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Later ("evening") circadian preference is associated with poorer executive, academic, and attentional functioning in adolescents with and without ADHD

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Background: Adolescents vary considerably in their circadian phase preference; those with greater "eveningness" (also known as "night owls") have later bedtimes, wake times, and peak arousal compared to those with greater "morningness." Prior research suggests that (a) greater eveningness is associated with worse academic, executive, and attentional functioning; and (b) adolescents with attention-deficit/hyperactivity disorder (ADHD) tend to be high in eveningness and to have deficits in these school-related constructs. However, few studies have examined circadian preference alongside two potential confounds—sleep duration and sleep quality—as predictors of daytime functioning, or whether the strength of associations differs across adolescents with and without ADHD. **Methods:** Participants were 302 adolescents (M_{age} = 13.17 years; 44.7% female; 81.8% White); approximately half (52%) had ADHD. A multi-method, multi-informant design was used. Specifically, adolescents reported on their circadian preference, school night sleep duration, and sleep quality. Adolescents provided ratings of their academic motivation (intrinsic, extrinsic, and amotivation) and were administered standardized achievement tests in reading and math. Adolescents and parents completed ratings of daily life executive functioning (behavioral, emotion, and cognitive regulation), and they and teachers also provided ratings of ADHD inattentive symptoms. **Results:** Above and beyond sleep duration, sleep quality, and covariates (sex, family income, pubertal development, medication use), greater eveningness was uniquely associated with poorer academic, executive, and attentional functioning across most measures. Sleep quality was uniquely associated with a handful of outcomes, and sleep duration was not significantly uniquely associated with any outcome in the regression analyses. ADHD status did not moderate effects. **Conclusions:** This study provides compelling evidence that poorer academic, executive, and attentional functioning are more closely associated with greater eveningness than with sleep duration or quality in adolescents. Findings suggest that targeting circadian preference may be important to reduce these problems in adolescents, especially in clinical samples such as ADHD for whom academic, executive, and attentional difficulties are exceptionally common.
Keywords: ADHD; academic performance; adolescence; chronotype; circadian preference; executive function.

Introduction

Driven by an interplay of maturational and social-environmental factors, adolescence has been described as the "perfect storm" for insufficient and misaligned sleep (Crowley, Wolfson, Tarokh, & Carskadon, 2018). The circadian system, which regulates physiological rhythms including alertness and sleep propensity, undergoes substantial changes during adolescence (Crowley et al., 2018). As children transition to adolescence, they normatively encounter a circadian phase delay (i.e., later "internal clock"), which is reflected behaviorally as a shift towards later phase preference (Carskadon, Acebo, & Jenni, 2004; Crowley et al., 2018). Within this developmental shift, adolescents vary considerably in their phase preference; those with a later preference (greater "eveningness") have later bedtimes, wake times, and peak arousal compared to those with an earlier preference (greater "morningness"; Crowley, Acebo, & Carskadon, 2007). Those with greater eveningness are routinely out of sync with school schedules, contributing to chronic insufficient sleep, poor sleep quality, and daytime sleepiness (Crowley et al., 2018).

The functional consequences of insufficient sleep duration and quality during adolescence have been well-documented (Carskadon, 2004; Shochat, Cohen-Zion, & Tzischinsky, 2014). A large body of research links shortened sleep duration and poor sleep quality with lower academic performance, executive functioning (EF) skills deficits, and attention regulation difficulties (Chaput et al., 2016; Spruyt, 2019; Turnbull, Reid, & Morton, 2013). Comparatively less research has examined circadian preference in relation to these academically-relevant domains or considered sleep duration, quality, and circadian factors simultaneously (Becker, 2023, 2024).

Circadian preference in relation to academic, EF, and attentional functioning in adolescents

A meta-analysis conducted over a decade ago found a small but significant association between eveningness

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preference and lower academic achievement ($r = -.14$, $p < .001$), though only 13 datasets were included and most focused on young adults, with only two focused on adolescents (Preckel, Lipnevich, Schneider, & Roberts, 2011). Since then, there has been growing support for an association between circadian preference and adolescents' academic functioning. Several studies found eveningness to be associated with lower school grades (Preckel et al., 2020; Russo, Biasi, Cipolli, Mallia, & Caponera, 2017), even when controlling for sleep duration and/or daytime sleepiness (Cohen-Zion & Shiloh, 2018; Díaz-Morales & Escribano, 2013; Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002; Preckel et al., 2013). When specific academic subjects have been examined, two studies found eveningness to be associated with lower math/science and language grades (Preckel et al., 2013; Russo et al., 2017), whereas another reported an association with lower math but not language grades (Escribano-Barreno & Díaz-Morales, 2013). These mixed findings point to the need for additional studies examining specific academic domains. Only one study that has examined circadian preference in relation to standardized achievement test scores, finding no association with reading comprehension or math scores (Preckel et al., 2020). It is possible that cumulative *knowledge* (as reflected in test scores) is less influenced by adolescent circadian preference than is academic *motivation*, a key enabler for school success (Roeser, Schlarb, & Kübler, 2013). Adolescents with an evening chronotype report lower general academic interest and learning motivation than adolescents with a morning chronotype (Preckel et al., 2020; Roeser et al., 2013).

