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RESEARCH ARTICLE

ADHD, chronotype, and circadian preference in a multi-site sample of college students

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Summary

Attention-deficit/hyperactivity disorder and an evening chronotype are both common among college students, and there is growing interest in understanding the possible link between attention-deficit/hyperactivity disorder and circadian function. However, mixed findings have been reported, and many of the existing studies have used small samples that were unable to examine chronotype across attention-deficit/hyperactivity disorder presentations. Participants were 4751 students (73% female; 80% White), aged 18–29 years ($M = 19.28$, $SD = 1.50$), from five universities who completed measures assessing attention-deficit/hyperactivity disorder, depressive and anxiety symptoms, as well as the Morningness–Eveningness Questionnaire to assess chronotype (categorical) and circadian preference (dimensional). Participants with either attention-deficit/hyperactivity disorder predominantly inattentive presentation or attention-deficit/hyperactivity disorder combined presentation had higher rates of being an evening type (47.2% and 41.5%, respectively) than participants without elevated attention-deficit/hyperactivity disorder (28.5%), and participants with attention-deficit/hyperactivity disorder predominantly inattentive presentation also had higher rates of being an evening type than participants with attention-deficit/hyperactivity disorder predominantly hyperactive–impulsive presentation (30.7%). Dimensional analyses indicated that attention-deficit/hyperactivity disorder inattentive symptoms were more strongly associated than hyperactive–impulsive symptoms with eveningness preference. Finally, greater eveningness preference strengthened the association between attention-deficit/hyperactivity disorder inattention and depressive symptoms but not anxiety symptoms. This is the largest study to document that college students with elevated attention-deficit/hyperactivity disorder symptoms are more likely to be evening types than other college students, and inattentive symptoms in particular are associated with later circadian preference.

KEYWORDS
attention-deficit/hyperactivity disorder, chronotype, circadian, inattention, Morningness–Eveningness Questionnaire, morningness–eveningness

1 | INTRODUCTION

Mounting evidence indicates that attention-deficit/hyperactivity disorder (ADHD) is associated with circadian phase delay involving a later biological clock (Becker, 2020; Bondopadhyay et al., 2022; Coogan & McGowan, 2017). It has more recently been suggested that circadian function may be part of the aetiology and pathophysiology of ADHD symptoms for at least a subset of individuals with ADHD (Bijlenga et al., 2019).

A systematic review of ADHD and circadian function concluded that ADHD was consistently associated with a later chronotype/evening circadian preference (Coogan & McGowan, 2017). Case–control studies have shown a greater preference for eveningness in individuals with ADHD compared with individuals without ADHD (Baird et al., 2012; Bijlenga, van der Heijden, et al., 2013; Bijlenga, Van Someren, et al., 2013; Gruber et al., 2012). However, in two of the studies the sample sizes were limited to 26 children (Gruber et al., 2012) or 13 adults (Baird et al., 2012) with ADHD. Another study included 12 adults with ADHD and confirmed delayed sleep phase syndrome, which indicates the ADHD group by definition had circadian dysfunction (Bijlenga, Van Someren, et al., 2013).

Other studies have used dimensional assessment of ADHD symptoms and circadian preference, and generally found ADHD symptoms to be associated with greater eveningness preference (Caci et al., 2009; Martinez-Cayuelas et al., 2022; Rybak et al., 2007; Voinescu et al., 2012). However, several other studies have not found ADHD symptom severity or ADHD status to be significantly associated with circadian preference (Becker et al., 2020; Tarakçioğlu et al., 2018; Van der Heijden et al., 2018). The mixed findings may be due at least in part to small sample sizes, as numerous studies had fewer than 100 participants.

Fewer studies have examined whether any link between ADHD and chronotype varies based on ADHD presentation (i.e. predominantly inattentive, predominantly hyperactive–impulsive, combined) or symptom dimension (i.e. inattention, hyperactivity–impulsivity). Two studies that each included college students and adults recruited from the community found ADHD inattentive but not hyperactive–impulsive symptoms to be associated with eveningness (Caci et al., 2009; Voinescu et al., 2012). In contrast, Bron et al. (2016) found a composite of total ADHD symptoms, but neither inattentive nor hyperactive–impulsive dimensions individually, to be associated with evening chronotype above and beyond internalizing symptoms and other covariates. Further complicating the picture, Sivertsen et al. (2015) found adolescents with delayed sleep phase had more symptoms of both inattention and hyperactivity–impulsivity than adolescents without delayed sleep phase. Finally, a recent study found college students with elevated ADHD symptoms were more likely to be evening types (59%) than college students without ADHD symptoms (44%), though the sample with ADHD symptoms was too small to examine chronotype across separate ADHD presentations (Gabay et al., 2022).

