 1000 Hz. MindWare HRV 3.0.12 was used to inspect, transform, and analyze the ECG signal. ECG data were visually inspected for artifacts (e.g., temporary loss of signal, large movements, or an unusual R-R interval) and artifacts were corrected manually. Epochs with more than 10% artifacts (i.e., 10% of R-waves estimated within an epoch) were excluded, and RSA for each task was only calculated for participants with at least 50% usable epochs. To calculate RSA, spectral power analyses were performed with a fast Fourier transformation. Consistent with Task Force recommendations (Camm et al., 1996), RSA was defined as power density in the .12–.40 Hz frequency band and was calculated by averaging across the 30-s epochs of each task. Finally, consistent with recommendations regarding statistical modeling of physiological stress reactivity (Burt & Obradović, 2013), RSA reactivity was calculated by regressing participants' average anticipation RSA onto their average resting RSA. A negative RSA residual score indicates greater RSA withdrawal/blunted RSA augmentation and a positive RSA residual score indicates less RSA withdrawal/greater RSA augmentation.

State Mood Youth's state sadness and anxiety were assessed using a 100 mm visual analogue scale (VAS), on which they were asked to indicate how they currently felt. The sadness VAS asked how youth were feeling from "very happy" to "very sad", and the anxiety VAS asked how youth felt from "very anxious" to "very calm". Youth completed the VAS before and after completing the TSST to assess for changes in state mood during the stressor.[3]

Life Stress Youth's experience with stress was assessed at each follow-up assessment using a modified version of the Daily Stress Inventory (DSI; Brantley et al., 1987). The DSI is a self-report measure that includes 58 minor stressors (e.g., performed poorly at a task, argued with another person). Participants are instructed to indicated whether a stressor occurred in the last 24 h, yielding a frequency (FREQ) count of the number of stressors endorsed. One item was omitted in the modified version of the DSI utilized in the current study, given its lack of relevance to adolescents (i.e., "had problem with kid[s]"). Additionally, the modified version of the DSI asked for the occurrence of stressors across each 2-week follow-up interval rather than only the past 24 h. Similar to what has been observed in previous studies using a modified weekly version of the DSI (Brantley et al., 1997), the DSI-FREQ demonstrated excellent internal consistency at each assessment (all αs = .96).

Children's Depression Inventory Adolescents' depressive symptoms were assessed both at the initial assessment and at each follow-up using the Children's Depression Inventory (CDI; Kovacs, 1981). At the initial assessment, CDI scores ranged from 0 to 35 with a mean score of 9.87 (*SD* = 7.83) and 13.7% of adolescents had CDI scores above the clinical cut-off of 19. Similar levels of depressive symptoms were observed at the follow-up assessments. The CDI demonstrated excellent internal consistency at each assessment (α range = .91 to .93).

Procedure

Potential participants were screened over the telephone to determine eligibility, and assent and consent were obtained from adolescents and their guardians at the initial assessment. To obtain a true baseline of resting RSA, the initial assent and consent forms did not include information regarding the TSST. After completing the initial assent, resting RSA data were collected from adolescents during a 5-min baseline period, and youth completed the attention task and the CDI. Finally, consent and assent to complete the TSST were obtained directly before this task began, and RSA was collected during the TSST.

After the initial assessment, participants completed follow-up surveys including the DSI and CDI online once every

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[2] RSA was only examined during the anticipation phase of the TSST for two reasons. First, speaking aloud leads to changes in respiration that impact RSA (Beda et al., 2007). Therefore RSA during the speech and math phases of the TSST could be adulterated by changes in respiration. Second, the anticipation phase of the TSST is the only phase of the TSST that can be truly standardized, as feedback that youth receive during the speech and math phases is, in part, due to their performance.

[3] Four participants did not exhibit an average increase in negative affect across the TSST. However, all results were maintained when excluding these participants.