A small and mostly separate body of research has focused on the relation between circadian preference and EF, which refers to higher-order mental abilities that regulate goal-oriented thoughts and behaviors (Toplak, West, & Stanovich, 2013). Adolescents perform better on performance-based EF tests when tested at their optimal versus nonoptimal time of day based on circadian preference (Hahn et al., 2012). Two studies also found greater eveningness, but not sleep duration, to be independently associated with self-report of poor application of EF skills in daily life (Cohen-Zion & Shiloh, 2018; Owens, Dearth-Wesley, Lewin, Gioia, & Whitaker, 2016). As both circadian preference and daily life EF were rated by adolescents in each study, these findings may be inflated by mono-informant biases. We are unaware of any studies that have examined adolescent circadian preference in relation to caregiver report of their adolescent's daily life EF, which is an important gap given the importance of a multi-informant perspective when assessing EF deficits (Andersen et al., 2024; Zabel et al., 2011).

Attention is closely tied to EF, and the ability to regulate and sustain attention is clearly impacted by short or insufficient sleep (Beebe et al., 2008; Lim & Dinges, 2008). There is also indication that eveningness is independently associated with inattention in adolescence. Evening chronotypes show poorer performance on laboratory-based tasks of attention (Vollmer, Pötsch, & Randler, 2013). In a sample of 61 adolescents, Hennig et al. (Hennig, Krkovic, & Lincoln, 2017) found both shorter sleep duration and eveningness preference to be associated with greater self-reported inattention.

Circadian preference, sleep, and ADHD

Adolescents with attention-deficit/hyperactivity disorder (ADHD) experience more sleep problems than their peers without ADHD (Becker, 2019; Marten et al., 2023), and there is evidence that individuals with ADHD also have a later circadian preference (Bondopadhyay, Diaz-Orueta, & Coogan, 2022; Lunsford-Avery, Carskadon, Kollins, & Krystal, 2024). Yet very few studies have examined circadian preference in adolescents diagnosed with ADHD. In a sample of 80 adolescents with ADHD, eveningness was associated with more sleep problems and daytime sleepiness but was not significantly associated with ADHD symptom severity (Becker, Kapadia, Fershtman, & Sciberras, 2020). However, another study of 84 adolescents with ADHD found eveningness to be associated with greater inattention/hyperactivity problems (Martinez-Cayuelas et al., 2022).

Although not as diagnostic as inattention, academic problems and deficits of EF in daily life are exceptionally common among adolescents with ADHD (Doidge, Saoud, & Toplak, 2020; Evans, Van der Oord, & Rogers, 2020). Yet we are unaware of any study that has examined circadian preference in relation to academic functioning or EF in adolescents with ADHD, and at least one study in this area *excluded* adolescents with ADHD from participation (Cohen-Zion & Shiloh, 2018).

Present study

Given the possible contribution of circadian preference to academic and cognitive functioning in adolescents without ADHD, coupled with the increased sleep and circadian disruptions in youth with ADHD, this study examined whether circadian preference is associated with academic, EF, and attentional functioning in adolescents, and whether that association differs across those with and without ADHD. This study builds on and extends previous research in several important ways. First, outcomes were assessed using a multi-method, multi-informant design including standardized academic achievement testing and parent, teacher, and adolescent self-report rating scales. This design allowed us to extend past potentially inflated associations resulting from mono-method, mono-informant biases. Second, this study concurrently assessed circadian preference, sleep duration, and sleep quality; this allowed us to test the unique effects of each, over and above the other potentially confounding sleep variables. Third, we aimed to increase specificity in the outcomes by examining academic achievement in the separate areas of reading and math as well as specific domains of academic motivation (i.e., extrinsic motivation, intrinsic motivation, amotivation) and daily life EF (i.e., behavioral, emotion, and cognitive regulation). This extends beyond the largely piecemeal outcomes of prior research. Finally, this study used a large sample, including the largest sample of adolescents with confirmed ADHD to date for a study associating circadian preference with academic or cognitive functioning, which allowed us to explore whether those associations differ for teens based on ADHD status. We hypothesized that, on the morningness-eveningness dimension, evening circadian preference would be associated with poorer academic, executive, and attentional functioning. We also explored whether associations were moderated by ADHD status but, given the absence of prior research, did not make *a priori* predictions.

Methods

Participants

Participants were 302 adolescents between the ages 12–14 years (M = 13.17, SD = 0.40; 44.7% females). For purposes of the larger study, recruitment targeted a similar number of adolescents with and without ADHD (n = 162 diagnosed with DSM-5 ADHD, 120 with Inattentive Presentation and 42 with Combined Presentation; n = 138 without ADHD). Further description of the sample and comparisons between the ADHD and comparison groups can be found in Table 1 and elsewhere (Becker, Langberg, Eadeh, Isaacson, & Bourchtein, 2019; Langberg et al., 2019). Slightly more than half of participants (53%) had a reported family income of $100,000 or higher, 31.2% between $50,000 and $100,000, and 14.5% less than $50,000. Around 40% of adolescents were currently taking any medication for ADHD, emotional problems (e.g., depression, anxiety), or sleep.

