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The hidden clock: how chronotype is related to depression, anxiety, and stress in adolescents – insights from the EHDLA study

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Abstract

Background Depression, anxiety, and stress symptoms are common among adolescents; however, studies exploring their relationship with chronotype in European youth populations is scarce. This study aimed to evaluate the association between chronotype status and depression, anxiety, and stress symptoms in adolescents.

Methods A secondary analysis of the Eating Healthy and Daily Life Activities (EHDLA) cross-sectional study was performed in 703 adolescents (56.3% girls) between 12 and 17 years from the *Valle de Ricote*, Spain. Chronotype preference was assessed using the Morningness/Eveningness Scale in Children (MESC), while symptoms were evaluated using the Depression, Anxiety, and Stress Scale (DASS-21). A robust generalized linear regression model was used to evaluate the associations between chronotype prefernces and symptoms of depression, anxiety and stress in adolescents.

Results After adjusting for potential covariates (sex, age, socioeconomic status, body mass index, sleep duration, physical activity, sedentary behavior, and energy intake), the highest probability of having depression, anxiety, and stress was identified in those with an eveningness chronotype preference (depression: 27.4%, 95% confidence interval [CI] 17.5–40.1%; anxiety: 28.5%, 95% CI 18.6–41.0%; stress: 47.6%, 95% CI 34.1–61.5%). Conversely, the lowest probability was observed in adolescents with a morningness chronotype preference (depression: 11.9%, 95% CI 8.3–16.8%; anxiety: 15.4%, 95% CI 11.2–28.9%; stress: 19.5%, 95% CI 14.7–25.5%). Significant differences were found when comparing participants with the eveningness chronotype to those with a morningness or intermediate chronotype preference ($p < 0.05$ for all comparisons).

Conclusions Depression, anxiety, and stress symptoms were more likely in adolescents with an eveningness chronotype preference than in those with morningness or intermediate chronotypes. Chronotype preferences should be taken into account for developing interventions that promote better mental health and healthy sleep habits in adolescents.

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Keywords Chronobiology, Circadian preference, Morningness, Eveningness, Mental health, Teenagers

Introduction

Depression, anxiety, and stress are public health concerns among adolescents, with significant implications for their overall mental and physical well-being [1, 2]. According to the World Health Organization (WHO), depression is a leading cause of illness and disability among adolescents, with an estimated global prevalence of 14% [1]. In addition, anxiety affects 5–10% of the adolescent population globally [3]. The European Union indicates that approximately 10–15% of adolescents experience mental health disorders, with depression and anxiety being the most common [2]. In Spain, approximately 69% of adolescents exhibit symptoms of depression and 55% present anxiety symptoms, while 62% experience some stress symptomology [4]. Furthermore, stress, although not always categorized as a clinical disorder, is widespread and often linked to various psychosocial stressors, such as academic pressure, social relationships, and family dynamics in adolescents [5].

Chronotype is a complex, biologically based trait that reflects an individual's preferred timing of sleep and daily activities, driven by underlying genetic, hormonal, and neurological mechanisms that regulate circadian rhythms, which are endogenous cycles aligning physiological and behavioral processes with the 24-hour light-dark cycle [6, 7]. Foremost, chronotype can be measured according to sleep behaviors with the Munich Sleep Timing Questionnaire; however, most investigations have analyzed the "morningness-eveningness" circadian preferences to perform different activities as a proxy of chronotype [8]. Understanding the relationship between chronotype and mental health in adolescents is crucial given the unique developmental and psychosocial challenges faced during puberty [9]. Furthermore, the beginning of adolescence is a period marked by physiological and social transformations that impact sleep patterns, leading to reduced sleep duration and heightened sleep variability; hence, chronotypes undergo an important adjustment during adolescence [10–12]. Indeed, adolescents often experience a shift towards eveningness, which may also be connected to more rigorous academic and social expectations, lenient parental control, more autonomy, and increased participation in night-time events [6, 13]. For instance, one study in a sample of adolescents residing in Italy reported that they generally exhibited a tendency to remain awake for longer periods at night, wake up later in the morning, and prolong their sleep duration during weekends [14]. Likewise, a national sample of Canadian adolescents showed that every one-hour shift in chronotype was linked to an increase in the occurrence of headaches, stomach aches, back aches, dizziness, and a decline in self-reported health status [15]. In addition, misalignment with societal demands, such as early school start times, can lead to insufficient sleep and various negative health outcomes, including increased vulnerability to mental health issues as well as cognitive and emotional functioning in adolescents [6, 10].