2 weeks for 8 weeks (4 follow-ups total). Thus, the CDI was completed at all assessments (T1-T5) and the DSI was completed at all follow-up assessments (T2-T5). Participants received \$25 for completing the baseline assessment and \$25 for completing the follow-up assessments. Additionally, to encourage follow-up survey completion, participants received one entry into a raffle to win a \$50 Amazon gift card for each follow-up they completed within 48 hours. Of the 95 participants, 49 (51.6%) completed all four follow-up assessments, 28 (29.5%) completed three follow-ups, 15 (15.8%) completed two follow-ups, and 3 (3.2%) completed only one follow-up. All study procedures were approved by Binghamton University's Institutional Review Board.

Analytic Plan

Linear mixed modeling was used for all analyses to account for the nested structure of the data (siblings nested within families and time points nested within participants). An unstructured covariance matrix (UN) was utilized for all longitudinal models, and random intercepts and slopes were included at the participant and family level. First, we examined whether sustained attention to emotional faces moderated the impact of real-world stress on prospective increases in youths' depressive symptoms during the follow-up. For these analyses, CDI at time T was the dependent variable, and Gaze Duration, Stress, and the Gaze Duration × Stress interaction were entered as predictors. Stress scores were person-centered to allow for an idiographic examination of the impact of increasing and decreasing levels of life stress relative to each person's own average level of stress. Lagged CDI at time T-1 was entered as a time-varying covariate in these analyses, allowing examination of residual change in CDI scores between each of the assessments. Analyses were conducted separately for duration of gaze to angry, happy, and sad faces.

Next, linear mixed modeling was used to test the hypothesis that sustained attention would predict individual differences in RSA reactivity to the laboratory-based stressor. Gaze Duration was entered as the predictor variable and the RSA reactivity score was examined as the dependent variable. As before, analyses were conducted separately for duration of gaze to angry, happy, and sad faces.

Finally, linear mixed modeling was used to examine the concordance between physiological reactivity to the laboratory-based stressor and mood reactivity to real-world stress. These analyses mirrored those described above except that they focused on RSA reactivity rather than gaze duration.

Results

An initial inspection of the variables indicated that CDI scores were significantly skewed for each time point ($z > 3.29$; cf. Tabachnick & Fidell, 2007); all other variables were normally distributed. A square root transformation was applied to CDI scores at each time point before any analyses to satisfy assumptions of normality. Additionally, given the presence of missing data (T2 DSI: 20.0%, T3 DSI: 20.0%, T4 DSI: 25.3%, T5 DSI: 8.4%, T2 CDI: 18.9%, T3 CDI: 20.0%, T4 CDI 24.2%, T5 CDI: 7.4%, Anticipation RSA: 1.1%), we examined whether the data were missing at random, thereby justifying the use of data imputation methods for estimating missing values (cf. Schafer & Graham, 2002). Little's missing completely at random (MCAR) test, for which the null hypothesis is that the data are MCAR, was not significant, $\chi^2(310) = 327.36, p = .24$. Therefore, maximum likelihood estimates of missing data were created and used for all analyses. Descriptive statistics for all study variables are presented in Table 1. Untransformed means and standard deviations are presented for the CDI to facilitate comparison with other research.

Preliminary analyses were then conducted to ensure that the TSST resulted in both physiological reactivity and state mood changes in adolescents. Focusing first on mood reactivity, there was a main effect of Time for state sadness, $F(1, 90.94) = 111.28$, $p < .001$, and anxiety, $F(1, 92.47) = 237.72$, $p < .001$, indicating that both state sadness and anxiety significantly increased from before to after the TSST. Focusing next on physiological reactivity, results also indicated a main effect of Time, $F(1, 94.00) = 12.85$, $p = .001$, indicating that RSA significantly decreased from baseline to the anticipation phase of the TSST.