Procedure

This study was approved by the institutional review boards (IRB) at Cincinnati Children's Hospital Medical Center and Virginia Commonwealth University. Data in the current study were collected at the initial visit of a broader study of adolescents with and without ADHD (Becker, Langberg, et al., 2019). Adolescents in eighth grade and their parents were recruited across two consecutive years. Parents contacted the research staff in response to recruitment materials, and families meeting screening criteria via phone were invited to receive a comprehensive assessment, during which written informed consent and assent were obtained prior to adolescents and their parents being administered study measures. Inclusion criteria included: (a) enrollment in eighth grade, (b) estimated Full Scale IQ ≥ 80 based on the Wechsler Abbreviated Scale of Intelligence, Second Edition (Wechsler, 2011), and (c) meeting criteria for either the ADHD or comparison group as defined below. Exclusion criteria included (a) past or current diagnoses per parent-report of autism spectrum disorders, bipolar disorder, or schizophrenia disorder and (b) previous diagnosis of an organic sleep disorder (i.e., obstructive sleep apnea, narcolepsy, restless leg syndrome, periodic limb movement disorder) according to parent report during the initial phone screen.

Measures

ADHD group status (covariate in the primary analysis, moderator in exploratory analysis). ADHD diagnosis was established based on the parent version of Children's Interview for Psychiatric Syndromes (P-ChIPS) (Weller, Weller, Rooney, & Fristad, 1999). Adolescents in the *ADHD Group* were required to meet criteria for either the ADHD Combined Presentation or Predominantly Inattentive Presentation on the P-ChIPS. Specifically, participants were included in the ADHD group if parents reported ≥6 symptoms of inattention at clinically significant levels; the presence of ADHD symptoms prior to age 12 years, the presence of ADHD symptoms in two or more settings (e.g., home, school), evidence that symptoms contribute to home, academic, and/or social impairment; and symptoms of ADHD were not better explained by another mental disorder. Participants meeting criteria for ADHD Predominantly Hyperactive–Impulsive Presentation (n = 2) were not included given the low prevalence of this presentation in adolescence and ongoing concerns about its validity after early elementary school (Willcutt, 2012). Adolescents were in the *Non-ADHD Comparison Group* if the parent endorsed <4 symptoms of ADHD in both domains (i.e., inattention, hyperactivity/impulsivity) on the P-ChIPS. Participants not meeting symptom criteria for either group were not eligible for inclusion; see Becker et al. (2019) for additional details.

Circadian preference, sleep quality, and school night sleep duration (predictors). These constructs were assessed via items from the self-report Sleep Habits Survey (Wolfson & Carskadon, 1998). The 10-item *circadian preference* subscale assesses preference for morningness or eveningness ("When does your body start to tell you it is time for bed"?), with items summed such that higher scores indicating greater morning preference. As in previous research (Acebo & Carskadon, 2002), *sleep quality* was based on the averaged responses on two items ("felt satisfied with your sleep," "had a good night's sleep") over the prior 2 weeks, with scores ranging from 1 (never) to 5 (every day/night). In the present study, αs = .77 and .82 for circadian preference and sleep quality, respectively. Finally, again following prior research (Acebo & Carskadon, 2002; Wolfson & Carskadon, 1998), each adolescent reported their typical *school night sleep duration*.

Standardized academic achievement testing (outcome). The Wechsler Individual Achievement Test, Third Edition (WIAT-III) is a widely-used individually-administered achievement battery (Wechsler, 2009). Age-based norms were used to derive standard scores for *Basic Reading, Numerical Operations*, and *Math Fluency* subtests, with a mean of 100 and standard deviation of 15. Higher scores reflect better performance, relative to others the same age.

Academic motivation (outcome). The Academic Motivation Scale (AMS) is a 28-item self-report measure (Vallerand et al., 1992) that yields three composite scores: *intrinsic motivation* (12 items; e.g., "I experience pleasure and satisfaction while learning new things"), *extrinsic motivation* (12 items; e.g., "I need at least a high-school degree in order to find a high-paying job later on"), and *amotivation* (4 items; e.g., "I once had good reasons for going to school, however now I wonder whether I should continue"). Each item is rated on a seven-point scale (1 = *does not correspond at all*, 7 = *corresponds exactly*). A mean score of items within each subscale computed, with higher scores indicating greater amotivation, intrinsic motivation, and extrinsic motivation. In the present study, αs = .80, .95, and .93 for amotivation, intrinsic motivation, and extrinsic motivation, respectively.

Table 1 Sample characteristics and differences between adolescents with and without ADHD

