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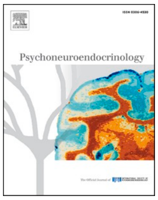

Attention to social threat predicts diurnal cortisol dynamics during the high school transition[☆]

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ABSTRACT

Adolescence is a developmental period marked by significant social shifts accompanied by concurrent changes across biological, cognitive, and emotional domains. Within adolescence, the high school transition is a pivotal time for youth that is ripe with opportunities yet has the potential to disrupt functioning. An increasingly sophisticated understanding of health and developmental biology indicates that the hypothalamic-pituitary-adrenal (HPA) axis plays an important role in transducing social experiences into physiological changes that have long-term impacts on health and wellbeing. There is reason to believe that attentional biases to social threat could impact cortisol, a steroid hormone indexing activity of the HPA axis, during the high school transition. The present study examined associations between attentional biases to socially threatening stimuli, measured using the Affective Posner paradigm, and components of the diurnal cortisol rhythm among youth across the first two days of high school. Participants included 67 youth ($N = 504$ saliva samples) with a mean age of 12.86 years and a relatively equal split with regard to both sex assigned at birth and gender identity (54 % male; 54 % boys). Findings build upon and extend previous work by demonstrating that greater attentional engagement bias to socially threatening stimuli is associated with a pattern of greater diurnal HPA axis reactivity across the first two days of the high school transition, as evidenced by a steeper cortisol awakening response and a steeper diurnal cortisol slope. This work extends our understanding of the mechanisms through which stress relates to wellbeing in youth by embedding biological development in the life course. Clinically, this work has the potential to inform interventions to protect youth against the biological embedding of stress by identifying a theoretically driven, socio-contextually relevant risk factor to be attenuated – namely, attentional bias to threat.

1. Introduction

The transition to high school is a pivotal time for youth. Occurring in the context of early adolescence, this transition often involves a striking shift from a supportive and predictable environment to a larger environment in which greater independence is expected (Benner, 2011). As a result, the transition to high school has the potential to disrupt functioning (Costello et al., 2011). Indeed, while some youth thrive during this major turning point, others have difficulty adjusting to changing expectations and environments (Merikangas et al., 2010). Despite the importance of this developmental transition, much of our understanding of the high school transition relates to students' academic outcomes. The impact of the transition on broader aspects of wellbeing among adolescents is largely understudied, though preliminary work indicates that many youth experience disruptions following the transition to high school and continue to struggle across the high school years (Benner and Graham, 2009).

Over the past several decades, an increasingly sophisticated understanding of health and developmental biology has provided insight into the ways that stressors occurring during adolescence impact long-term wellbeing (Romeo and McEwen, 2006). Human experiences are thought to be biologically embedded through the regulation of the hypothalamic-pituitary-adrenal (HPA) axis, a major stress response system that culminates with the synthesis and release of the hormone cortisol (Smith and Vale, 2006). While early work examining the HPA axis largely focused on cortisol reactivity to acute laboratory-based

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stressors and cortisol levels at rest, more recent work has focused on components of the diurnal cortisol rhythm (Adam et al., 2017). Cortisol follows a well-documented diurnal pattern: cortisol levels increase sharply following awakening and subsequently decrease across the day, reaching a nadir around midnight (though individual differences in diurnal patterns exist; see for instance Kirschbaum and Hellhammer, 1989; Wust et al., 2000). The distinct rise in cortisol levels following awakening has been termed the cortisol awakening response (CAR), while the subsequent decline is referred to as the diurnal cortisol slope (DCS). Individual components of the diurnal cortisol rhythm are becoming viewed as essential indicators of HPA axis functioning, and deviations within each diurnal component (i.e., levels of cortisol at wake, CAR, and DCS) in either direction (e.g., hyperactivity or hypoactivity) are indicative of HPA-axis dysregulation (Adam and Kumari, 2009).

The HPA axis plays an important role in transducing subjective social-environmental experience into physiological changes relevant to health and wellbeing (Adam and Kumari, 2009). The potential for experiences during adolescence to be embedded biologically is particularly high given the rapid biological, cognitive, emotional, and psychosocial development occurring during the transition from childhood to adolescence (National Academies of Sciences, 2019). These rapid changes position adolescence as a paradoxical period of both opportunity and vulnerability, as biological plasticity also renders individuals vulnerable to the potential of stress becoming embedded (Romeo and McEwen, 2006). Therefore, it is crucial to understand the mechanisms impacting HPA axis functioning during times of stress across this developmental period.