Sustained Attention Predicting Mood Reactivity

First, we examined whether sustained attention moderated the impact of real-world stress on prospective changes in adolescents' depressive symptoms (see Supplementary Table 1). Consistent with hypotheses, the Gaze Duration × Stress interaction was significant for sad faces, $t(163.40) = 2.26$, $p = .03$, $r_{effect\ size} = .17$, but not for angry or happy faces ($ps > .14$). Examining the form of this interaction by conducting a simple slopes analysis following the guidelines of Aiken and West (1991) revealed that the relation between stress and prospective increases in depressive symptoms was stronger for adolescents with greater gaze duration to sad faces (+1 *SD*), $t(214.38) = 5.37$, $p < .001$, $r_{effect\ size} = .34$, than adolescents with lower gaze duration to sad faces (−1 *SD*), $t(167.72) = 3.61$, $p < .001$, $r_{effect\ size} = .27$ (Fig. 1).

In a series of exploratory analyses, we then examined whether youth age or sex moderated the any of the Gaze Duration × Stress interactions examined above. Focusing first on youth age as a moderator, the Age × Gaze Duration × Stress interaction was significant for gaze duration to angry, $t(205.58) = 3.60$, $p < .001$, $r_{effect\ size} = .24$, and sad, $t(220.44) = 2.17$, $p = .03$, $r_{effect\ size} = .14$, faces. The forms of

Table 1 Descriptive Statistics and Correlations Among Study Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Gaze Duration: Angry	–	.56***	.74***	−.03	−.01	−.18	−.12	−.05	−.19	−.05	−.09	−.05	−.10	.003
2. Gaze Duration: Happy	.56***	–	.55***	−.10	−.03	−.08	−.02	−.06	−.08	−.10	−.05	−.02	−.05	−.05
3. Gaze Duration: Sad	.74***	.55**	–	−.08	.03	−.02	.10	.11	.05	.16	−.02	.05	.07	.05
4. RSA: Rest	−.03	−.10	−.08	–	.57***	−.03	.01	.01	.01	.01	−.04	−.05	−.01	.03
5. RSA: Anticipation	−.01	−.03	.03	.57***	–	−.07	.05	.11	.07	.01	.07	.03	−.05	−.01
6. CDI T1	−.18	−.08	−.02	−.03	−.07	–	.89***	.80***	.81***	.81***	.54***	.37***	.46***	.37***
7. CDI T2	−.12	−.02	.10	.01	.05	.89***	–	.89***	.85***	.84***	.55***	.36***	.45***	.31***
8. CDI T3	−.05	−.06	.11	.01	.11	.80***	.89***	–	.88***	.83***	.59***	.50***	.45***	.36***
9. CDI T4	−.19	−.08	.05	.01	.07	.81***	.85***	.88***	–	.87***	.61***	.48***	.56***	.40***
10. CDI T5	−.05	−.10	.16	.01	.01	.81***	.84***	.83***	.87***	–	.57***	.39***	.52***	.43***
11. DSI T2	−.09	−.05	−.02	−.04	.07	.54***	.55***	.59***	.61***	.57***	–	.81***	.67***	.71***
12. DSI T3	−.05	−.02	.05	−.05	.03	.37***	.36***	.50***	.48***	.39***	.81***	–	.71***	.80***
13. DSI T4	−.10	−.05	.07	−.01	−.05	.46***	.45***	.45***	.56***	.52***	.67***	.71***	–	.86***
14. DSI T5	.003	−.05	.05	.03	−.01	.37***	.31***	.36***	.40***	.43***	.71***	.80***	.86***	–
15. Mean (*SD*)	1123.13 (169.18)	1196.96 (185.96)	1131.45 (171.62)	6.64 (0.96)	6.33 (0.96)	9.87 (7.83)	7.69 (6.95)	8.50 (8.34)	7.39 (8.10)	6.68 (7.09)	26.43 (10.78)	25.22 (12.41)	22.59 (10.64)	25.36 (12.06)