	Total sample (N = 302)	ADHD group (n = 162)	Comparison group (n = 140)	
	$M \pm SD$	$M \pm SD$	$M \pm SD$	Group differences
Age	13.17 ± 0.40	13.17 ± 0.41	13.18 ± 0.40	$t = 0.26, p = .80$
Pubertal development				
Female	3.07 ± 0.62	3.11 ± 0.57	3.05 ± 0.66	$t = 0.60, p = .55$
Male	2.34 ± 0.58	2.31 ± 0.56	2.39 ± 0.61	$t = 0.86, p = .39$
Primary household income ($USD)	93,073 ± 34,856	84,875 ± 35,864	102,500 ± 31,213	$t = 4.56, p < .001$
	***n* (%)**	***n* (%)**	***N* (%)**	
Female	135 (44.7)	57 (35.2)	78 (55.7)	$\chi^2 = 12.80, p < .001$
Race				
American Indian/Alaskan	1 (0.3)	1 (0.6)	0 (0)	$\chi^2 = 9.17, p = .06$
Asian	14 (4.6)	4 (2.5)	10 (7.1)	
Black	16 (5.3)	12 (7.4)	4 (2.9)	
Multiracial	24 (7.9)	16 (9.9)	8 (5.7)	
White	247 (81.8)	129 (79.6)	118 (84.3)	
Hispanic/Latinx	14 (4.6)	7 (4.3)	7 (5.0)	$\chi^2 = 0.08, p = .78$
Highest maternal education				
High school degree or less	14 (4.3)	10 (6.2)	4 (2.9)	$\chi^2 = 7.82, p = .05$
Partial college/vocational	56 (18.5)	33 (20.4)	23 (16.4)	
College graduate	126 (41.7)	73 (45.1)	53 (37.9)	
Graduate/professional degree	106 (35.1)	46 (28.4)	60 (42.9)	
Medication use				
ADHD (any)	96 (31.8)	96 (59.3)	0 (0)	$\chi^2 = 121.63, p < .001$
Methylphenidate	48 (15.9)	48 (29.6)	0 (0)	$\chi^2 = 49.32, p < .001$
Amphetamine[a]	47 (15.6)	47 (29.0)	0 (0)	$\chi^2 = 48.10, p < .001$
Nonstimulant[b]	20 (6.6)	20 (12.3)	0 (0)	$\chi^2 = 18.51, p < .001$
Other psychiatric (any)	29 (9.6)	22 (13.6)	7 (5)	$\chi^2 = 6.37, p = .01$
Antidepressant	24 (7.9)	18 (11.1)	6 (4.3)	$\chi^2 = 4.78, p = .03$
Antianxiety	2 (0.7)	1 (0.6)	1 (0.7)	$\chi^2 = 0.01, p = 1.00$[e]
Antipsychotic	3 (1.0)	3 (1.9)	0 (0)	$\chi^2 = 2.62, p = .25$[b]
Sleep (any)	32 (10.6)	23 (14.2)	9 (6.4)	$\chi^2 = 4.79, p = .03$
Melatonin	31 (10.3)	22 (13.6)	9 (6.9)	$\chi^2 = 4.17, p = .04$
Other sleep medication	1 (0.3)	1 (0.6)	0 (0)	$\chi^2 = 0.87, p = 1.00$[d]
Other psychiatric diagnoses[c]	107 (35.4)	74 (45.7)	33 (23.6)	$\chi^2 = 16.04, p < .001$
Any externalizing (ODD/CD)	41 (13.6)	35 (21.6)	6 (4.3)	$\chi^2 = 19.20, p < .001$
Any anxiety	73 (24.2)	46 (28.4)	27 (19.3)	$\chi^2 = 3.40, p = .07$
Any depression	24 (7.9)	16 (9.9)	8 (5.7)	$\chi^2 = 1.78, p = .18$

ADHD, attention-deficit/hyperactivity disorder; ODD/CD, oppositional defiant disorder/conduct disorder. Any anxiety = the presence of generalized anxiety disorder, social phobia, obsessive-compulsive disorder, and/or posttraumatic stress disorder (PTSD). Any depression = the presence of major depression or dysthymia.
[a]Includes amphetamine and mixed amphetamine salts.
[b]Includes guanfacine, atomoxetine, and clonidine.
[c]The presence of comorbid mental health diagnosis based on parent or adolescent report (only parents were administered ODD and PTSD modules) during the diagnostic interview.
[d]Significance based on Fisher's exact test since at least one cell had an expected count less than 5.

EF in daily life (outcome). EF in daily life (outcome) was assessed using the parent (63 items) and youth self-report (55 items) versions of the Behavior Rating Inventory of Executive Function—Second Edition (BRIEF-2; Gioia, Isquith, Guy, & Kenworthy, 2015). Each form yields three superordinate Index Scores, used in the present study. The *Behavioral Regulation Index* (*BRI*) assesses the ability to effectively regulate and monitor behavior, including the ability to inhibit impulses and monitor the impact of behavior on others and the surroundings. The *Cognitive Regulation Index* (*CRI*) assesses the ability to control and manage cognitive processes and problem-solve effectively, including learning and recall of complex information and strategically applying knowledge. The *Emotional Regulation Index* (*ERI*) assesses the ability to regulate emotional responses, including during changing situations (Gioia et al., 2015). *T*-scores were used in the present study, with a normed mean = 50, standard deviation = 10, and higher scores indicating greater EF deficits.

Inattention (outcome). Adolescents, parents, and teachers reported on the frequency of the 9 symptoms of *inattention* listed in the DSM-5. The ADHD Self-Report Scale (Kessler et al., 2005) has well-documented internal validity and convergent validity with interview-assessed ADHD symptoms (Sonnby et al., 2015). The parent- and teacher-completed Vanderbilt ADHD Diagnostic Rating Scale (VADRS) also has demonstrated strong reliability and concurrent validity with other ADHD assessment instruments (Wolraich, 2003). A mean item score was computed for each reporter, with strong internal consistency in the present study (self-report $\alpha = .86$, parent-report $\alpha = .95$, teacher-report $\alpha = .95$).