Previous research has suggested that eveningness, insomnia symptoms, poor sleep quality, and female gender are associated with higher levels of depression and suicide risk among adolescents [16–18]. Foremost, a systematic review and meta-analysis reported a significant association between eveningness with mood-related issues, anxiety disorders, psychotic symptoms, and maladaptive eating behaviors in youth populations [19]. However, limited research has focused on chronotype status and mental health symptoms in European adolescents. Examining the associations between chronotype preference and symptoms of depression, anxiety, and stress will provide valuable insights into how sleep and activity patterns might influence mental health in this demographic group. Therefore, this study aimed to fill this gap in the literature by exploring how chronotypes preferences are related to symptoms of depression, anxiety, and stress in a large sample of adolescents from Spain.

Methods

Study design and population

The present study analyzed data from the Eating Healthy and Daily Life Activities (EHDLA) cross-sectional study, which was performed on adolescents aged 12–17 years from the *Valle de Ricote* (Region of Murcia, Spain). The data were collected from three secondary schools in 2021/2022 with a total population of 1496 adolescents. Sample selection was calculated using the following formula: $n = (Z)^2 \left(\frac{p(1-p)}{e^2}\right)$, considering the "p" or prevalence of overweight and obesity (40.0%) in Spain [20], "n" as sample size, "Z" as 1.96 (95% confidence interval [CI]), and "e" as margin of error (3%). Consequently, the minimum sample size (by considering 10% non-response rate) was 1,138 participants for the EHDLA study. Full details of the methodological approach for this study can be found elsewhere [21]. The schedules of the three schools in *Valle de Ricote* were similar. Hence, the school day began around 8:00 a.m. and continued until 2:00 p.m., with 30 min recess at approximately 11:00 am. Initially, 1378 adolescents were selected randomly. Of these, 523 (38.0%) were excluded due to missing data on the DASS-21 score. Furthermore, 102 (7.4%) participants were excluded due to lack of chronotype data. Next, 50 participants (3.6%) without covariate data (e.g., body mass index, physical activity) were removed. Thus, a final sample of 703 adolescents (56.3% girls) was included in the present analyses.

To be eligible for inclusion, participants met the following conditions: (1) adolescents between 12 and 17 years of age and (2) registered and/or lived in the *Valle de Ricote*. Participants were excluded if they (1) had any pathology that contraindicates physical activity or demanded special attention; (2) were exempt from the subject of Physical Education at school, as data collection was conducted during physical education lessons; (3) were receiving some kind of pharmacological treatment; (4) declined to take part in the research project; or (5) did not have permission from their parents or legal guardians to take part in the research study.

Variables

The chronotype preference (independent variable) of adolescents was assessed using the validated Spanish translation of the Morningness/Eveningness Scale in Children (MESC) [22, 23]. The MESC evaluates chronotypes through questions about the preferences of adolescents towards the evening or morning, evaluating their ideal timing of activities, and their ability to execute planned tasks at particular times of the day. The scale contains ten items, each with four to five response options. The participants were presented with a hypothetical scenario and asked to choose the statement that most closely reflected their feelings, using a scoring system that ranged from 1 to 4 for seven questions, and 1 to 5 for three questions (e.g., "Gym class is set for 7:00 in the morning. How do you think you will do?", with the following answer options: (a) my best, (b) okay, (c) worse than usual, and (d) awful). The scores varied between 10 and 43, with lower scores indicating a preference for being more active in the evening and higher scores indicating a preference for being more active in the morning. Cutoff points of 18 and 30 are usually applied to classify evening (≤ 18 points), intermediate (19–29 points), and morning types (≥ 30 points).

The symptoms of depression, anxiety and stress (dependent variable) of adolescents were evaluated by the validated Spanish version of the DASS-21 [24]. The scale consists of 21 items rated on a 3-point Likert-type scale from 0 (did not apply to me at all) to 3 (applied to me very much or most of the time), which was divided uniformly into three subscales: depression, anxiety, and stress. Additionally, the cut-off points for depression, stress, and anxiety were ≥ 6, ≥5, and ≥ 6 points, respectively.