In addition to the need for additional studies examining ADHD presentation and symptoms in relation to circadian preference, it is important to evaluate whether circadian preference is associated with functional outcomes commonly experienced by individuals with ADHD. Approximately 60% of adults with ADHD have a co-occurring internalizing disorder (Miller et al., 2007), and internalizing symptoms are themselves strongly linked to circadian function (Coles et al., 2015; Salgado-Delgado et al., 2011). ADHD inattentive symptoms are especially linked to internalizing symptoms (Willcutt et al., 2012), and so it is possible that the joint presence of ADHD inattentive symptoms and eveningness preference are related to higher internalizing symptoms.

This study had three objectives. First, we used a large, multi-site study of college students to examine the frequency of elevated ADHD symptoms and chronotype and their overlap. Our sample size was sufficiently large to also examine ADHD presentations separately. Second, we examined whether ADHD inattentive and/or hyperactive–impulsive symptoms were uniquely associated with chronotype and circadian preference above and beyond demographic characteristics and internalizing symptoms. Third, as both ADHD inattentive symptoms and eveningness preference are associated with internalizing symptoms, we explored whether circadian preference interacted with ADHD inattentive symptoms in predicting internalizing symptoms. By using a large, multi-site sample of college students, we were able to examine these questions in a population that experiences particularly high rates of ADHD symptoms, evening chronotype and internalizing symptoms.

2 | METHODS

2.1 | Participants

Participants were 4751 undergraduate students enrolled at five universities in several regions of the USA. Participant ages ranged from 18 to 29 years ($M = 19.28$, $SD = 1.50$). As summarized in Table 1, the majority of participants self-identified as female (73%), White (80%) and non-Hispanic (88%). Approximately half (51%) were in their first year of college. Most participants (87%) indicated that they do not typically take any medications for attentional, learning or behavioural difficulties.

2.2 | Procedure

Data were collected during the 2018–2019 academic year. The study was approved by each university's local Institutional Review Board (IRB). Students enrolled in introductory psychology (general education) courses were able to participate in a research study (or studies) to fulfil a course requirement (or, alternatively, to complete an alternative assignment such as a brief paper). Students were able to choose from a number of studies and could choose to participate in this study if they were ≥ 18 years old (there were no other inclusion/exclusion criteria). For this study, four of the five universities administered an online Qualtrics survey with measures of the study included, while students at the fifth university selected available time slots to provide in-person consent and then complete the same survey online on their own time. Following completion of the survey, participants were granted course credit. Debriefing information was generated at the end of the survey.

TABLE 1 Demographic characteristics of study participants ($N = 4751$)

Variable	% (*n*)
Sex[a]	
Male	27.1% (1289)
Female	72.7% (3455)
Other	0.1% (7)
Year of study	
Freshman	51.3% (2435)
Sophomore	23.7% (1124)
Junior	15.1% (717)
Senior	9.7% (462)
Other	0.3% (13)
Race[a]	
White	79.9% (3782)
Black	7.0% (330)
Asian	6.7% (318)
American Indian/Alaska Native	0.5% (24)
Native Hawaiian/Pacific Islander	0.7% (34)
Biracial/Multiracial	5.2% (248)
Ethnicity[a]	
Non-Hispanic	88.2% (4184)
Hispanic	11.8% (559)
Psychiatric medication use	
No	86.5% (4110)
Yes	13.5% (639)

[a]Fifteen participants did not complete the race question, eight did not complete the ethnicity question, and two did not complete the medication use question.

All participants received the contact information of the local investigator, IRB, and student counselling centre.

2.3 | Measures

2.3.1 | Circadian preference

The Morningness–Eveningness Questionnaire (MEQ; Horne & Östberg, 1976) is a self-report instrument consisting of 19 items that assesses individual differences in morningness and eveningness (e.g. "what time would you get up if you were entirely free to plan your day?"). Item scores are used to calculate the degree to which a person identifies as a morning or evening type person, where higher scores indicate a greater preference for morningness. In addition to a continuous score of circadian preference, and consistent with previous research (Horne & Östberg, 1976), participants were categorized into evening types (scores 16–41), intermediate types (scores 42–58) and morning types (scores 59–86). In the present study, $\alpha = 0.77$.