Theoretical models suggest that individual differences in cognition underlie biological stress system responsivity (LeMoult, 2020). In addition, evidence suggests that early adolescent youth are particularly sensitive to influences within the social context, given the considerable social re-orienting occurring during this period (Nelson et al., 2005). As such, individual differences in socially relevant cognitive biases (defined as systematic deviations in the ways that individuals process information) could differentiate youth for whom the stress of the high school transition "gets under the skin" through, for example, alterations in diurnal patterns of cortisol output (Mathews and MacLeod, 2005). The high school transition involves a social context characterized by social threat, as both peer acceptance and peer rejection become more salient for youth (Kilford et al., 2016; Symonds and Galton, 2014). Therefore, attentional biases to socially threatening stimuli could particularly impact cortisol output. In support of this proposition, recent work has documented associations between attentional bias to social threat and cortisol hyperreactivity in response to a socio-evaluative laboratory stressor in youth (Jopling et al., 2021). Similarly, in adults, greater attentional bias to threat is associated with greater cortisol reactivity in response to acute social-evaluative laboratory stressors (Roelofs et al., 2007). This work is in line with theoretical and empirical understandings supporting the role of the HPA axis in preparing the body to respond to challenge and/or threat and provides further support for the argument that attentional biases to social threat, rather than biases to stimuli of other valences (e.g., happy and sad stimuli), could impact HPA activity during the high school transition (Herman et al., 2016). However, while prior work has examined associations between attentional biases and HPA responsivity to acute laboratory stressors, it is unclear whether the attention-HPA axis association is observed in response to stressors in everyday life. This is a critical gap given the influence of diurnal cortisol production on long-term trajectories of physical and mental illnesses (LeMoult et al., 2015). Indeed, meta-analytic evidence supports a robust association between dysregulated patterns of diurnal cortisol and poorer mental and physical health outcomes across the lifespan including depression, anxiety, fatigue, inflammatory and metabolic diseases, cancer, and mortality (Adam et al., 2017).

1.1. The current study

Filling critical gaps in the literature, the present study examined the association between attentional biases to socially threatening stimuli and diurnal cortisol during the transition to high school. Toward this goal, we examined whether attentional biases to valenced social information (i.e., threatening, happy, and sad) were associated with three components of the diurnal cortisol rhythm: levels of waking cortisol, the CAR, and the DCS. Importantly, we considered both attentional engagement and attentional disengagement bias scores, as evidence suggests that engagement and disengagement biases are distinct components of attentional selectivity, with experimental evidence indicating that biases in engagement and disengagement from negative information are unrelated to one another (Rudaizky et al., 2014). It has also been posited that these two biases could mediate different aspects of the stress response; whereas facilitated engagement to social threat could serve to increase reactivity to stress, impaired disengagement could serve to increase perseverative processes following stress exposure (Rudaizky et al., 2014; Rudaizky et al., 2012).

We hypothesized that, above and beyond biases of other valences, attentional engagement biases to social threat would be associated with a pattern of cortisol output indicative of diurnal HPA axis hyperactivity including a steeper CAR in the broader context of the high school transition. In contrast, we expected that attentional disengagement biases to social threat (but not biases to happy or dysphoric stimuli) would be associated with a pattern of diurnal cortisol output indicative of prolonged HPA activation, evidenced by a flatter DCS. These hypotheses are based: a) on evidence linking attentional biases to social threat with cortisol hyperreactivity in youth, and b) on evidence highlighting possible associations between facilitated engagement and increased stress system reactivity and impaired disengagement with prolonged stress system activation (Jopling et al., 2021; Rudaizky et al., 2014; Rudaizky et al., 2012).

2. Method

2.1. Participants

Adolescent youth who were about to transition from elementary to high school were eligible for study participation if they were fluent in English. In the school system in which this research was conducted, youth transition directly from elementary school (Kindergarten to Grade 7) to high school (Grade 8 to Grade 12). School boards in the study area function according to both catchment and feeder systems. Within a catchment system, students are only eligible to attend a given school if they live within a specified geographic area around that school. Within a feeder system, several elementary schools feed into one larger high school. However, given overlapping catchment boundaries, it is possible that a student could transition to a different high school than the majority of their peers. Students in the present study transitioned from elementary schools with an average of 428 students ($SD = 156$) to high schools with an average of 1171 students ($SD = 434$). Participants were excluded if conditions were present that could impact cognitive processing or biological responsivity to stress (LeMoult et al., 2015), including history of serious head trauma, presence of medical conditions known to affect activity of the HPA axis, current substance use disorder, or use of current corticosteroids, depot neuroleptics, or oral or inhaled steroids. Further, participants were not eligible for participation if they had a significant learning or psychiatric problem likely to interfere with completing the study protocol (e.g., mania, psychosis). Efforts were made to recruit participants from diverse neighborhoods. For example, we partnered with school boards in both high and low-income areas, used both online and paper advertisements distributed across geographically diverse neighborhoods, and offered compensation for transportation to the university so that transportation costs were not a barrier to participation.