Note. RSA = Respiratory Sinus Arrhythmia. CDI = Children's Depression Inventory. DSI = Daily Stress Inventory Frequency. T = Time. Gaze Duration presented in ms. RSA presented in (ln[ms^2]). $^{***}p < .001$

these interactions are depicted in Fig. 2. To probe these interactions, the Gaze Duration × Stress interaction was examined separately for older and younger adolescents using a median split of age. Focusing first on gaze duration for angry faces, the Gaze Duration × Stress interaction was significant for older adolescents, $t(112.98) = 4.60$, $p < .001$, $r_{effect\ size} = .40$, but not younger adolescents, $t(62.95) = -0.31$, $p = .76$, $r_{effect\ size} = .04$. Among older adolescents, higher levels of stress at a given time point predicted prospective increases in depressive symptoms for those with greater gaze duration to angry faces (+1 *SD*), $t(113.46) = 4.77$, $p < .001$, $r_{effect\ size} = .41$, but decreases in depressive symptoms for those with lower gaze duration to angry faces (−1 *SD*), $t(116.24) = -2.08$, $p = .04$, $r_{effect\ size} = .19$. Similarly, gaze duration to sad faces significantly moderated the impact of stress on prospective increases in depressive symptoms for older, $t(101.54) = 3.45$, $p = .001$, $r_{effect\ size} = .32$, but not younger, $t(61.05) = 1.57$, $p = .12$, $r_{effect\ size} = .20$, adolescents. Among older adolescents, higher levels of stress at a given time point predicted prospective increases in depressive symptoms for those with greater gaze duration to sad faces (+1 *SD*), $t(112.26) = 4.05$, $p < .001$, $r_{effect\ size} = .36$, but not for those with lower gaze duration to sad faces (−1 *SD*), $t(103.78) = -0.93$, $p = .35$, $r_{effect\ size} = .09$. Next, analyses examining youth sex as a moderator indicated that the Sex × Gaze Duration × Stress interaction was significant for gaze duration to angry faces, $t(212.51) = 2.51$, $p = .01$, $r_{effect\ size} = .17$ (see Fig. 3). Examining the form of this interaction, the Gaze Duration × Stress interaction was significant for females, $t(128.24) = 2.99$, $p = .003$, $r_{effect\ size} = .26$, but not males, $t(58.74) = 0.96$, $p = .34$, $r_{effect\ size} = .12$. Finally, among females, higher levels of stress at a given time point predicted prospective increases in depressive symptoms for those with greater gaze duration to angry faces, (+1 *SD*), $t(126.88) =$

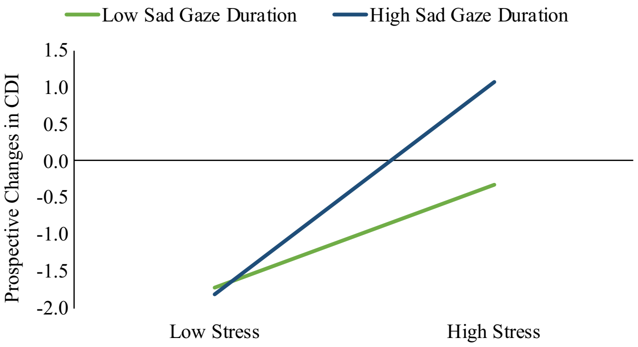
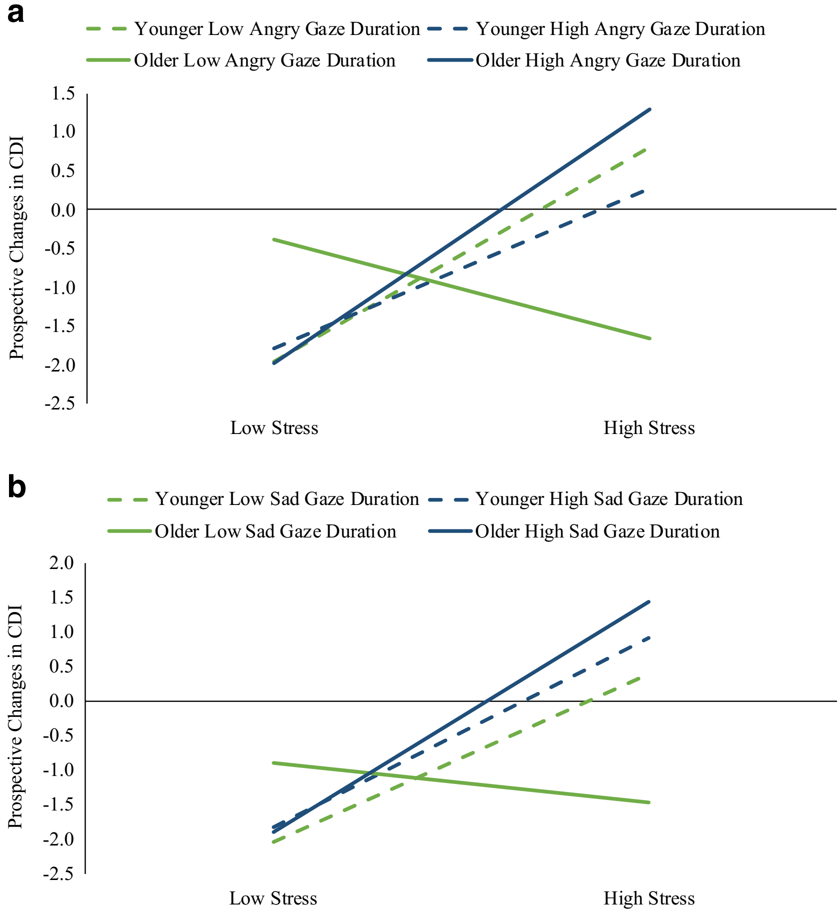