2.3.2 | ADHD symptoms

The Barkley Adult ADHD Rating Scale-IV (BAARS-IV; Barkley, 2011) was used to assess self-reported ADHD symptoms. The BAARS-IV includes ADHD scales assessing ADHD inattention (nine items; e.g. "I have difficulty organizing tasks and activities") and ADHD hyperactivity–impulsivity (nine items; e.g. "I fidget with hands or feet or squirm in seat"). Participants indicate on a four-point scale (0 = *not at all*, 3 = *very often*) how often each statement describes their behaviour over the past 6 months. These subscales have well supported internal consistency and test–retest reliability in adult samples (Barkley, 2012), including among college students (Becker et al., 2018). In addition to continuous scores of inattention and hyperactivity–impulsivity, participants were categorized as having elevated ADHD symptoms if they endorsed five or more symptoms as occurring "often" or "very often" in the inattention and/or hyperactivity–impulsivity domain. This symptom count cut-off was selected based on DSM-5 criteria for individuals ≥ 17 years old (American Psychiatric Association, 2013). This resulted in participants being classified as having no elevated ADHD symptoms or elevations in the predominantly inattentive presentation, predominantly hyperactive–impulsive presentation, or combined presentation. In the present study, $\alpha = 0.89$ and 0.82 for inattention and hyperactivity–impulsivity, respectively.

2.3.3 | Depressive and anxiety symptoms

The depression and anxiety subscales of the Depression Anxiety Stress Scale-21 (DASS-21; Antony et al., 1998; Lovibond & Lovibond, 1995) were used to assess adult self-reported depressive and anxiety symptoms. The DASS-21 has demonstrated strong reliability estimates in clinical and non-clinical populations (Antony et al., 1998). Participants responded to each item on the depression (seven items; e.g. "I was unable to become enthusiastic about anything") and anxiety subscale (seven items; e.g. "I felt scared without any good reason") in reference to the past week using a four-point scale (0 = *did not apply to me at all*, 3 = *applied to me very much or most of the time*). In the present study, $\alpha = 0.90$ and 0.79 for depression and anxiety, respectively.

2.4 | Data quality check

An instructional manipulation check (IMC), trap questions, and questions measuring participants' effort were used throughout the survey to improve quality of responses. The IMC question instructs the participant to select a designated answer to a question prior to proceeding the remainder of the survey. In addition to the IMC, trap questions were periodically included in the study, which specified the answer for the participant to click. Finally, one question at the end of the survey asked participants to answer how much effort they put into the entire study. A threshold of 50% accuracy or higher for the trap questions and a self-reported effort rating of 5 or higher on a 0 to 10 scale

(0 = *not much effort*, 10 = *my best effort*) was designated. The same threshold has been used in previous college student samples (Becker et al., 2018; Holdaway et al., 2018), and is intended to identify participants who put forth sufficient effort while not excluding participants with occasional attentional lapses. Of the 5053 participants who completed the survey, 297 (6%) did not meet the threshold criteria for the trap questions and were removed from data analyses. The remaining 4756 (94%) participants met criteria and were eligible for inclusion in the current study. Five participants did not complete sufficient items to calculate a MEQ score, resulting in a final sample size of 4751.

2.5 | Data analyses

First, rates of chronotype (evening, intermediate, morning) and ADHD presentation (none, ADHD-I, ADHD-HI, ADHD-C) were computed. Second, a chi-square test was conducted to examine whether ADHD presentations differed in their likelihood of being classified with evening, intermediate or morning chronotype. Given the large sample size, a value of $p < 0.001$ from the chi-square test was required to perform the six subsequent tests across the four ADHD/comparison groups (per-comparison $p < 0.008$, Bonferroni correction).