2.2. Measures

2.2.1. Attentional bias

Attentional bias to social stimuli was measured using a modified Affective Posner paradigm (Kircanski et al., 2015; Koster et al., 2005; Posner, 1980). Each trial began with two white frames presented side-by-side for 499 ms on a black background, with a white cross between them. Participants then presented with a picture of an affective stimulus in either the right or the left frame. Affective stimuli consisted of a stimulus set of faces expressing angry (i.e., threatening),[1] happy, dysphoric, and neutral affectivity drawn from the NimStim Face Stimulus Set (Tottenham et al., 2009). Facial stimuli, which participants viewed for 1000 ms, were presented in colour at a size of 14 cm×14 cm. The affective stimulus was then immediately masked by two white frames for 50 ms. Next, a probe letter (an “E” or an “F”) appeared either in the location that was previously occupied by the cue (valid cue trial) or on the other side of the screen (invalid cue trial), and participants indicated whether an “E” or an “F” appeared by pressing a corresponding computer key as quickly and accurately as possible. Participants were then presented with a black screen for 700 ms, following which the subsequent trial began. Following the procedures of previous studies using affective modifications of the Posner task, only reaction times (RTs) on accurate trials were considered in analyses, which resulted in the exclusion of less than 2 % of trials (Koster et al., 2005; Koster et al., 2006). Similarly, based on previous work, reaction times (RTS) <150 ms or >1000 ms were also excluded from analyses which resulted in the exclusion of approximately 7 % of accurate trials (Posner, 1980). A visual depiction of both a valid and invalid trial is presented in Fig. 1.

Attentional engagement bias was calculated separately for each valence using the formula proposed by Koster et al. (2005) in which attentional engagement bias is modelled as the difference between RTs to valid neutral cues and RTs to valid valenced cues. Therefore, three attentional engagement variables were developed for each participant: attentional engagement bias for socially threatening stimuli (EngageThreat), attentional engagement bias for happy stimuli (EngageHappy), and attentional engagement bias for dysphoric stimuli (EngageSad). For example, based on the formula proposed by Koster et al. (2005), attention to social threat was calculated as follows:

EngageThreat = RT valid neutral cue – RT valid threatening cue.

A *positive* attentional engagement bias indicates increased attentional engagement with stimuli of a valenced cue. In other words, a higher positive engagement score indicates enhanced attentional capture by cues of a specific valence (i.e., threatening, happy, or sad) compared with neutral cues. A negative score indicates decreased attentional engagement with the valenced cue. Similarly, as described by Koster et al. (2005), attentional disengagement bias was modelled as the difference between RTs to invalid valenced cues and RTs to invalid neutral cues for each valence. Therefore, three attentional disengagement variables were developed for each participant: attentional disengagement bias for threatening stimuli (DisengageThreat), attentional disengagement bias for happy stimuli (DisengageHappy), and attentional disengagement bias for dysphoric stimuli (DisengageSad). For example, based on the formula proposed by Koster et al. (2005), attentional disengagement bias from social threat was calculated as follows:

DisengageThreat = RT invalid valenced cue – RT invalid neutral cue.

A *positive* attentional disengagement bias indicates slower disengagement of attention from the valenced cue. In other words, a higher positive disengagement score means that more time was required for an individual to shift attention *away* from the valenced material compared to neutral material. A negative score, on the other hand, indicates faster attentional disengagement from the valenced cue.

2.2.2. Salivary cortisol

Youth provided eight saliva samples across the first two days of high school for the assessment of diurnal cortisol. Saliva samples were provided on two consecutive days immediately upon awakening, 30-minutes post-awakening, mid-afternoon, and at bedtime. This sampling protocol is consistent with current expert consensus guidelines for pediatric populations and prior work in this population (Kuhlman et al., 2019; Stalder et al., 2016). Specifically, participants were instructed not to eat, drink, or brush their teeth one hour before providing each sample, and they reported any deviations from these instructions. Saliva samples were stored at −20°C until analyses were carried out in the endocrinological laboratory at the Technische Universität Dresden (Institute of Biological Psychology). After thawing, Salivettes were centrifuged at 3000 rpm for 5 minutes; this process resulted in a clear supernatant of low viscosity. Cortisol concentrations were measured using chemiluminescence immunoassay with high sensitivity (IBL International, Hamburg, Germany). Following current practices and consistent with past research (Gotlib et al., 2015), outliers ($n = 16$ samples) were winsorized to 2 standard deviations (SDs) from the mean to adjust for skew. Post-transformation skewness statistics were acceptable, ranging from −0.53–0.53. The intra-assay coefficient of variance (CV) was 3.4 % while the inter-assay CV was 6.1 %, which are well within the industry standards of < 10 % for intra-assay CVs and < 15 % for inter-assay CVs (Stalder et al., 2016).

2.2.3. Covariates

2.2.3.1. Demographic variables.

To assess youths’ demographic characteristics, participants and caregivers completed a brief questionnaire assessing variables including youth’s age, sex assigned at birth, gender identity, household income, and racial identity.