Based on previous research, potential confounding factors included age, sex, socioeconomic status, physical activity and sedentary behavior, overall sleep duration, and energy intake [16–18, 25]. Adolescents self-reported their sex and age, while their socioeconomic status was assessed using the Family Affluence Scale (FAS-III) [26]. The FAS-III score was calculated by adding up responses from six categories concerning family (vehicles, bedrooms, computers, bathrooms, dishwashers, and travel). The total score varies from 0 to 13 points, with higher scores indicating a higher socioeconomic status. Furthermore, measurements of height (in meters) and body weight (in kilograms) were taken in a controlled environment, while body mass index was calculated as the body weight (in kilograms) divided by the square of the height (in meters) [21]. In addition, the validated Spanish translation of the Youth Activity Profile Physical (YAP-S) was used to assess physical activity and sedentary behavior in adolescents [27]. The YAP score consists of a 15-item self-administered 7-day recall questionnaire with a 5-point Likert scale divided into three domains: out-of-school activity, school activity, and sedentary habits. The scores for physical activity (school/out-of-school) and sedentary behavior (sedentary habits) were calculated by summing the items in each domain. Moreover, sleep duration was obtained by asking about their typical bedtime and wake-up time individually on weekends and weekdays. Afterwards, the average daily sleep duration for each adolescent was calculated using the following formula: [(average nocturnal sleep duration on weekends × 2) + (average nocturnal sleep duration on weekdays × 5)]/7. In addition, energy intake was assessed using a validated Spanish translation of the self-reported food frequency questionnaire (FFQ) consisting of 45 items [28]. Hence, participants were surveyed about their weekly/monthly intake of various food groups, including meat (red and processed meat, sausages, poultry, and chicken), fish and seafood, eggs, vegetables (salads and vegetables), dairy products (milk and others), fruits (fresh and preserved), grains (bread, pasta, rice, breakfast cereals, cookies, and pastries), sweets (sugar and chocolates), potatoes, legumes, nuts, sugary drinks, low-calorie drinks, and alcoholic beverages. The average weekly servings of these food groups were then calculated to determine the overall energy intake.

Statistical analysis

Density and quantile–quantile plots were used to evaluate the normal distribution of variables, along with the Shapiro-Wilk test. Categorical variables are shown as counts (n) and percentages (%), whereas continuous variables are presented as medians and interquartile ranges (IQRs). Since there was no significant interaction between chronotype and sex regarding DASS-21 scores or status ($p > 0.05$ for all), both girls and boys were analyzed together. To examine the associations between chronotype (i.e., "eveningness," "intermediate," or "morningness") and symptoms of depression, anxiety and stress in adolescents, generalized linear regression models (GLMs) were applied. These models use robust methods to address heteroscedasticity and outliers. For continuous outcomes, GLMs with a Gaussian distribution using the "*SMDM*" method were employed (i.e., using an S-estimate followed by an M-estimate, a design adaptive scale estimate, and another M-step). For dichotomic outcomes, GLMs with a binomial distribution were conducted using the "*Mqle*" method. Additionally, the estimated marginal means (M) of the DASS-21 score (i.e., symptoms of depression, anxiety, or stress) or predictive probabilities (%) of depression, anxiety, or stress, along with their 95% CIs, were calculated based on different chronotypes. All models were adjusted for several covariates, including sex, age, socioeconomic status, overall sleep duration, physical activity, sedentary behavior, and energy intake. In addition, two behavioral proxies of chronotype were calculated: social jetlag and mid-sleep on free days corrected for sleep debt (MSFsc). These variables were derived from self-reported sleep onset and wake times on weekdays and weekends. Mid-sleep was defined as the midpoint between sleep onset and wake time. Social jetlag was calculated as the absolute difference in hours between mid-sleep on weekdays and weekends. MSFsc was calculated as mid-sleep on free days (weekends) corrected by sleep debt, using the formula: MSFsc = MSF – 0.5 × (weekend sleep duration – weekday sleep duration), following the Munich Chronotype Questionnaire methodology [7, 29]. Both variables were treated as continuous predictors in the GLMs. Statistical analyses were conducted using R statistical software (version 4.4.0) by the R Core Team in Vienna, Austria, and RStudio (2024.04.1 + 748) from Posit in Boston, MA, USA. Statistical significance was set at $p < 0.05$.