Third, bivariate correlations were conducted to examine correlations among demographic variables, psychopathology dimensions and circadian preference. Because seven participants identified as "other" when reporting on sex, these participants were not included in the correlation analyses. However, to avoid excluding participants from primary analyses, two dummy code vectors were created with female as the reference group. We also conducted Steiger's *z*-tests for dependent correlations to examine whether inattentive symptoms were more strongly associated than hyperactivity–impulsivity symptoms with having an evening chronotype (dichotomous) and greater eveningness circadian preference (dimensional). Fourth, regression analyses were conducted to examine ADHD symptom dimensions in relation to circadian preference (dimensional) and evening type (categorical). For the logistic analysis examining evening type, the morning type and intermediate type categories were combined. In both regression models, age, sex, race, ethnicity, psychiatric medication use,[1] anxiety symptoms and depressive symptoms were included as covariates. Fifth, and finally, to evaluate whether circadian preference moderated the association between ADHD inattentive symptoms and internalizing symptoms, the PROCESS macro using bootstrapped sampling (5000 iterations; Hayes, 2017) was used to test two moderation models. Specifically, we tested whether inattentive symptoms would interact with circadian preference in relation to either depressive or anxiety symptoms. Significant interactions were probed via simple slopes analyses by testing the relation between inattentive symptoms and internalizing symptoms at specific levels of circadian preference (i.e. $-1SD$, the mean, and $+1SD$). Given the large sample size, alpha level for significance tests was set at $p < 0.001$ for these analyses.

3 | RESULTS

3.1 | Frequencies and co-occurrence of chronotype and ADHD symptom presentations

A total of 656 participants (13.8%) reported elevated ADHD symptoms. Of these, 299 (45.6%) were categorized as ADHD predominantly inattentive presentation, 215 (32.8%) with ADHD predominantly hyperactive–impulsive presentation, and 142 (21.6%) with ADHD combined presentation. For chronotype, 2999 (63.1%) were categorized as intermediate type, 1432 (30.1%) as evening type, and 320 (6.7%) as morning type.

Co-occurrence of chronotype and ADHD symptom presentations are summarized in Table 2. The chi-square test indicated a significant difference in rates of chronotype across ADHD presentations, $X^2(6) = 67.23$, $p < 0.001$, Cramer's $V = 0.12$. Rates of each chronotype based on ADHD presentation were compared, using a Bonferroni-adjusted *p*-value of 0.008 to account for multiple comparisons. As summarized in Table 2, participants with either ADHD predominantly inattentive presentation or ADHD combined presentation had higher rates of being an evening type (47.2% and 41.5%, respectively) than participants without elevated ADHD (28.5%), and participants with ADHD predominantly inattentive presentation also had higher rates of being an evening type than participants with ADHD predominantly hyperactive–impulsive presentation (30.7%). Conversely, participants without elevated ADHD were more likely to be an intermediate type (64.6%) than participants with either ADHD predominantly inattentive or combined presentations (50.8% and 53.5%, respectively). Lastly, participants without elevated ADHD or with ADHD predominantly hyperactive–impulsive presentation were more likely to be a morning type (6.9% and 11.2%, respectively) than participants with ADHD predominantly inattentive presentation (2.0%).

3.2 | Bivariate correlations

Bivariate correlations among study variables are presented in Table 3. A significant association was found between ADHD status and both having an evening chronotype (categorical) and eveningness circadian preference (dimensional), though both effects were small ($r = 0.09$ and -0.10, respectively). Significant but small effects were also found between ADHD hyperactive–impulsive symptoms and both evening chronotype and eveningness circadian preference ($r = 0.06$ and -0.08, respectively). Significant and small-to-medium effects were found between ADHD inattentive symptoms and both evening chronotype and eveningness circadian preference ($r = 0.16$ and -0.21, respectively). Steiger's *z*-tests indicated that the ADHD inattentive symptoms were more strongly associated than ADHD hyperactive–impulsive symptoms with having an evening chronotype ($z = 7.41$, $p < 0.001$) and, likewise, with greater eveningness preference ($z = 9.69$, $p < 0.001$).

The ADHD symptoms, as well as evening chronotype and greater eveningness preference, were all associated with both depressive and anxiety symptoms, with effects ranging from small to

TABLE 2 Co-occurrence of chronotype with ADHD symptom presentations in college students

	ADHD presentation				
Chronotype	1. No elevated ADHD ($n = 4095$)	2. Predominantly hyperactive–impulsive ($n = 215$)	3. Predominantly inattentive ($n = 299$)	4. ADHD combined ($n = 142$)	Contrasts
Evening preference	1166 (28.5%)[a]	66 (30.7%)[a,c]	141 (47.2%)[b]	59 (41.5%)[b,c]	1 < 3, 4; 2 < 3
Intermediate	2646 (64.6%)[a]	125 (58.1%)[a,b]	152 (50.8%)[b]	76 (53.5%)[b]	1 > 3, 4
Morning preference	283 (6.9%)[a]	24 (11.2%)[a]	6 (2.0%)[b]	7 (4.9%)[a,b]	1, 2 > 3

Note: $N = 4761$. Cell numbers and percentages indicate percentage within each ADHD presentation group. Row frequencies with different superscripts differ significantly at $p < 0.008$ (Bonferroni correction).
Abbreviation: ADHD, attention-deficit/hyperactivity disorder.