2.2.3.2. Psychiatric diagnosis.

To assess for the presence of present and lifetime psychiatric diagnosis, youth completed the Kiddie Schedule for Affective Disorders and Schizophrenia for School Aged Children – Present and Lifetime Version for DSM-5 (K-SADS PL DSM-5; Kaufman et al., 2016).

2.2.3.3. Pubertal staging.

Pubertal staging was measured using the self-report Tanner Staging Questionnaire which asks adolescents to examine line drawings of pubertal development at each Tanner stage and to indicate the image most closely resembling their development (Marshall and Tanner, 1968). In line with previous work, drawings from the Sexual Maturity Scale by Morris and Udry were used. Scores on this measure correlate highly with physicians’ physical examinations of pubertal development (Shirtcliff et al., 2009; Morris and Udry, 1980). In line with previous work, we averaged Tanner scores for each participant to create an index of average pubertal development (Dorn et al., 2006). Overall, 21 % of participants were missing data on the Tanner Staging Questionnaire. Little’s MCAR test was not significant, and thus we failed to reject the null hypothesis that the missing data were missing completely at random (MCAR; $ps \geq .780$). Therefore, we proceeded to address missing values using Bayesian Stochastic regression imputation using a multivariate imputation by chained equations (MICE) approach implemented in the ‘mice’ package for R (Buuren and Groothuis-Oudshoorn, 2011).

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[1] Consistent with previous empirical and theoretical work, angry faces were conceptualized as indicating threat (see Fox et al., 2000; (Marinetti et al., 2012)) (Fox et al., 2001; Marinetti et al., 2012).

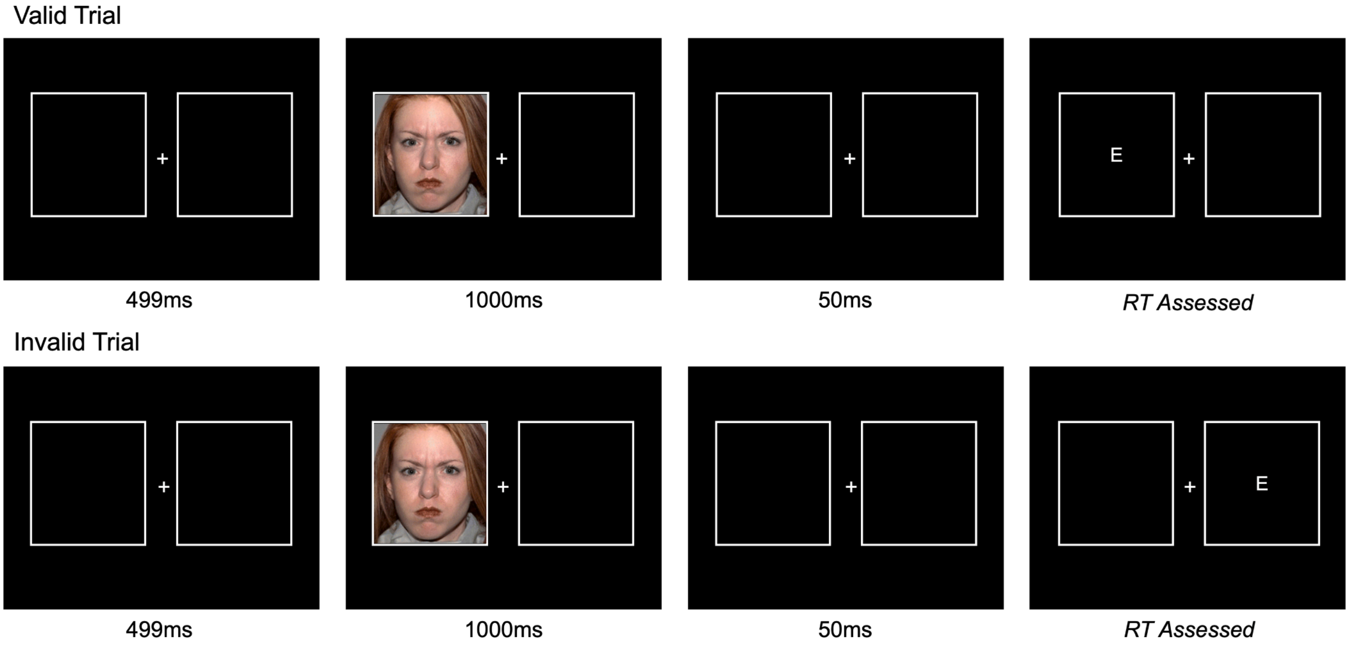

Fig. 1. Valid and Invalid Trials of Modified Affective Posner Paradigm.