Fig. 1 Impact of stress on prospective increases in depressive symptoms at high and low levels of gaze duration for sad faces. CDI = Children's Depression Inventory. CDI change scores are presented as untransformed to facilitate comparisons with other research

Fig. 2 Age × Gaze Duration × Stress interaction predicting prospective increases in depressive symptoms for angry (A) and sad (B) faces. CDI = Children's Depression Inventory CDI change scores are presented as untransformed to facilitate comparisons with other research.

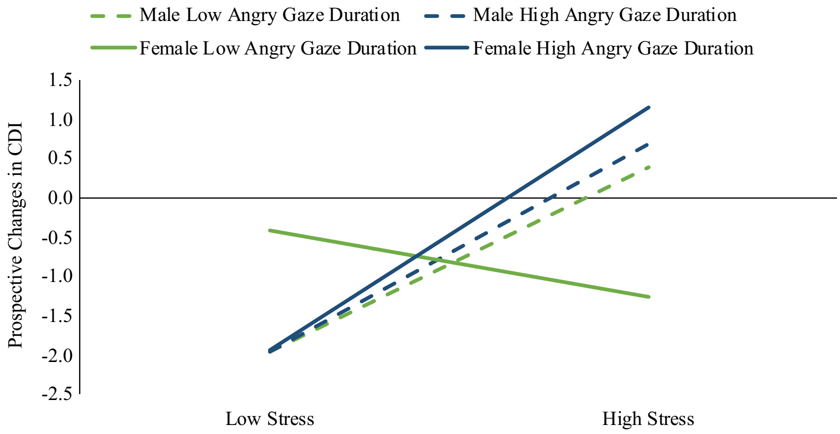


4.45, $p < .001$, $r_{effect\ size} = .37$, but not for those with lower gaze duration to angry faces, (−1 *SD*), $t(118.54) = -0.62$, $p = .53$, $r_{effect\ size} = .06$.

Sustained Attention Predicting RSA Reactivity

Second, we examined whether gaze duration to emotional faces was associated with RSA reactivity to the TSST (see Supplementary Table 2). Contrary to hypotheses, none of the relations between gaze duration and RSA reactivity were significant (all *ps* > .40). As before, exploratory analyses were conducted to examine whether youth age or sex moderated the relation between adolescent gaze duration and RSA reactivity. Youth sex did not moderate any of the examined relations, but the Age × Gaze Duration interaction was significant for sad faces predicting RSA reactivity, $t(91.00) = 1.95$, $p = .05$, $r_{effect\ size} = .20$ (see Fig. 4). Simple slope analyses (Aiken & West, 1991) revealed that the relation between gaze duration to sad