Covariates. *Pubertal development* was assessed via adolescent self-report on the 6-item Physical Development Scale (Petersen, Crockett, Richards, & Boxer, 1988), with higher scores suggesting more advanced pubertal development.

Current medication use was assessed via an adaptation of the Services Use in Children and Adolescents – Parent Interview (SCA-PI) (Hoagwood et al., 2004), and a binary (yes/no) variable was used to indicate whether the adolescent was taking any medication for ADHD, sleep (including melatonin), and/or an emotional/behavioral problem (e.g., anti-depressants). Parents also reported on *family income* and their *child's sex*.

Statistical analyses

SPSS® version 26 (IBM Corporation, Armonk, NY, USA) for Windows® was used for all analyses. All study variables had skewness and kurtosis values between −2 and 2, suggesting reasonably normal distributions. First, preliminary analyses examined zero-order correlations among study variables (note that the associations between a continuous variable and a dichotomous variable are point-biserial correlations). As a rule of thumb, a correlation of .10 is considered a small effect, .30 is considered a medium effect, and .50 is considered a large effect (Cohen, 1988). Second, primary analyses were comprised of a series of multiple regressions to determine the unique associations of morningness-eveningness, sleep duration, and sleep quality. Specifically, our three circadian/sleep variables were entered simultaneously with the covariate variables (i.e., study group, sex, family income, pubertal development, medication status) to allow for determining which circadian/sleep variable(s) were uniquely associated with the outcome variables above and beyond the other independent variables included in the model. A separate regression model was conducted for each outcome variable (15 total regression models). We did not employ a Bonferroni or other correction as such corrections also present methodological challenges (Nakagawa, 2004; Perneger, 1998), but instead report exact *p*-values to provide readers with complete information for evaluating the statistical effects. Third, to explore whether any associations between sleep and study outcomes differed for adolescents with or without ADHD, the PROCESS macro (Hayes, 2017) using bootstrapped sampling (5,000 iterations) was used to test moderation models. Specifically, we tested whether ADHD diagnostic status would interact with circadian preference, sleep duration, or sleep quality in relation to each outcome variable (separate moderation model for each outcome variable). Any significant interaction would be probed via simple slopes analyses by testing the relation between the circadian/sleep variable and the outcome variable separately for adolescents with and without ADHD. This study was not pre-registered.

Results

Preliminary bivariate correlations

Sleep duration and sleep quality were positively but moderately correlated ($r = .34$, $p < .0001$). Longer and better-quality sleep also both correlated with higher morningness preference ($r = .20$, $p = .0005$ and $r = .35$, $p < .0001$, respectively). Table 2 shows the bivariate correlations of the predictor variables (circadian preference, sleep quality, sleep duration) and covariates (ADHD group status, sex, family income, pubertal development, medication status) with the academic, EF, and attentional outcome variables. Greater morningness and better sleep quality were both significantly but modestly correlated with nearly all outcomes. Longer sleep duration was significantly and modestly associated about half of the outcomes, particularly self-reported EF. No sleep or circadian variable was significantly associated with WIAT-III Basic Reading scores, nor teacher-reported ADHD-IN symptoms. As expected, ADHD status was significantly associated with all attentional, academic, and executive functioning outcomes (Table 2). Unexpectedly, ADHD group status was not significantly associated with either sleep duration or sleep quality (*r*s = −.07 and −.09, respectively, both *p*s > .10), and there was a small though nonsignificant association between ADHD status and greater eveningness circadian preference ($r = -.10$, $p = .07$).

Primary regression analyses

As summarized in Table 3, above and beyond covariates, circadian preference remained uniquely associated with nearly all our measures of poorer academic, EF, and attentional functioning. Sleep quality was uniquely associated with a handful of outcomes, and sleep duration was not significantly uniquely associated with any outcome in the regression analyses.

In considering academic outcomes, greater morningness was the only predictor uniquely associated with higher WIAT-III Numerical Operations ($\beta = .20$, $p = .0008$), higher WIAT-III Math Fluency ($\beta = .20$, $p = .0009$), and lower academic motivation ($\beta = -.18$, $p = .005$). Greater morningness and higher sleep quality each uniquely predicted greater academic intrinsic motivation ($\beta = .19$, $p = .002$ and $\beta = .13$, $p = .044$, respectively). High sleep quality was also uniquely associated with greater academic extrinsic motivation ($\beta = .15$, $p = .018$) whereas circadian preference was not ($\beta = .02$, $p = .771$).

For daily life EF outcomes, greater morningness, but neither sleep duration nor sleep quality, was uniquely associated with fewer self-reported problems with behavior regulation, emotion regulation, and cognitive regulation ($\beta = -.14$, $p = .012$; $\beta = -.20$, $p = .0007$; and $\beta = -.27$, $p < .0001$, respectively), as well as fewer parent-reported problems with cognitive regulation ($\beta = -.12$, $p = .003$). Greater morningness and higher sleep quality were each significantly and uniquely associated with fewer parent-reported problems with emotion regulation ($\beta = -.11$, $p = .036$ and $\beta = -.15$, $p = .009$, respectively). Higher sleep quality was also uniquely associated with lower parent-reported problems with behavior regulation ($\beta = -.12$, $p = .026$) whereas circadian preference was not ($\beta = -.04$, $p = .390$).