Results

Table 1 shows the descriptive data of study participants according to their chronotype status preference. A total of 703 adolescents were included in the analysis, of which 340 (48.4%) presented an intermediate chronotype preference, 283 (40.3%) presented morningness, and 80 (11.4%) presented eveningness. Indeed, the highest proportion of depression, anxiety, and stress symptoms were observed in adolescents with an eveningness chronotype preference (51.2%, 48.7%, and 66.2%, respectively). In comparison, the lowest symptoms of depression, anxiety, and stress were identified in the morningness chronotype preference. Furthermore, Table S1 displays the descriptive characteristics of the study participants (sample included with complete cases versus total sample). No clear pattern indicating potential selection bias was observed, as the distribution of categorical variables (proportions) and the central tendency and dispersion of continuous variables (median and IQRs) were similar between the included sample (complete cases) and the total sample.

Table 2 displays the association between chronotype status preference and potential covariates (i.e., sex, age, socioeconomic status, BMI, overall sleep duration,

Table 1 Descriptive data of the study participants according to chronotype status preferences ($n = 703$)

Variable		Chronotype status preferences		
		Eveningness	**Intermediate**	**Morningness**
Participants	*n* (%)	80 (11.4)	340 (48.4)	283 (40.3)
Sex	Boys	22 (37.9)	141 (41.5)	144 (50.9)
	Girls	58 (62.1)	199 (58.5)	139 (49.1)
Age (years)	Median (IQR)	14.0 (13.0, 15.0)	14.0 (13.0, 15.0)	13.0 (12.0, 15.0)
FAS-III (score)	Median (IQR)	9.0 (7.0, 9.5)	8.0 (7.0, 9.0)	8.0 (7.0, 10.0)
BMI (kg/m^2)	Median (IQR)	22.4 (19.2, 25.9)	21.6 (19.5, 25.1)	21.6 (19.0, 25.4)
Overall sleep duration (hour)	Median (IQR)	7.6 (5.7, 9.5)	8.3 (7.2, 9.4)	8.5 (7.4, 9.6)
YAP-S physical activity (score)	Median (IQR)	2.3 (1.9, 2.8)	2.6 (2.1, 2.9)	2.7 (2.3, 3.2)
YAP-S sedentary behaviors (score)	Median (IQR)	2.8 (2.4, 3.4)	2.6 (2.2, 3.0)	2.4 (2.0, 2.8)
Energy intake (kcal)	Median (IQR)	2.9 (1.4, 4.4)	2.6 (1.1, 4.1)	2.4 (1.1, 3.7)
DASS-21 Depression (score)	Median (IQR)	6.0 (2.0, 13.5)	3.0 (0.0, 7.0)	2.0 (0.0, 5.0)
Depression (%)	No	39 (48.8)	232 (68.2)	220 (77.7)
	Yes	41 (51.2)	108 (31.8)	63 (22.3)
DASS-21 Anxiety (score)	Median (IQR)	4.0 (1.0, 10.5)	3.0 (1.0, 6.0)	2.0 (0.0, 5.0)
Anxiety (%)	No	41 (51.3)	218 (64.1)	208 (73.5)
	Yes	39 (48.7)	122 (35.9)	75 (26.5)
DASS-21 Stress (score)	Median (IQR)	8.0 (3.5, 12.0)	4.0 (1.0, 8.0)	3.0 (0.0, 7.0)
Stress (%)	No	27 (33.8)	207 (60.8)	195 (68.9)
	Yes	53 (66.2)	133 (39.2)	88 (31.1)

Abbreviations: BMI, body mass index; DASS-21, Depression, Anxiety and Stress Scale – 21 Items; FAS-III, Family Affluence Scale-III; IQR, interquartile range; YAP-S, Spanish Youth Activity Profile

Table 2 Association between chronotype status preference and the depression, anxiety and stress scale – 21 items (DASS-21) scores among adolescents ($N = 703$)