2.3. Procedure

The study was approved by the University of British Columbia Institutional Review Board. Data were collected in a multi-session procedure. During an initial laboratory session, youth and caregivers completed a brief demographic questionnaire and youth completed the Tanner Staging Questionnaire, the K-SADS PL DSM-5, and the Affective Posner task. Finally, over the first two days of high school, youth self-collected samples of saliva for the assessment of diurnal cortisol.

2.4. Planned data analyses

As the present study involves nested levels of analysis (i.e., repeated measurements of cortisol nested within participants as a function of time), a hierarchical linear modeling (HLM) approach was used to examine associations between attentional biases and diurnal cortisol production. Further, HLM offers a statistical advantage over other approaches as it mitigates concerns related to multiple comparisons by utilizing a partial pooling approach, which yields more valid and unbiased estimates than other approaches by building multiplicity into statistical models from the start (Gelman et al., 2012). Using a multilevel piecewise model, the following components of the diurnal cortisol rhythm were specified at Level 1: cortisol at waking, CAR (from awakening to 30-minutes post-awakening), and the DCS (from 30-minutes post-awakening to bedtime). See equation below.

Level 1 (Engagement and Disengagement Models)

Diurnal Cortisol = π_{0j} (waking) + π_{1j}(cortisol awakening response) + π_{2j} (daytime cortisol slope) + e_{ij}

Coefficients, variance components, and standard errors were based on a sample size of 67 at Level 2, which exceeds best-practice recommendations of sample sizes for the stable estimation of variance and covariance components in HLM based on simulation studies (Maas and Hox, 2005).

A series of variables with the potential to influence trajectories of diurnal cortisol were tested as potential covariates in relation to youths' cortisol production: age, current use of psychotropic medication, current use of non-psychotropic medication, pubertal stage, sex assigned at birth, minutes between midnight and the first sample, days between assessment of cognitive bias and cortisol, and presence of a psychiatric diagnosis. Given that model parsimony increases the reliability of level and rhythm estimates in the context of diurnal cortisol, and following best-practice recommendations, only significant covariates were retained in the final Level 2 models (Murtaugh, 1998; Shirtcliff et al., 2012).

Next, to examine the contribution of attentional biases to components of diurnal cortisol production, biases across valences (i.e., threatening, happy, dysphoric) were included in each model at Level 2 to disentangle the specific impact of attentional biases to threat over and above biases to happy and dysphoric stimuli. Two separate HLM models were specified: Model 1 included attentional engagement biases at Level 2, while Model 2 included attentional disengagement biases at Level 2. Level 2 equations are presented below.

Level 2 (*Model 1*: Engagement model)

i) Waking: $\pi_{0j} = \beta_{00} + \beta_{01}(\text{EngageThreat}) + \beta_{02}(\text{EngageHappy}) + \beta_{03}(\text{EngageSad}) + r_0$
ii) Cortisol Awakening Response: $\pi_{1j} = \beta_{10} + \beta_{11}(\text{EngageThreat}) + \beta_{12}(\text{EngageHappy}) + \beta_{13}(\text{EngageSad}) + r_1$
iii) Daytime Cortisol Slope: $\pi_{2j} = \beta_{20} + \beta_{21}(\text{EngageThreat}) + \beta_{22}(\text{EngageHappy}) + \beta_{23}(\text{EngageSad}) + r_2$

Level 2 (*Model 2*: Disengagement model)

i) Waking: $\pi_{0j} = \beta_{00} + \beta_{01}(\text{DisengageThreat}) + \beta_{02}(\text{DisengageHappy}) + \beta_{03}(\text{DisengageSad}) + r_0$
ii) Cortisol Awakening Response: $\pi_{1j} = \beta_{10} + \beta_{11}(\text{DisengageThreat}) + \beta_{12}(\text{DisengageHappy}) + \beta_{13}(\text{DisengageSad}) + r_1$
iii) Daytime Cortisol Slope: $\pi_{2j} = \beta_{20} + \beta_{21}(\text{DisengageThreat}) + \beta_{22}(\text{DisengageHappy}) + \beta_{23}(\text{DisengageSad}) + r_2$

In sum, the Level 1 equation models diurnal trajectories of cortisol within person across the day that are predicted by participant-level attentional biases at Level 2. In line with current recommendations, Akaike Information Criterion (AIC) (Akaike, 1987) values are reported as indicators of comparative model fit, with smaller values indicating better model fit with lower predictive error (Hox et al., 2010).

3. Results

3.1. Participants

A total of 109 participants enrolled in the broader study from which this data stems (see Jopling et al., 2021, 2023; Rnic et al., 2022). Of those participants, a total of 67 participants (N = 504 saliva samples; maximum of 8 saliva samples/participant) provided data required for the present study (i.e., attention bias and diurnal cortisol). Participants who were included in the present sample did not differ from those who were not included with respect to sex, gender, pubertal stage, racial identity, or household income, *ps* $\geq$.072.