Fig. 3 Sex × Gaze Duration for Angry Faces × Stress interaction predicting prospective increases in depressive symptoms. CDI = Children's Depression Inventory. CDI change scores are presented as untransformed to facilitate comparisons with other research



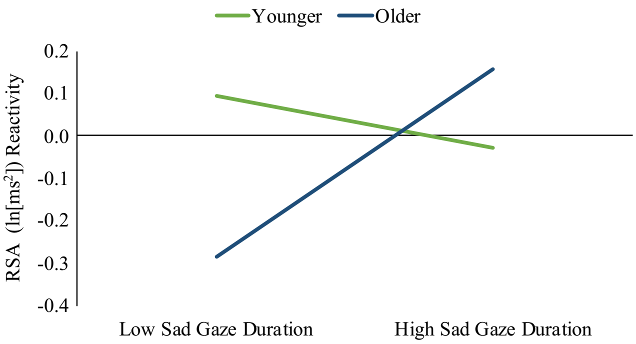


Fig. 4 Impact of gaze duration for sad faces on RSA reactivity among younger and older adolescents. RSA Reactivity = Respiratory Sinus Arrhythmia Residual Reactivity Score

faces and RSA reactivity was significant for older adolescents (+1 *SD*), $t(91.00) = 2.08$, $p = .04$, $r_{effect\ size} = .21$, but not younger adolescents (−1 *SD*), $t(91.00) = -0.66$, $p = .51$, $r_{effect\ size} = .07$, such that for older adolescents, less gaze duration to sad faces was associated with greater RSA withdrawal.

Concordance between Physiological and Mood Stress Reactivity

Finally, we evaluated the concordance between physiological and mood reactivity to stress by examining whether individual differences in RSA reactivity during the TSST moderated the impact of stress on prospective changes in depressive symptoms during the follow up (see Supplementary Table 3). In these analyses, neither the main effect of RSA reactivity nor the RSA Reactivity × Stress interaction predicted adolescents' change in depressive symptoms (all *p*s > .37). Additionally, neither youth age nor sex significantly moderated any of the concordance analyses (all *p*s > .19).

Discussion

The overarching goal of this study was to examine the impact of sustained attention on adolescents' reactivity to stress. In doing so, we examined depressive mood reactivity to real-world stress over a multi-wave two-month follow-up as well as physiological (i.e., RSA) reactivity to a standardized laboratory-based stressor. Consistent with vulnerability-stress models of risk, adolescents who exhibited more sustained attention to sad faces experienced larger depressive symptom increases following real-world stress than those who exhibited less sustained attention to sad faces. These findings for sustained attention to sad faces are consistent with what has been observed in adults. Specifically, consistent with vulnerability-stress models of depression (for reviews, see Abramson et al., 2002; Gibb & Coles, 2005), preferential attention to dysphoric stimuli (i.e., negative words and sad faces) has been shown to moderate the impact of life stress on prospective increases in depressive symptoms in two studies of adults (Beevers et al., 2011; Beevers & Carver, 2003). The current study extends this previous research and is the first to test attentional vulnerability-stress models of depression in a sample of adolescents.

Some potentially interesting findings also emerged from exploratory analyses, suggesting evidence of a developmental difference in the vulnerability-stress effects for both mood and physiological stress reactivity. Regarding mood reactivity, among older youth less sustained attention to sad faces was associated with lower mood reactivity to real-world stress. Paralleling this, sustained attention for sad faces was associated with RSA reactivity to the TSST, but again only for older adolescents. Contrary to our hypothesis, however, increased RSA reactivity was associated with attentional avoidance of, rather than preferential attention for, sad faces among older adolescents. This said, there are important developmental changes in RSA reactivity across childhood and adolescence that suggest increased RSA reactivity may reflect a more adaptive physiological stress response among older youth. Indeed, RSA reactivity appears to follow a U-shaped pattern from early childhood to late adolescence. Specifically, there is evidence that RSA reactivity decreases across early and middle childhood, with younger children showing greater RSA withdrawal than older children (Alkon et al., 2003; El-Sheikh, 2005), and then increases again with age across adolescence (Hollenstein et al., 2012). Blunted RSA withdrawal may therefore be indicative of atypical RSA reactivity for older adolescents, whereas increased RSA withdrawal may be indicative of atypical RSA reactivity for younger adolescents. Supporting this, these patterns of RSA reactivity may differentially increase risk for depression across adolescence given evidence that greater RSA withdrawal (i.e., greater decreases in RSA) is associated with depression risk for pre-adolescent children (Boyce et al., 2001; Obradović et al., 2011), whereas blunted RSA withdrawal increases risk for adolescents (Mclaughlin et al., 2014). Therefore, across both self-reported mood and physiological indices of stress reactivity, attentional avoidance of sad faces (i.e., lower gaze duration to sad faces) appeared to be protective among older adolescents, though replication studies are needed to confirm findings.