DASS-21 Depression (score)					
Predictor	***B***	**SE**	**95% CI**		***p*-value**
			Lower	**Upper**	
Eveningness	Reference				
Intermediate	-2.26	0.55	-3.35	-1.18	< 0.001
Morningness	-2.96	0.58	-4.09	-1.83	< 0.001
Age	-0.01	0.11	-0.23	0.21	0.943
Boys	Reference				
Girls	2.25	0.34	1.58	2.92	< 0.001
FAS-III (per one point)	-0.25	0.08	-0.40	-0.10	0.001
BMI (per one kg/m^2)	0.02	0.03	-0.05	0.09	0.601
Overall sleep duration (per one hour)	-0.49	0.20	-0.88	-0.10	0.014
YAP-S physical activity (per one point)	0.34	0.25	-0.15	0.84	0.176
YAP-S sedentary behaviors (per one point)	0.49	0.29	-0.09	1.06	0.099
Energy intake (per 1000 kcal)	0.01	0.09	-0.16	0.17	0.928
DASS-21 Anxiety (score)					
Predictor	*B*	SE	95% CI		*p*-value
			Lower	Upper	
Eveningness	Reference				
Intermediate	-1.29	0.51	-2.28	-0.29	0.012
Morningness	-2.01	0.53	-3.05	-0.97	< 0.001
Age	-0.07	0.10	-0.27	0.14	0.527
Boys	Reference				
Girls	2.07	0.32	1.45	2.69	< 0.001
FAS-III (per one point)	-0.14	0.07	-0.28	0.00	0.053
BMI (per one kg/m^2)	0.03	0.03	-0.03	0.09	0.361
Overall sleep duration (per one hour)	-0.31	0.18	-0.67	0.05	0.094
YAP-S physical activity (per one point)	0.27	0.24	-0.19	0.73	0.251
YAP-S sedentary behaviors (per one point)	0.35	0.27	-0.19	0.88	0.202
Energy intake (per 1000 kcal)	0.09	0.08	-0.06	0.24	0.248
DASS-21 Stress (score)					
Predictor	*B*	SE	95% CI		*p*-value
			Lower	Upper	
Eveningness	Reference				
Intermediate	-2.36	0.58	-3.49	-1.23	< 0.001
Morningness	-3.10	0.60	-4.29	-1.92	< 0.001
Age	0.10	0.12	-0.13	0.33	0.409
Boys	Reference				
Girls	2.60	0.36	1.90	3.31	< 0.001
FAS-III (per one point)	-0.13	0.08	-0.29	0.03	0.106
BMI (per one kg/m^2)	0.03	0.04	-0.04	0.10	0.382
Overall sleep duration (per one hour)	-0.51	0.21	-0.91	-0.10	0.014
YAP-S physical activity (per one point)	0.20	0.27	-0.32	0.73	0.452
YAP-S sedentary behaviors (per one point)	-0.05	0.31	-0.66	0.55	0.859
Energy intake (per 1000 kcal)	0.10	0.09	-0.06	0.27	0.221

Abbreviations: B, unstandardized beta coefficient; BMI, body mass index; DASS-21, Depression, Anxiety and Stress Scale – 21 Items; FAS-III, Family Affluence Scale-III; SE, standard error; YAP-S, Spanish Youth Activity Profile; 95% CI, 95% confidence interval

physical activity, sedentary behavior, and energy intake) with symptoms of depression, anxiety, and stress. Likewise, the estimated marginal means of the symptoms of depression, anxiety, and stress among chronotype preferences are shown in Figure S1. The greatest estimated marginal means of depression, anxiety, and stress were observed in adolescents with an eveningness chronotype preference (depression: 4.8 points, 95% CI 3.7 to 5.9; anxiety: 3.8 points, 95% CI 2.8 to 4.8; stress: 5.8 points, 95% CI 4.6 to 6.9). On the other hand, the lowest probability

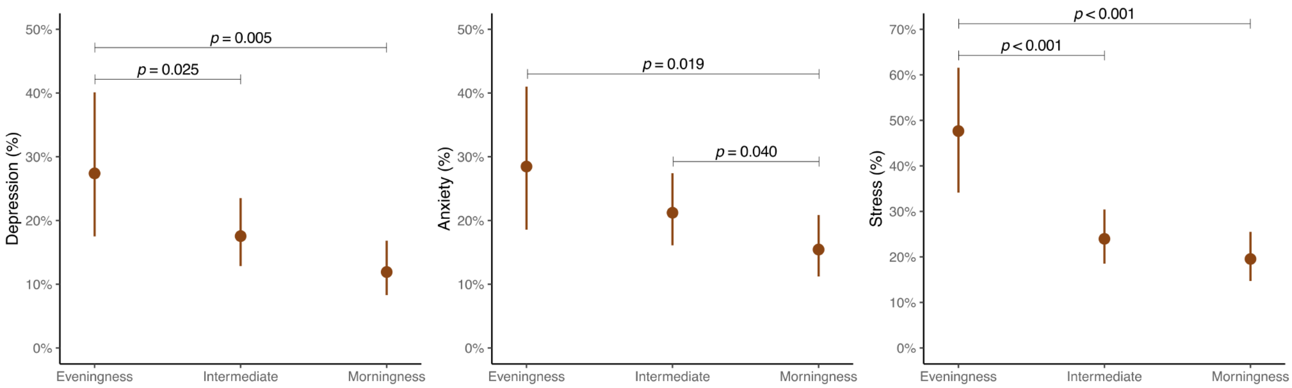

Fig. 1 Predictive probabilities of depression, anxiety, and stress symptoms among adolescents according to their chronotype preference ($n = 703$)