Finally, greater morningness, but neither sleep duration nor quality, was uniquely associated with fewer or less-frequent self-reported inattention symptoms ($\beta = -0.26$, $p < .0001$). Greater morningness and higher sleep quality were each significantly and uniquely associated with lower parent-reported inattention symptoms ($\beta = -.11$, $p = .008$ and $\beta = -.09$, $p = .043$, respectively). Consistent with

Table 2 Bivariate correlations of predictors and covariates with outcome variables

	Predictor variables and covariates							
	Sleep duration	Sleep quality	Circadian preference	Group	Sex	Family income	Pubertal development	Medication status
Academic functioning								
Basic reading	.04	.11	.01	−.21***	−.04	.26***	.04	−.10
Numerical operations	.13*	.19***	.25***	−.35***	.04	.28***	−.01	−.18**
Math fluency	.14*	.12*	.22***	−.32***	−.07	.29***	−.14*	−.20***
Amotivation	−.11	−.10	−.26***	−.21***	−.11	−.09	−.001	.16**
Intrinsic motivation	.14*	.20***	.23***	−.23***	.11	.10	.13*	−.14*
Extrinsic motivation	.12*	.15**	.06	−.21***	.14*	.03	.10	−.13*
Executive functioning								
Self-Report Beh Reg	−.12*	−.16**	−.26***	.41***	−.19***	−.17**	−.01	.26***
Self-Report Emot Reg	−.22***	−.21***	−.30***	.35***	−.11	−.16**	.04	.28***
Self-Report Cog Reg	−.23***	−.23***	−.36***	.47***	−.05	−.20***	.04	.32***
Parent-Report Beh Reg	−.04	−.17**	−.17**	.64***	−.13*	−.27***	−.07	.47***
Parent-Report Emot Reg	−.05	−.22***	−.22***	.49***	−.02	−.23***	−.02	.42***
Parent-Report Cog Reg	−.11	−.17**	−.24***	.77***	−.18**	−.28***	−.12*	.45***
Attentional functioning								
Self-report	−.17**	−.26***	−.36***	.47***	−.06	−.23***	.04	.27***
Parent-report	−.06	−.15*	−.22***	.74***	−.22***	−.27***	−.14*	.37***
Teacher-report	−.02	−.07	−.11	.47***	−.27***	−.17**	−.19**	.25***

For sleep duration and sleep quality, higher scores indicate longer sleep duration and better sleep quality, respectively. For circadian preference, higher scores indicate greater morningness preference whereas lower scores indicate greater eveningness preference. For group, 0 = non-ADHD, 1 = ADHD. For sex, 0 = male, 1 = female. For medication status, 0 = not taking any medications for ADHD, sleep, or emotional/behavioral concerns, 1 = taking at least one medication for ADHD, sleep, or emotional/behavioral concerns. Beh Reg, behavior regulation index; Cog Reg, cognitive regulation index; Emot Reg, emotion regulation index. *$p < .05$; **$p < .01$; *** $p < .001$.

the bivariate correlation analyses, no sleep or circadian variable was significantly uniquely associated with teacher-reported inattention symptoms.

Exploratory moderation analyses

We explored whether any effects were moderated by ADHD group status, and all interaction effects were nonsignificant (*p*s > .05). Thus, in no instance were effects of sleep duration, sleep quality, or circadian preference in the primary regression analyses (Table 3) different for adolescents with or without ADHD.

Discussion

The present study suggests that adolescents' evening circadian preference is associated with poorer executive, academic, and attentional functioning. By using a multi-method, multi-informant design, and including several important covariates, our findings indicate that when sleep duration, sleep quality, and circadian preference are examined simultaneously, circadian preference is more consistently associated than either sleep duration or sleep quality with academic functioning and the school-relevant constructs of executive functioning and attention in adolescents with and without ADHD.

Across both adolescent and parent ratings, and above and beyond sleep quality and quantity, a stronger preference for eveningness was associated with greater inattention and worse EF in two key domains: emotion and cognitive regulation. Our findings add to a small body of research showing greater eveningness to be associated with greater adolescent-reported EF deficits (Cohen-Zion & Shiloh, 2018; Owens et al., 2016) and inattentive symptoms (Hennig et al., 2017). Within our multi-informant design, the consistency in our findings across both adolescent and caregiver reports bolsters confidence that circadian preference truly is associated with the broad domains of cognitive and emotion regulation EF deficits as well as ADHD symptoms specifically.

In contrast, eveningness was independently associated with poorer behavioral regulation per adolescent report but not parent report, with effect sizes for both informants notably smaller than for emotion and cognitive EF deficits. This is somewhat surprising given evidence linking circadian misalignment

Table 3 Covariate-adjusted regression analyses examining sleep duration, sleep quality, and circadian preference as predictors of academic functioning