Despite finding that sustained attention to sad faces was related to real-world mood reactivity to stress and physiological reactivity to the laboratory-based stressor among older youth, there was no evidence for concordance between mood and physiological stress reactivity in the current study. Although physiological reactivity to stress is believed to reflect real-world mood reactivity (Obradović, 2012), it may be that in the current study, the physiological and mood indices may reflect different aspects of an individual's stress response. Specifically, whereas RSA reactivity to stress within the lab assessed youths' physiological reactivity as they experienced a stressor, the real-world mood reactivity assessed sustained mood reactions to a variety of stressors across a prolonged period of time (i.e., two weeks). Therefore, it may be that, within the current study, RSA reactivity reflected in-the-moment reactivity, whereas real-world mood reactivity reflected recovery from stress.

The current study is the first to examine the impact of adolescents' sustained attention on their mood and physiological stress reactivity. As previously noted, sustained attention for sad faces was specifically associated with stress reactivity across multiple levels of analyses among older, but not younger, adolescents. Though exploratory, this finding is in line with hypotheses that the form and function of attentional biases may change from childhood to adulthood (for a review, see Gibb et al., 2016). Although no previous studies have formally examined whether the nature of the relation between sustained attention and depression risk changes across adolescence, there is evidence from neuroimaging studies that the PFC does not exert an inhibitory effect on the amygdala until approximately age ten, after which negative PFC-amygdala functional connectivity increases through early adulthood (Gee et al., 2013). Given the critical role that PFC-limbic connectivity plays in top-down attentional processes (for reviews, see De Raedt & Koster, 2010; Disner et al., 2011), it may be that one's ability to disengage attention from emotional stimuli may not function as an effective emotion regulation strategy until later adolescence, once PFC-limbic functional connectivity has strengthened. Correspondingly, the pattern of results from the current study suggest that less sustained attention to sad faces functions as a protective factor that buffers youth against maladaptive reactions to stress (i.e., greater mood reactivity, blunted RSA reactivity) for older, but not younger, adolescents. Although replication is needed before definitive conclusions can be drawn, the current findings provide important preliminary evidence that the function of attentional allocation to emotional stimuli changes across adolescence, such that less sustained attention to sad faces only effectively contributes to adaptive patterns of mood and physiological stress reactivity during later adolescence.

Importantly, just as questions remain regarding how the function of attention may change across development, it is also unclear how attentional biases develop and when they stabilize. Though there is evidence that aberrant patterns of attention in children at elevated risk for depression emerge in infancy (Boyd et al., 2006), no studies have examined developmental trajectories of depression-relevant attentional biases. Further, the few studies focusing on attention towards threat-relevant stimuli have relied on reaction-time indices of attentional biases, and have shown no evidence of attentional stability in childhood (Waters et al., 2018) or adolescence (Britton et al., 2013). As results from primary analyses suggest that greater sustained attention to sad faces may increase risk for depression when faced with elevated levels of stress, a better understanding of when these attentional patterns develop and stabilize is essential to identify windows of development where targeted interventions may be most effective.