was shown in those with a morningness chronotype preference (depression: 1.8 points, 95% CI 1.2 to 2.4; anxiety: 1.8 points, 95% CI 1.2 to 2.3; stress: 2.7, 95% CI 2.1 to 3.3). Significant differences were observed when comparing individuals with an eveningness chronotype preference to those with a morningness or intermediate chronotype preference ($p < 0.05$ across all comparisons).

The predicted probabilities of the symptoms of depression, anxiety, and stress based on the different chronotypes preferences are displayed in Fig. 1. Following adjustment for the above-mentioned covariates, we observed statistically significant variations in the DASS-21 scores across the various chronotypes preferences. The highest probability of having depression, anxiety, and stress was identified in those with an eveningness chronotype preference (depression: 27.4%, 95% CI 17.5–40.1%; anxiety: 28.5%, 95% CI 18.6–41.0%; stress: 47.6%, 95% CI 34.1–61.5%). Conversely, the lowest probability was observed in adolescents with a morningness chronotype preference (depression: 11.9%, 95% CI 8.3–16.8%; anxiety: 15.4%, 95% CI 11.2–28.9%; stress: 19.5%, 95% CI 14.7–25.5%). Significant differences were found when comparing participants with the eveningness chronotype preference to those with a morningness or intermediate chronotype preference ($p < 0.05$ for all comparisons). The full results of the GLMs assessing the associations between chronotype preference and depression, anxiety, and stress among adolescents are shown in Table S2.

Additionally, as an exploratory analysis, we tested the associations of social jetlag and MSFsc with symptoms of depression, anxiety, and stress. These variables were calculated using self-reported weekday and weekend sleep data. However, neither social jetlag nor MSFsc were significantly associated with any of the DASS-21 outcomes in our sample. Full models are available in Table S3 and S4.

Discussion

The present study examined the associations of chronotype status preference with depression, anxiety, and stress in a community-based adolescent sample from Spain. Currently, there is limited evidence evaluating the connection between chronotypes preferences and depression, anxiety, and stress symptoms in European adolescents. Chauhan et al. (2024) [30] reported no direct relationship between eveningness and poor mental health outcomes (depression, anxiety, and stress) in young Indian adults. Additionally, a systematic review and meta-analysis by Cheung et al. (2023) [19] analyzed 81 observational studies and demonstrated an important association between eveningness and overall mental health ($r = 0.20$), mood-related issues ($r = 0.17$), and anxiety disorders ($r = 0.13$) in youths. In general, our findings indicate that adolescents with an eveningness chronotype preference had higher symptoms of depression, anxiety, and stress as well as greater predictive probabilities of having these conditions in comparison with their peers with an intermediate or a morningness chronotype preference. These results are in line with previous studies, which suggested an individual higher prevalence of depression, anxiety, and stress symptoms, particularly among adolescents with eveningness preferences [16–18]. For example, a cross-sectional study in Hong Kong reported that insomnia symptomatology, rather than eveningness, was linked to anxiety and suicidal ideation [22]. Moreover, an actigraphy-based sleep estimate study in adolescents showed that the evening chronotype was linked to an increase in risky behaviors and substance use among boys, but not related to depressive symptoms [10]. Most importantly, we recommend caution when interpreting our results considering the smaller sample size of the eveningness group. While it is true that many studies on adolescent chronotypes report a greater proportion of evening types, the distribution observed in our sample could be influenced by several factors. First, the societal structure and early start times (around 8:00 AM) in the schools where data was collected may favor morning-intermediate preference as students adjust their sleep-wake patterns to academic demands, potentially leading to underrepresentation within school settings. Indeed, prior research has suggested that school start times can influence chronotype expression in adolescents [11, 31, 32]. Second, methodological factors, such as sample recruitment, geographic location, or cultural influences on sleep behaviors [33, 34]. For example, Spanish social life tends to be more evening-oriented compared to other European countries [34], yet our sample was drawn from a specific region and may not fully reflect broader national trends. Third, the MESC thresholds to define chronotype categories may affect the underrepresentation of eveningness preferences due to their arbitrary classification [23]. Although the specific mechanisms by which chronotype preference may influence the development of depression, anxiety and stress symptoms in adolescents are not fully elucidated, it is important to understand the specific mechanisms by which chronotype may promote the development of mental health deterioration, such as such as circadian rhythms, sleep disorders, diet habits, brain characteristics, psychological factors, genetic clocks polymorphisms, and socio-environmental stressors [6, 8, 9, 35, 36]. Despite these facts, there are several potential explanations that could account for our results.