TABLE 3 Means, standard deviations and bivariate correlations of study variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Age	–											
2. Sex	−0.13*	–										
3. Race	−0.09*	0.03	–									
4. Ethnicity	0.05	0.03	−0.08*	–								
5. Medication use	0.04	0.03	0.11*	−0.05*	–							
6. ADHD status	0.01	0.01	0.003	0.03	0.18*	–						
7. ADHD inattention	0.02	−0.002	−0.01	0.02	0.23*	0.63*	–					
8. ADHD hyp-imp	−0.003	0.02	0.07*	0.03	0.20*	0.58*	0.56*	–				
9. Chronotype	−0.04	−0.03	0.02	0.02	0.05*	0.09*	0.16*	0.06*	–			
10. Circadian preference	0.07*	0.03	−0.02	−0.04	−0.06*	−0.10*	−0.21*	−0.08*	−0.75*	–		
11. Depressive symptoms	0.04	0.01	−0.03	0.004	0.16*	0.35*	0.54*	0.35*	0.14*	−0.17*	–	
12. Anxiety symptoms	0.01	0.07*	−0.001	0.001	0.21*	0.39*	0.52*	0.48*	0.07*	−0.10*	0.65*	–
Mean	19.28	–	–	–	–	–	1.74	1.71	–	45.98	0.58	0.53
Standard deviation	1.50	–	–	–	–	–	0.56	0.51	–	8.27	0.64	0.54

Note: For sex, 0 = male, 1 = female. For race, 0 = non-White, 1 = White. For ethnicity, 0 = non-Hispanic, 1 = Hispanic. For medication use, 0 = not taking any prescribed psychiatric medication, 1 = taking at least one prescribed psychiatric medication. For ADHD status, 0 = no elevated ADHD symptoms, 1 = elevated ADHD symptoms. For chronotype, 0 = morning/intermediate type, 1 = evening type. For circadian preference, higher scores indicate a greater preference for morningness.
Abbreviation: ADHD, attention-deficit/hyperactivity disorder; hyp-imp, hyperactivity–impulsivity.
*$p < 0.001$.

large ($|r| = 0.07$–0.54; Table 3). In general, demographic variables were unassociated or had small effect associations with psychopathology and circadian function variables (Table 3).

3.3 | ADHD dimensions in relation to circadian preference and chronotype

Results of the regression analyses of ADHD symptom dimensions in relation to circadian preference (continuous) and chronotype (dichotomous) are summarized in Table 4. Above and beyond participant characteristics (i.e. age, sex, race, ethnicity, psychiatric medication use) and internalizing symptoms, ADHD-IN symptoms were significantly associated with both eveningness preference and evening chronotype (both $p < 0.001$). ADHD-HI symptoms were not significantly associated with circadian preference or chronotype above and beyond the other variables in the model.

3.4 | Circadian preference as a moderator of the link between ADHD and internalizing symptoms

The moderation analyses included the same variables as the previous regression analyses, with the exception that separate models were conducted with depressive and anxiety symptoms as the outcome variable. Above and beyond participant characteristics, ADHD hyperactive–impulsive symptoms and anxiety symptoms, there was a significant ADHD inattention × circadian preference interaction ($b = -0.01$, $SE = 0.001$, $t = -4.05$, $p < 0.001$). As shown in Figure 1, there was a significant association between ADHD inattentive

TABLE 4 Regression analyses examining demographic characteristics, internalizing symptoms and ADHD dimensions in relation to circadian preference and chronotype in college students