The sample had a mean age of 12.86 years (*SD* = 0.37) and had a relatively equal split with regard to both sex assigned at birth (54 % male) and gender identity (54 % boys). All participants identified as cisgender and the average pubertal stage was Tanner Stage 2.96. With regard to racial identity, the majority of the sample self-identified as White (57 %) followed by Chinese (18 %); Latin-x and South Asian (5 % each); and Canadian Indigenous, Japanese-White, and Korean-White (3 % each). The remaining 6 % of individuals identified additional endorsed racial identities. Additional participant characteristics are presented in Table 1

3.2. Preliminary analyses

Models were fit using full information maximum likelihood estimates to calculate deviance and AIC and restricted maximum likelihood for estimating model parameters. Robust standard errors were used to reduce bias (Raudenbush and Bryk, 2002). A baseline model, prior to the inclusion of attentional biases at Level 2 (*AIC* = 1451.46), indicated that the expected pattern of diurnal cortisol was observed across the first two days of the high school transition: participants' level of cortisol was significantly different than zero at waking, $t(66) = 17.74$, $p < .001$, increased significantly from waking to 30-minutes post-waking (CAR), $t(66) = 5.01$, $p < .001$, and decreased significantly across the remainder of the day (DCS), $t(66) = -17.52$, $p < .001$. Further, and in line with previous work in adolescent samples, the CAR and the DCS were significantly negatively correlated, $r = -.732$; $p < .001$ (Buthmann et al., 2023). Crucially, the variance components associated with each diurnal component were significant (*ps* <.001), indicating that significant variability remained to be predicted by Level 2 variables and thus justifying the inclusion of attentional biases. Of the covariates tested, only pubertal stage was significantly associated with diurnal cortisol production, *ps* $\leq$.007. Therefore, pubertal stage was included as a covariate in the corresponding analyses.

Table 1
Participant Characteristics.

Variable	
Age, *M(SD)*	12.86 (0.37)
Sex, % (*n*)	
Male	54 % (36)
Female	46 % (31)
Gender, % (*n*)	
Boys	54 % (36)
Girls	46 % (31)
Non-Binary	0 % (0)
Pubertal Stage, *M*(*SD*)	2.96 (1.07)
Bias Score, *M(SD)*	
EngageThreat	−2.26 ms (44.95)
EngageHappy	−8.58 ms (44.15)
EngageSad	−4.97 ms (33.35)
DisengageThreat	−0.60 ms (41.72)
DisengageHappy	1.23 ms (39.95)
DisengageSad	−0.53 ms (43.16)
With Psychiatric Diagnosis,% (*n*)	7.5 % (5)
Racial Identity, % (*n*)[a]	
White	57 % (38)
Chinese	18 % (12)
Latinx	5 % (3)
South Asian	5 % (3)
Canadian Indigenous	3 % (2)
Japanese-White	3 % (2)
Korean-White	3 % (2)
Additional endorsed racial identities[b]	6 % (4)
Household Income, % (*n*)	
$20,000-$39,999	5 % (3)
$40,000-$59,999	7 % (4)
$60,000-$79,999	8 % (5)
$80,000-$99,999	12 % (7)
$100,000-$119,999	18 % (11)
$120,000-$139,999	8 % (5)
$140,000-$159,999	13 % (8)
$160,000-$179,999	7 % (4)
$180,000-$199,999	7 % (4)
$200,000 and over	16 % (10)

[a] One participant did not endorse a racial identity.

[b] Additional endorsed racial identities included Chinese-Japanese-White, Chinese-Japanese, Chinese-Korean, South Asian-Latinx, and West Asian.

3.3. Main analyses

3.3.1. Model 1: Engagement model

Results from Model 1 (*AIC* = 1328.59) indicated that attentional engagement biases were associated with individual differences in youths' diurnal cortisol production during the high school transition. In line with hypotheses, attentional engagement to socially threatening stimuli was associated with the CAR, $B = 0.001$, $t(51) = 2.97$, $p = .004$, such that greater bias to social threat was associated with a steeper CAR. In other words, the faster an individual was to engage with threatening faces, the steeper their morning cortisol increase. Similarly, attentional engagement to socially threatening stimuli was associated with the DCS, $B = -0.00004$, $t(51) = -2.25$, $p = .029$, such that greater bias to social threat was associated with a steeper DCS. In other words, the faster an individual was to engage with threatening faces, the greater their decline in cortisol from their morning peak. These associations are illustrated in Fig. 2.

Attentional engagement bias to threat was not associated with levels of cortisol at wake, $B = -0.008$, $t(51) = -0.67$, $p = .507$. Further, in line with hypotheses, neither attentional engagement biases to other valences (i.e., happy, dysphoric; *ps* $\geq$.070). See online supplement for additional details.