Outcome variable	Sleep duration				Sleep quality				Circadian preference			
	B	*SE*	β	*t*	*B*	*SE*	β	*t*	*B*	*SE*	β	*t*
Academic functioning												
Basic reading	−0.12	0.60	−.01	−0.20	0.39	0.73	.04	0.52	−0.04	0.15	−.02	−0.26
Numerical operations	0.47	0.96	.03	0.49	0.94	1.16	.05	0.81	0.79	0.23	.20	3.38***
Math fluency	0.33	0.76	.03	0.43	−0.85	0.92	−.06	−0.92	0.62	0.19	.20	3.36***
Amotivation	−0.06	0.06	−.06	−0.95	−0.003	0.08	−.002	−0.04	−0.04	0.02	−.18	−2.82**
Intrinsic motivation	0.07	0.08	.05	0.89	0.19	0.09	.13	2.02*	0.06	0.02	.19	3.06**
Extrinsic motivation	0.06	0.07	.05	0.83	0.20	0.09	.15	2.28*	0.01	0.02	.02	0.29
Executive functioning												
Self-Report Beh Reg	−0.24	0.49	−.03	−0.50	−0.88	0.60	−.09	−1.45	−0.30	0.12	−.14	−2.52**
Self-Report Emot Reg	−0.92	0.51	−.10	−1.80	−0.99	0.63	−.10	−1.58	−0.43	0.12	−.20	−3.43***
Self-Report Cog Reg	−0.77	0.47	−.09	−1.62	−0.69	0.58	−.07	−1.18	−0.59	0.12	−.27	−5.10***
Parent-Report Beh Reg	0.78	0.49	.08	1.58	−1.35	0.60	−.12	−2.24*	−0.10	0.12	−.04	−0.86
Parent-Report Emot Reg	0.91	0.52	.09	1.74	−1.67	0.64	−.15	−2.62**	−0.27	0.13	−.11	−2.11*
Parent-Report Cog Reg	−0.03	0.44	−.002	−0.06	−0.90	0.53	−.07	−1.69	−0.32	0.11	−.12	−3.03**
Attentional functioning												
Self-report	−0.02	0.02	−.03	−0.65	−0.06	0.03	−.11	−1.88	−0.03	0.01	−.26	−4.93***
Parent-report	0.03	0.03	.04	0.93	−0.07	0.04	−.09	−2.03*	−0.02	0.01	−.11	−2.67**
Teacher-report	0.02	0.03	.03	0.51	−0.04	0.04	−.06	−0.98	−0.01	0.01	−.04	−0.61

Covariates included: study group, sex, family income, pubertal development, and medication status. For sleep duration and sleep quality, higher scores indicate longer sleep duration and better sleep quality, respectively. For circadian preference, higher scores indicate greater morningness preference whereas lower scores indicate greater eveningness preference. ADHD-IN, attention-deficit/hyperactivity disorder inattentive symptoms; BRIEF-2, Behavior Rating Inventory of Executive Function Second Edition; Beh Reg = behavior regulation index; Cog Reg, cognitive regulation index; Emot Reg, emotion regulation index.
**p* < .05. ***p* < .01. ****p* < .001.

with impulsivity and disinhibition (Hasler & Clark, 2013). However, most previous work in this area assessed response inhibition and impulsivity using laboratory-based tasks (e.g., Hahn et al., 2012; Hasler et al., 2022) or used rating scales specific to risk-taking and sensation-seeking behaviors (e.g., Hisler, Dickinson, Bruce, & Hasler, 2022; Tonetti et al., 2010), whereas the current study used a global rating scale measure of behavioral regulation in daily life. It is also noteworthy that, although parent-reported behavior regulation was not uniquely associated with circadian preference, it was uniquely associated with adolescent-reported sleep quality. These findings highlight the importance of studies employing a multi-informant approach. Taken together, it appears that adolescent sleep is related to behavior regulation, but the specific nature of that relationship remains unclear. Additional studies are needed that include multiple measures, as well as more fine-grained domains of executive and behavioral functioning.

In terms of academic functioning, eveningness preference was uniquely associated with lower achievement scores on both math tasks examined in this study but not with reading achievement. Our findings are consistent with those reported in an earlier study using adolescent self-reported grades (Escribano-Barreno & Díaz-Morales, 2013). The reading subtest used in this study is not timed and primarily taps phonics/decoding and word recognition skills which benefit from automatic processes (Torgesen, 2004). In contrast, one of the math subtests used in this study focused on fluency, and both math subtests rely more strongly than word reading on working memory, processing speed, and active problem-solving. It is possible that eveningness impacts EF/attentional deficits which in turn contribute to lower achievement in domains such as math that rely more strongly on working memory and processing speed abilities. In addition, by middle school, the developmental "curve" of reading decoding is relatively flat but the math skills tested on the WIAT continue to grow (c.f., Wechsler, 2009); insofar as circadian preference changes over time, this could attenuate associations between circadian preference during middle school and reading decoding skills that were primarily developed earlier in childhood.

Previous studies have linked eveningness to academic motivation (Preckel et al., 2020; Roeser et al., 2013). The present study suggests this association may be specific to internal motivation and amotivation and not external motivation. Amotivation is associated with lower academic achievement, and intrinsic motivation is especially predictive of academic achievement (Smith, Langberg, Cusick, Green, & Becker, 2020; Taylor et al., 2014), in part because it increases student engagement (Froiland & Worrell, 2016). It is conceivable that greater eveningness preference contributes to weaker academic motivation and engagement during the school day, which in turn impacts learning. Experimental and longitudinal research will be needed to test these types of mechanistic hypotheses.