	Evening circadian preference (continuous)				Evening type (dichotomous)			
	B	*SE*	*β*	*t*	*B*	*SE*	Wald	OR (95% CI)
Age	0.43	0.08	0.08	5.47*	−0.08	0.02	12.08*	0.92 (0.88, 0.97)
Sex (Male)	−0.62	0.27	−0.03	−2.33	0.15	0.07	4.24	1.16 (1.01, 1.34)
Sex (Other)	2.25	3.29	0.01	0.68	−1.00	1.11	0.81	0.37 (0.04, 3.27)
Race	−0.47	0.30	−0.02	−1.59	0.15	0.08	3.24	1.16 (0.99, 1.37)
Ethnicity	−1.11	0.37	−0.04	−3.02	0.18	0.10	3.20	1.20 (0.98, 1.46)
Medication use	−0.54	0.36	−0.02	−1.52	0.13	0.10	1.72	1.13 (0.94, 1.37)
Depression	−1.58	0.25	−0.12	−6.28*	0.38	0.07	32.46*	1.47 (1.29, 1.67)
Anxiety	0.93	0.31	0.06	3.03	−0.28	0.08	10.98*	0.76 (0.64, 0.89)
ADHD-IN	−2.91	0.29	−0.20	−10.22*	0.56	0.08	53.57*	1.76 (1.51, 2.04)
ADHD-HI	0.84	0.29	0.05	2.91	−0.16	0.08	3.89	0.86 (0.73, 1.00)

Note: For sex (male), 0 = female/other, 1 = male. For sex (other), 0 = male/female, 1 = other. For race, 0 = non-White, 1 = White. For ethnicity, 0 = non-Hispanic, 1 = Hispanic.
Abbreviation: ADHD, attention-deficit/hyperactivity disorder; CI, confidence interval; HI, hyperactivity–impulsivity; IN, inattention; OR, odds ratio.
*$p < 0.001$.

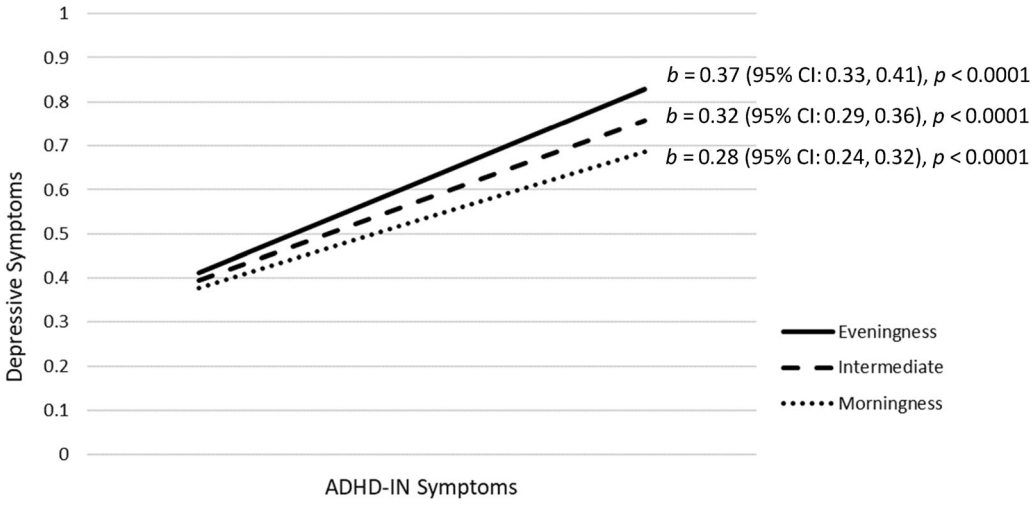

FIGURE 1 Preference for evening strengthens the association between attention-deficit/hyperactivity disorder inattention (ADHD-IN) and depressive symptoms.

symptoms and depressive symptoms at all levels of circadian preference. However, the association between ADHD inattention and depression was stronger as circadian preference for eveningness increased. Main effects were also found for ADHD hyperactive–impulsive symptoms ($b = -0.08$, $SE = 0.02$, $t = -4.87$, $p < 0.001$) and anxiety symptoms ($b = 0.63$, $SE = 0.02$, $t = 41.39$, $p < 0.001$) in relation to depressive symptoms.