3.3.2. Model 2: Disengagement model

In contrast to expectations, results from Model 2 (*AIC* = 1334.71) indicated that attentional disengagement biases for any valence were not associated with patterns of diurnal cortisol production, *ps* $\geq$.122. See online supplement for additional details.

4. Discussion

The transition to high school represents a naturalistic stressor during which youth's wellbeing is challenged. This study builds upon and extends previous work by demonstrating that greater attentional engagement bias to socially threatening stimuli is associated with a pattern of greater diurnal HPA axis reactivity across the first two days of the high school transition, as evidenced by a steeper CAR and a steeper DCS.

There is a surprising paucity of work examining associations between cognitive bias and diurnal cortisol in youth. However, the present findings are consistent with prior work showing an association between attentional bias to social threat and HPA axis hyperactivity in the context of stress exposure. For instance, greater attentional bias to threat has been shown to predict greater cortisol reactivity in response to laboratory stressors and a corresponding steeper slope of recovery (Jopling et al., 2021). A similar pattern of results was documented in the current study in the diurnal context, with greater attentional engagement bias to threat associated with a steeper initial cortisol increase to

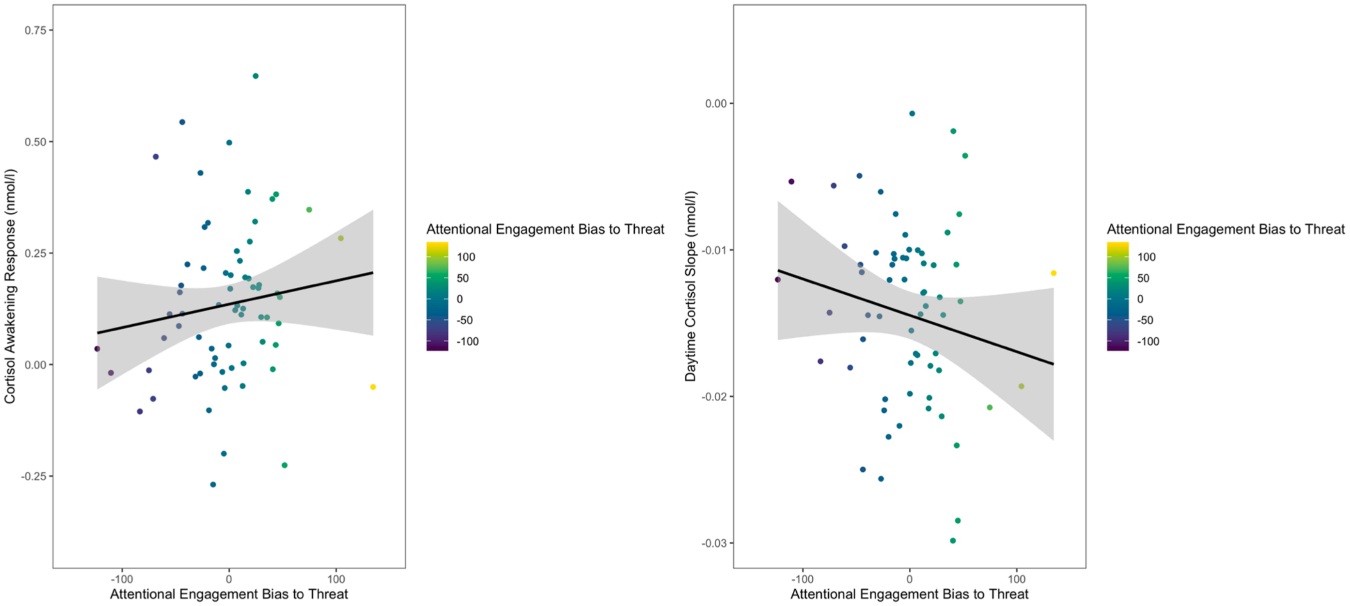

Fig. 2. Attentional Engagement Bias to Social Threat and Diurnal Cortisol Dynamics.

awakening, as well as a steeper slope of cortisol decline across the course of the day. Further, effect size magnitudes found between attentional engagement bias to threat and HPA axis hyperactivity in the current study are comparable to those found in prior work examining links between diurnal cortisol hyperactivity and engagement in maladaptive emotion regulation strategies, symptoms of anxiety, and a history of maternal depression (LeMoult et al., 2015; Ma et al., 2019; Rnic et al., 2022).