Circadian preference was far and away more consistently associated with academic, executive, and attentional functioning outcomes in comparison to sleep duration and quality. Somewhat surprisingly, and conflicting with findings in a smaller sample of adolescents (Hennig et al., 2017), sleep duration was not uniquely associated with any of our outcomes. Experimental studies have repeatedly shown that shortened sleep duration contributes to poorer cognitive functioning in adolescents with and without ADHD (Becker, Epstein, et al., 2019; Beebe et al., 2008; Beebe, Field, Milller, Miller, & LeBlond, 2016). In real-world settings, early school start times are a key limiting factor to adolescents' sleep duration, particularly impacting those with later circadian phases (Crowley et al., 2018). Studies designed to tease apart the independent or joint contributions of sleep duration and circadian phase on daytime functioning are needed.

Circadian preference was not differentially associated with executive, academic, or attentional functioning in adolescents with or without ADHD. Yet, as expected, adolescents with ADHD had poorer functioning across all attention, executive, and academic functioning outcomes (Table 2). Attention problems are central to the diagnostic criteria for ADHD, and adolescents with ADHD are also highly likely to have executive function and academic impairments (Doidge et al., 2020; Evans, Van der Oord, & Rogers, 2020). Chronotype and circadian function may play an important role. For instance, Gabay et al. (2022) recently showed that college students with ADHD had a greater decrement in attentional functioning when performing cognitive tests at times misaligned with their circadian preference compared to college students without ADHD. Our findings join this recent research in underscoring the value of additional research investigating chronotype and circadian function in relation to daytime impairments in adolescents with ADHD.

Several interventions target circadian function and warrant further examination in adolescents, including possible downstream effects on daytime functioning. Morning light exposure is an important intervention component for adolescents with a late circadian preference (Gasperetti, Dolsen, & Harvey, 2021) and may also reduce eveningness among individuals with ADHD (Rybak, McNeely, Mackenzie, Jain, & Levitan, 2006). Melatonin is also commonly used, especially among adolescents with ADHD, though existing studies have primarily evaluated melatonin as a somnolent to shorten sleep onset latency rather than as a chronobiotic to advance circadian phase (Coogan & McGowan, 2017). A cognitive-behavioral intervention impacted subjective and objective measures of circadian function in adolescents with a late circadian preference (Harvey et al., 2018), though effects on circadian preference were not found when the same intervention was used in adolescents with ADHD (Becker et al., 2022). However, the latter study was a small open trial in 14 adolescents with ADHD and did not specifically recruit evening-type adolescents; larger, randomized trials are needed to evaluate effects and the possible moderating role of circadian preference.

Some limitations are important to acknowledge and point to future directions. First, our study was cross-sectional in design, and so causality and directionality cannot be assumed. Prospective longitudinal and experimental research is needed to strengthen causal inference and evaluate possible mechanisms (see, e.g., Fredrick, Cook, Langberg, & Becker, 2023). In addition to mechanisms discussed above that may link circadian preference with daytime functioning, there is also a need for rigorous research investigating factors that may be relevant to adolescent sleep patterns, particularly among "owls" who may delay bedtime and/or sleep onset, such as use of electronic devices (Hisler, Hasler, Franzen, Clark, & Twenge, 2020), cognitive-emotional processes (e.g., procrastination, pre-sleep arousal; Li, Buxton, Kim, Haneuse, & Kawachi, 2020), and psychopathology symptoms that frequently co-occur with ADHD (e.g., anxiety, depression, cognitive disengagement syndrome; Becker, Cusick, Sidol, Epstein, & Tamm, 2018; Sadeghi-Bahmani & Brand, 2022). Second, although our study included achievement testing in addition to multi-informant rating scales, our achievement battery was limited to basic reading and two math domains; it would be informative for future studies to examine circadian preference in relation to more comprehensive achievement domains and other methods not used in the current study (e.g., performance-based tests of EF). In addition, our study used adolescent self-report of sleep duration, sleep quality, and circadian preference, and it would be beneficial to examine objective measures of sleep duration and quality, such as actigraphy, as well as circadian rhythm, such as dim-light melatonin onset (DLMO) in future research. Finally, our sample was mostly White and comprised of families with higher incomes, which limits the generalizability of our findings. It is critical for future research to include more diverse and representative samples.

Despite these limitations, the current study using a multi-method, multi-informant design provides compelling evidence that greater eveningness preference is associated with poorer academic, executive, and attentional functioning in adolescents. Not only are these associations significant even after accounting for sleep duration and quality, but circadian preference seemed more consistently and uniquely associated with functional outcomes than were sleep duration or quality. In addition, associations did not differ across adolescents with or without ADHD. Findings suggest that targeting circadian preference may be important to reduce these problems in adolescents, especially in clinical samples such as ADHD for whom academic, executive, and attentional difficulties are exceptionally common.

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Data availability statement
The data that support the findings of this study are available on request from the corresponding author.

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Key points

- Adolescents with greater "eveningness" (also known as "night owls") have later bedtimes, wake times, and peak arousal compared to those with greater "morningness."
- Few studies have examined circadian preference in relation to daytime functioning alongside two potential confounds—sleep duration and sleep quality.
- We examined circadian preference in relation to multi-informant, multi-method academic, executive, and attentional functioning in adolescents with and without ADHD.
- Findings suggest that poorer academic, executive, and attentional functioning are more closely associated with greater eveningness than with sleep duration or quality in adolescents.

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