There was not a significant ADHD inattention × circadian preference interaction in relation to anxiety symptoms. Main effects were found for ADHD hyperactive–impulsive symptoms ($b = 0.24$, $SE = 0.01$, $t = 18.12$, $p < 0.001$), depressive symptoms ($b = 0.43$, $SE = 0.01$, $t = 41.39$, $p < 0.001$), psychiatric medication use ($b = 0.11$, $SE = 0.02$, $t = 6.27$, $p < 0.001$) and female sex ($b = 0.07$, $SE = 0.01$, $t = 5.93$, $p < 0.001$) in relation to anxiety symptoms.[2]

4 | DISCUSSION

This study advances the existing literature on ADHD and chronotype/circadian preference in several ways. By using a large, multisite sample of college students, we confirmed that students with elevated ADHD symptoms clearly differ from their peers without ADHD in their chronotype, with ADHD being associated with an evening chronotype. We also found that this association is primarily attributable to inattentive, rather than hyperactive–impulsive, symptoms. This study also showed, for the first time, that the association between ADHD inattentive symptoms and depressive symptoms is stronger for individuals with greater preference for eveningness. Taken together, this study shows that ADHD, and inattentive symptoms considered dimensionally, are associated

with later chronotype, and that inattentive symptoms and eveningness preference are jointly associated with increased depressive symptoms in college students.

Previous studies have found that 24%–59% of adults with ADHD or elevated ADHD symptoms report an evening chronotype, though sample sizes were often small (Gabay et al., 2022; Rybak et al., 2007; Voinescu et al., 2012). The only study comprised solely of college students was conducted by Gabay et al. (2022), who found that college students with elevated ADHD symptoms were more likely to be evening types (59%) than college students without ADHD symptoms (44%). In the current study, we too found that college students with elevated ADHD symptoms were more likely to be classified as evening types (40.5%) than students without ADHD symptoms (28.5%), though our rates were lower than those reported in Gabay et al. (2022). Possible reasons for the discrepant rates include Gabay et al. using a shorter, five-item measure of morningness–eveningness, as well as their smaller sample size of 363 students (98 with elevated ADHD symptoms). Our sample size of 4761, including 656 with elevated ADHD symptoms, allowed us to examine chronotype in specific ADHD presentations, finding that the higher rates of evening type in the participants with ADHD was specific to students with inattentive symptoms (either predominantly inattentive presentation or combined presentation).

This finding was further supported in our analyses using dimensional measures of ADHD symptoms, wherein higher inattentive symptoms were uniquely associated with both evening preference and evening chronotype above and beyond participant characteristics and internalizing symptoms, whereas hyperactive–impulsive symptoms were not. Although some mixed findings have been reported in previous studies examining ADHD dimensions and circadian preference (Bron et al., 2016; Sivertsen et al., 2015), our findings are consistent with previous studies that included college students specifically (Caci et al., 2009; Voinescu et al., 2012). Circadian rhythms are known to impact neurocognition (Schmidt et al., 2007), and the present study is the largest to date to examine the association between chronotype and clinical ADHD inattentive symptoms specifically.

In moderation analyses, we found greater eveningness preference to strengthen the association between ADHD inattention and depressive symptoms. This effect was specific to depressive symptoms, as similar moderation was not found in relation to anxiety symptoms. Inattentive symptoms are more strongly associated than hyperactive–impulsive symptoms with mood disorder symptoms, whereas the ADHD dimensions do not differ in their associations with anxiety disorder symptoms (Willcutt et al., 2012). In this study we found depressive but not anxiety symptoms to be associated with our dimensional measure of circadian preference. It thus appears that inattention, circadian preference and depressive symptoms are themselves closely intertwined. It is possible that the combined presence of significant inattentive symptoms and a preference for eveningness compound in contributing to worsened mood. College students with ADHD who are also evening types may also encounter challenges with time management, academic demands and evening activities, including social media and alcohol use, which in turn contribute to poorer overall functioning and greater depressive symptoms (DuPaul et al., 2021; Mochrie et al., 2020).