While the HPA axis in general is responsible for preparing the body to respond to challenge and/or threat (Smith and Vale, 2006), the CAR in particular is critical for preparing the body for the challenges of the coming day (Stalder et al., 2016). In the context of the transition to high school, during which youth face an unfamiliar environment, moderate HPA system responsiveness is likely adaptive insofar as it prepares youth to face possible unknown challenges. However, for youth who may overestimate the threat associated with the transition to high school – for instance, youth with heightened attentional bias to threat – the CAR may be exaggerated, consistent with the current findings. Specifically, it is likely that attentional bias to threat increases HPA axis reactivity as it orients an individual to potential threat in their environment, indicated in the diurnal context as an exaggerated CAR. For an individual who has heightened vigilance for potential threat (i.e., greater attentional bias), the HPA axis could demonstrate hyperactivation in response to perceived threats/challenges and, over time, hyperactivity of the HPA axis can result in a greater allostatic load (i.e., greater cumulative cost of stress system activation) which has well-documented pathophysiological consequences (McEwen, 2000). Therefore, while the present results are in line with previous work, they also extend the literature by documenting the association attentional bias to social threat has with adolescents' response to a naturalistic stressor.

It is interesting that attentional engagement bias to threat, but not attentional disengagement bias to threat, was associated with diurnal cortisol production. While an attentional engagement bias for threat reflects an increased tendency for threatening material to *attract* attention, attentional disengagement bias for threat reflects an increased tendency for threatening material to *hold* attention (Mogg and Bradley, 1998). Considering our findings, it is possible that there is a developmental sequence in the formation of attentional biases, in which attentional engagement biases lead to attentional disengagement biases by enhancing attention for threatening information, which over time, leads to difficulty disengaging from threatening information. Given the young age of our sample, we have captured an early engagement bias that may, across adolescence, become associated with a disengagement bias. While this proposition is supported by experimental work documenting cascading developmental effects of threat-related information processing biases, where one bias contributes to the development of another bias over time (White et al., 2011), it has not been investigated in the context of attentional engagement and disengagement biases and is therefore ultimately speculative.

It has also been suggested that attentional engagement biases may specifically serve to enhance reactivity to a stressor, while attentional disengagement biases may serve to prolong activation following a stressor (Rudaizky et al., 2014). In line with this, previous work has shown associations between attentional *engagement* biases to threat (rather than disengagement biases to threat) and HPA hyperactivity under conditions of stress. For instance, under conditions of stress, an association has been found between HPA hyperactivity and heightened vigilance for threatening stimuli among adults (Roelofs et al., 2007). Conceptualizing the high school transition as a stressor (Benner, 2011), it is possible that exposure to the high school transition primed youth to allocate attentional resources to social threat, leading to a pattern of diurnal HPA hyperactivity, and this priming was particularly potent for youth with existing biases for threat.

The present findings should be interpreted in light of several study limitations, which highlight exciting future directions. First, the current study design is unable to determine the directionality of the observed association between diurnal cortisol and attentional engagement bias to threat. Although attentional biases were measured several months (*Mdays* = 109.89) prior to the high school transition and there is reason to believe that attentional biases to threat could prolong activation of the HPA axis, there is also reason to believe that this association is bidirectional given the marked impacts of cortisol hypersecretion on neural regions involved in attention (Romeo and McEwen, 2006; LeMoult, 2020). As such, it will be important for future work to disentangle the temporal aspect of these associations by including repeated concurrent assessments of both attentional biases and diurnal cortisol over time. In addition, experimental work making use of attentional bias modification (ABM) training paradigms would be valuable in disentangling the directionality of associations between cortisol production and attentional engagement bias to threat. Future work should also examine whether HPA axis dysregulation represents a mechanism through which attentional bias to threat leads to psychopathology.

Specifically, it would be interesting to examine longitudinal associations between attentional bias to threat, diurnal cortisol, and psychopathology across adolescence given that this is when rates of onset of many psychiatric illnesses (including anxiety and depression) peak. It will also be important for future work to examine whether the bias-related diurnal hyperactivity of the HPA axis is meaningfully related to long-term outcomes at a deeper level: for example, through impacts on other biological systems, such as the immune system. In addition, this work could be extended by considering early-life factors (e.g., temperament, early life adversity) and the presence of cognitive biases at other levels of processing (e.g., interpretation bias) that could influence the observed associations between cognitive biases and diurnal cortisol. Finally, though the present study used an objective method to verify self-reported sampling times (online real-time reporting of sampling time), we did not use an objective method to verify self-reported awakening times (e.g., research grade actigraphy devices).

The transition to high school represents a near-ubiquitous and naturalistic stressor that challenges youths' wellbeing. During this transition, the present study identified an association wherein greater attentional bias to threat was associated with diurnal hyperactivity of the HPA axis. While moderate cortisol reactivity is important for preparing the body to respond to challenges, excess exposure to cortisol has documented neurotoxic effects and is a risk factor for both physical and mental pathologies (Adam et al., 2017). These findings highlight the importance of examining the impact of theoretically driven, socio-contextually relevant risk factors on youth wellbeing during times of challenge. If replicated, this work could have relevance for the development of interventions aimed at protecting high-risk youth against the development of mental and physical illness.

Declaration of Competing Interest

All authors declare that they have no conflicts of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psyneuen.2024.107226.

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