A disruption of circadian rhythms can lead to chronic sleep deprivation which may promote the development of mental health deterioration, mood changes, and even psychiatric disorders (e.g., depression, anxiety, substance use, bipolarity, and eating disorders) [8, 9, 35]. Moreover, the lack of synchronization between internal and external time is generally referred to as social jetlag [29] and this can negatively impact the physical ability to regulate mood, cognition, and emotional stability [6, 8, 10]. Variations among individuals can influence distinct circadian rhythms in diverse ways, particularly those linked to the adrenal cortex, which adjusts in response to changes in activity and rest patterns [8]. In contrast, rhythms associated with the pineal gland tend to align more closely with cycles of light and darkness [6]. Alterations in the timing of endogenous melatonin release are associated with disruption in sleep patterns. Consequently, individuals experiencing social jetlag often report diminished performance or a state of desynchronization resulting from this phase shift [6, 8]. As proof, Lyall et al. (2018) [37] has reported an association between circadian rhythm disturbances and various mental health conditions, including major depressive and seasonal affective disorders, in over 90,000 adults. Additionally, these dysfunctions were associated with negative mental states, characterized by increased feelings of loneliness, diminished happiness, and lower levels of overall satisfaction [37]. A systematic review of children and adolescents identified an important association between social jetlag and both clinical and seasonal depression, particularly among female participants residing in high-latitude areas [38]. Although previous literature suggests that circadian misalignment, particularly social jetlag, may contribute to poor mental health in adolescents [7, 29, 37, 38], our additional models including social jetlag and MSFsc did not reveal significant associations with depression, anxiety, or stress symptoms. These findings might reflect measurement limitations, contextual factors, or the possibility that subjective chronotype preferences may capture psychosocial aspects more strongly related to mental health than behavioral sleep-timing metrics alone. Nonetheless, our inclusion of these variables provides a more comprehensive view of chronotype and supports future investigations into biological and behavioral rhythms in adolescent populations.

Reduced sleep quality and sleep disorders can significantly influence mental health, especially among adolescents [9, 10]. In particular, adolescence represents a developmental phase characterized by a tendency for the sleep-wake cycle shift to a later timing in comparison with children [10]. Variations in sleep patterns between the morningness and eveningness types during this period may be affected by hormonal changes, heavier academic and social pressures, lack of parental restrictions, increased personal autonomy, and greater participation in late-night activities [6, 10]. Indeed, a significant number of adolescents encounter sleep difficulties during their high school years as they transition into young adulthood, and various markers of inadequate sleep have been linked to heightened levels of depressive symptoms [10]. Consequently, chronic sleep deprivation affects brain function, emotional regulation, and stress response, increasing the risk of developing mental health problems such as depression, anxiety, and irritability [10, 15, 17]. Inadequate sleep can impair cognitive processes, including attention, memory, and decision-making, exacerbating stress and emotional difficulties [10, 15]. Moreover, insomnia is a sleep disorder characterized by difficulty falling asleep, which affects 20–25% of the youth population worldwide [39]. Above all, insomnia among adolescents is linked to future mental health challenges and a higher likelihood of experiencing interpersonal issues and psychiatric disorders such as anxiety, depression, risk-taking behaviors, substance use disorders, and suicidal ideation [16, 39]. Furthermore, the association between sleep problems, school start times, and later chronotypes in adolescents is well-documented in the medical literature [40]. Rodríguez-Ferrante et al. [11] found that earlier school start times were associated with greater delays in chronotype development, particularly for those with an earlier baseline chronotype. Similarly, a systematic review and meta-analysis supported these findings, indicating that later school start times were associated with longer sleep duration, reduced social jetlag, and later chronotypes [32].