Findings from the present study point to several areas for further inquiry. The cross-sectional nature of our study does not allow for inferring causality or directionality, and experimental and longitudinal studies are needed to disentangle the complex relations between circadian phase and attention. We focused on ADHD symptoms in relation to circadian function so we could simultaneously examine the unique effects of inattention and hyperactive–impulsive dimensions, though it is also possible that inattention contributes to circadian phase (e.g. via disorganization and time-management difficulties; Barkley, 2012; Becker et al., 2018; Jarrett et al., 2017). In addition, there is some indication that college students with ADHD have poorer cognitive performance when completing tasks at times that are desynchronous with their circadian phase (Gabay et al., 2022), and additional studies are needed to further evaluate time of day effects, including domains of cognitive and academic functioning most impacted. It is also possible that college students with ADHD may do better in classes that are better matched to their circadian phase (e.g. afternoon rather than early morning classes). In terms of treatment, several studies have examined melatonin in children with ADHD, though studies with adults are lacking and the existing studies conducted in children primarily used melatonin as a somnolent to shorten sleep-onset latency rather than as a chronobiotic to advance circadian phase (Coogan & McGowan, 2017). Morning light therapy reduced ADHD symptoms, improved mood and decreased eveningness preference in an open trial of 29 adults with ADHD, with a need for confirmation in a larger, randomized trial (Rybak et al., 2006). Finally, a transdiagnostic cognitive-behavioural intervention was shown to impact circadian phase in adolescents with an evening type (Harvey et al., 2018), and it would be informative to test this intervention in college students specifically, including students with ADHD.

Several limitations are important to note. First, as noted above, the cross-sectional design precludes drawing causal or directional inferences. Second, we relied solely on rating scale measures, and it would be beneficial for future studies to include more robust measurement of ADHD (e.g. diagnostic interviews, collateral report) and circadian function (e.g. dim light melatonin onset, actigraphy-assessed mid-sleep). In particular, our sample had a high percentage of students with predominantly hyperactive–impulsive symptoms, which on one hand ensured we had sufficient numbers for group comparisons and variability in ADHD-HI symptoms, though this presentation is less common after early childhood (Willcutt et al., 2012). It is important to recall that our study grouped participants based solely on ADHD symptoms and was therefore not a comprehensive assessment or diagnosis that considered all diagnostic criteria (e.g. symptoms across settings, impairment, age of onset, symptoms not better explained by another mental disorder). In addition, it would be beneficial for future studies to more thoroughly assess medical history/illness and specific medication formulations/doses, which may impact both ADHD symptoms and circadian function. Third, we focused specifically on the association between ADHD and chronotype/circadian function, and there is a need for research that simultaneously considers the extent to which sleep and circadian factors contribute to, maintain or exacerbate ADHD symptoms and other psychopathologies (Becker, 2023).

Fourth, we do not know what percentage of potentially eligible participants chose to participate or whether certain students were more or less likely to participate in this study. Fifth, although our sample size was large and drawn from multiple universities in an effort to increase representativeness and generalizability, only five universities were included, and most participants were female and non-Hispanic White.

Despite these limitations, the current study leveraged a sample of over 4700 college students from five universities in different regions of the USA to examine ADHD presentations and symptom dimensions in relation to chronotype and circadian preference. Using both categorical and dimensional approaches, ours is the largest study to document that college students with elevated ADHD symptoms are more likely to be evening types than other college students, and inattentive symptoms in particular are associated with later circadian preference above and beyond participant characteristics and internalizing symptoms. Finally, ours is the first study to show that the association between ADHD inattentive and depressive symptoms is stronger for college students with greater preference for eveningness.

AUTHOR CONTRIBUTIONS

Stephen P. Becker: Conceptualization; investigation; writing – original draft; methodology; writing – review and editing; formal analysis; project administration; data curation; resources. **Aaron M. Luebbe:** Conceptualization; investigation; writing – review and editing; data curation; resources; project administration; methodology. **Michael J. Kofler:** Conceptualization; investigation; writing – review and editing; data curation; resources; project administration; methodology. **G. Leonard Burns:** Conceptualization; investigation; writing – review and editing; project administration; data curation; resources; methodology. **Matthew A. Jarrett:** Conceptualization; investigation; writing – review and editing; project administration; data curation; resources; methodology.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTES

[1] Results were unchanged when ADHD medication use (dichotomous) was used instead of any psychiatric medication use, and ADHD medication use was not a significant predictor variable in any model. We did not collect information on specific ADHD medications (e.g. stimulant versus non-stimulant) or dose.

[2] Our moderation analyses focused on ADHD inattention and circadian preference given that ADHD inattentive symptoms are more strongly associated than ADHD hyperactive–impulsive symptoms with internalizing symptoms (Willcutt et al., 2012). We conducted analyses to explore whether there was significant interaction between ADHD hyperactive–impulsive symptoms and circadian preference and internalizing symptoms. A significant interaction was not found for either depressive or anxiety symptoms.

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