Across both primary and exploratory analyses, findings suggest that greater sustained attention to sad faces is a risk factor associated with stress reactivity. However, it is also important to note that there may be circumstances in which "maladaptive" patterns of attentional allocation may, in fact, be adaptive. For example, attentional avoidance of sad faces observed in offspring of depressed mothers may serve as an emotion regulation strategy during infancy (Bistricky et al., 2011) before increasing vulnerability to depression in childhood (Gibb et al., 2009). Additionally, if one lives in a dangerous environment, then hypervigilance for threat may be adaptive as one is able to quickly detect and respond to potential danger. Therefore, it is possible that greater sustained attention to sad faces may not always reflect increased risk, but rather, may specifically contribute to risk when this bias is exhibited inflexibly across contexts.

In addition to the hypothesized relations observed for attention to sad faces, an unexpected exploratory finding emerged for sustained attention to angry faces. Specifically, although attention to angry faces was not associated with RSA reactivity to the laboratory-based stressor, less sustained attention to angry faces was associated with reduced mood reactivity to real-world stressors for older adolescents and females. Although the relation between attention and youth depression risk is most consistently observed for attentional biases for sad faces (Platt et al., 2017), there is evidence that greater attention for angry faces is also associated with increased risk for the recurrence of major depressive disorder among adult women (Woody et al., 2016). Thus, sustained attention to angry faces may also be relevant for depression risk, perhaps particularly among females.

The current study had a number of strengths including the use of eye-tracking to assess patterns of sustained attention, the assessment of stress reactivity across multiple units of analysis, an idiographic assessment of real-world stress, and the multi-wave longitudinal follow-up. However, there are also some important limitations that should be acknowledged. For example, the current study only followed participants for two months, which may have not been a long enough follow-up window to capture significant variability in stress and mood. Similarly, due to the short follow-up window, the study focused on the occurrence of minor life stressors, rather than moderate to severe stressors, and utilized a checklist rather than an interview-based assessment. Future studies should utilize a longer follow-up window as well as contextual interview-based assessments of stress, which allow for the assessment of the objective negative impact of stressful life events and are considered the "gold-standard" for life stress assessment (Harkness & Monroe, 2016). Finally, and potentially most importantly, a number of significant results were observed with the context of exploratory moderation analyses. Although findings are consistent with a large body of literature suggesting that older adolescents and females demonstrate increased depression risk (Hankin et al., 1998; Nolen-Hoeksema & Girgus, 1994) and stress reactivity (Hankin et al., 2007; Hollenstein et al., 2012; Li et al., 2009; Shih et al., 2006), replication studies are needed to confirm the results of the current study.

In conclusion, the current study extends prior research on the relation between patterns of sustained attention associated with depression risk and individual differences in stress reactivity, and provides support for vulnerability-stress models of attention in adolescents. Furthermore, a pattern of exploratory findings emerged suggesting that, at least in older adolescents, less sustained attention to sad faces (perhaps reflecting an increased ability to disengage attention from depression-relevant stimuli) is a protective factor associated with decreased real-world mood reactivity and adaptive RSA reactivity to stress. However, given the exploratory nature of these findings, future studies are needed to confirm these results. If replicated, the current findings suggest that attending less to sad faces, potentially through a greater ability to disengage from dysphoric stimuli, is an effective emotion regulation strategy in older adolescents that may buffer against aberrant mood and physiological stress reactivity. Further, given evidence that attention bias modification is associated with a reduction in both depressive symptoms (Yang et al., 2016) and stress reactivity (Lemoult et al., 2016) in youth, greater sustained attention to sad faces may be an important target for intervention if findings are replicated, particularly for older adolescents.

Acknowledgments This project was supported by a National Science Foundation Graduate Research Fellowship under Grant No. DGE1144464 awarded to C. Feurer. We would like to thank Serah Narine, Jemy Paulson, Margarita Ashkinazi, Lillian Harrington, Louis Cafaro, Stephanie Mcgory, and Kevin Kunz for their help in conducting assessments for this project.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All study procedures were approved by the university Institutional Review Board.

Informed Consent Informed consent and assent were obtained from all parents and adolescents.

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