Diet habits can indeed explain the differences in chronotypes and associated mental health deterioration in adolescents. Teixeira et al. (2022) [41] found that eveningness chronotypes are more prone to exhibit detrimental dietary behaviors, including late-night eating, frequent breakfast omission, and preference for processed or ultra-processed foods in adults. The timing of nutrient intake could influence circadian rhythms, and consuming large meals late at night can disrupt sleep-wake cycle preference, leading to a later chronotype [8]. This disruption may result in poor sleep quality and quantity, which are intricately linked to mental health issues such as depression and anxiety [9]. In contrast, chronotype can also modulate eating behaviors in adolescents with mental health issues [42, 43]. For instance, adolescents with an evening chronotype were more prone to disordered eating behaviors compared to those with a morning or intermediate chronotype [42]. In the same way, evening chronotypes were more likely to experience insomnia and night eating, which can indirectly contribute to disordered eating attitudes [43].

On the one hand, the present analysis has some limitations that should be considered when interpreting the findings. The current cross-sectional design restricts causal inferences between disorders and risk factors and prevents the determination of the direction of the association. Therefore, additional longitudinal studies with larger sample sizes are necessary to elucidate the association direction of chronotype status between depression, anxiety, and stress in adolescents, and it is indeed possible that the association is bi-directional. Second, recall and desirability bias may be present, as the information was obtained from questionnaires. Third, missing information was observed in a large proportion of the initial study sample, which could predispose data sparsity bias. Fourth, we have not applied statistical methods or weighting techniques to enhance generalizability of the sample, which could bias results interpretation. In the same way, considering the early school shifts, the generalizability of our results could be limited within early start school settings. Fifth, the measure used to study circadian rhythms in this study was the MESC, which evaluates circadian preferences and is not a chronotype questionnaire. Sixth, our study did not consider another proxy of chronotype based on behaviors rather than preferences, such as social jetlag and the MSFsc. However, we conducted exploratory analyses incorporating social jetlag and MSFsc as behavioral proxies of chronotype. These additional variables were not significantly associated with DASS-21 outcomes, but their inclusion enhances the analytical depth and suggests the need for future longitudinal and objective assessments of sleep timing and variability. On the other hand, our analysis has several strengths. It included various covariates, thereby reducing the impact of confounding variables and enhancing the credibility of the relationship between chronotypes and depression, anxiety, and stress. Additionally, validated techniques were employed to evaluate chronotypes in adolescents, along with rigorous data analysis methods. Furthermore, we have provided the descriptive characteristics of the study participants (sample included with complete cases versus total sample) where no clear pattern indicating potential selection bias was observed. Finally, it is worth noting that despite the smaller sample size of the eveningness group, the statistical methods employed in our study accounted for this discrepancy, ensuring the robustness of our findings.

In view of these findings, it could be recommended that the subject of chronotype should be incorporated in both health and school facilities especially for adolescent students. Health workers should consider chronotype assessments when evaluating their patients, especially adolescents with evening chronotype profiles, as they are likely to be more prone to depression, anxiety, and stress. Establishing early risk factors could help to rectify this problem, such as improving sleep hygiene and altering circadian rhythms. Lack of control over start times and a rigid schedule in schools cause stress and poor students' mental health; hence, flexible school start times and personalized learning schedules might improve students' well-being. Such knowledge could also be implemented through chronotype education within the schools to enable students to appreciate the effect of their chronotype on their day-to-day functioning.

Conclusions

Our study suggests that an evening chronotype was associated with more symptoms of depression, anxiety, and stress among adolescents. Understanding the impact of chronotypes on these conditions can play a significant role in promoting better mental health outcomes in adolescents. Addressing these mechanisms involves promoting healthy sleep habits, considering flexible school start times, and providing support for adolescents struggling with chronotype-related challenges.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions
JFLG acquired study data and oversaw data collection procedures. JFLG, BS and HGE conducted statistical analyses. CM and JFLG conceived the presented idea. CM, LS, and CCM drafted the main manuscript text. CM, JFLG, JOA, and RYS interpreted study results. BS and JFLG prepared all tables and figures. All authors reviewed the manuscript and approved the final manuscript for publication.

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Data availability
Due to the sensitive nature of the data used in this manuscript, these data are not publicly available.

Declarations

Ethics approval
This research was approved by the Ethics Committee of the Albacete University Hospital Complex and the Albacete Integrated Care Management (ID 2021-85) and the Bioethics Committee of the University of Murcia (ID 2218/2018). In addition, the study was conducted in compliance with the Helsinki Declaration and upheld the human rights of all the enrolled individuals.

Competing interests
The authors declare no competing interests.

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