# RESEARCH





# The association of chronotype on depression in adolescents: the mediating role of sensation seeking and sleep quality

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### Abstract

**Objectives** This study explores the relationships among chronotype, sensation seeking, sleep quality and depressive symptoms in adolescents with diagnosed depression, aiming to clarify the mechanisms by which chronotype is associated with depression.

Methods This cross-sectional study assessed 216 adolescents with diagnosed depression using a demographic questionnaire, the Morningness-Eveningness Questionnaire, the Sensation Seeking Scale, the Pittsburgh Sleep Quality Index, and the Beck Depression Inventory. Descriptive and correlational analyses were performed using SPSS 27.0, and structural equation modeling was conducted via AMOS to explore the mediating roles of sensation seeking and sleep quality in the relationship between chronotype and depression.

**Results** The study found that 60.6% of adolescents with depression were evening chronotypes. Evening chronotype was associated with higher sensation seeking (r = -0.134, p < 0.05), poorer sleep quality (r = -0.303, p < 0.01), and more severe depressive symptoms (r = -0.376, p < 0.01). Chronotype showed a direct effect on depressive symptoms (effect size = -0.318, 95% CI = -0.602 to -0.049, p < 0.05) and an indirect effect via sleep quality, accounting for 80.5% of the total effect. While sensation seeking alone was not a significant mediator, it contributed to a chain mediation with sleep guality, accounting for 13% of the total effect (combined effect size = -0.053, 95% CI = -0.163 to -0.005, p < 0.01).

**Conclusions** Chronotype may play a significant role in adolescent depression, with both direct and indirect effects mediated by sleep quality and sensation seeking. The findings highlight the potential importance of sleep quality as a mediating factor, indicating that interventions targeting sleep improvement could be a promising avenue for further exploration in alleviating depressive symptoms in adolescents.

**Keywords** Depression, Chronotype, Sensation seeking, Sleep quality, Adolescent

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#### Introduction

Adolescent depression has become an increasingly prevalent concern worldwide, significantly impacting both mental health and overall quality of life [1, 2]. This multifactorial condition is shaped by biological, psychological, and social factors [3]. While the prevalence and consequences of adolescent depression are well-documented, the underlying mechanisms remain insufficiently understood [2].

Chronotype, an individual's intrinsic preference for specific sleep-wake cycles, is typically categorized as morning-type (M-type), intermediate-type (I-type), or evening-type (E-type) [4]. Emerging evidence suggests a significant association between adolescent depression and chronotype, with the E-type considered a risk factor for adolescent mental health [5]. During puberty, the secretion of gonadal hormones [6] and external factors such as artificial lighting and electronic device usage contribute to circadian rhythm disruptions, leading adolescents to shift toward an E-type chronotype [7–9]. Furthermore, adolescents with depression are more likely to display an E-type [10]. There may be a bidirectional relationship between chronotype and depression, with E-type predisposing individuals to depressive symptoms, and depressive symptoms potentially exacerbating circadian misalignment over time [11].

Circadian disruption is a well-established mechanism linking chronotype to mood disorders. E-types are particularly susceptible to circadian misalignment, which can disrupt sleep architecture [12] and impair emotional regulation [13]. For example, irregular sleep patterns in E-types may lead to disturbances in REM sleep [14], which is critical for emotional processing [15]. This disruption may exacerbate depressive symptoms by impairing the brain's ability to regulate negative emotions. Additionally, circadian misalignment in E-type adolescents often results from a conflict between their delayed sleep patterns and societal demands, such as early school start times [16]. This misalignment can lead to chronic sleep deprivation, further degrading sleep quality and increasing vulnerability to depressive symptoms [17, 18]. Despite the well-established association between chronotype and depression, the precise pathways linking the two remain unclear, necessitating further investigation into how circadian disruption interacts with other factors, such as sleep quality and sensation seeking, to influence depressive symptoms in adolescents.

A promising avenue for exploration is the potential mediating roles of sensation seeking and sleep quality in the chronotype-depression relationship. Sensation seeking, defined as the desire for novel and intense experiences, peaks during adolescence and has been linked to higher engagement in risk-taking behaviors [19, 20]. These behaviors may disrupt regular sleep patterns, exacerbating the misalignment between an individual's chronotype and daily schedule [18]. Research has identified a significant relationship between chronotype and sensation seeking, with E-type individuals exhibiting higher levels of sensation seeking than M-type individuals [21]. Moreover, sensation seekers often engage in stimulating activities as a coping mechanism for stress, but such behaviors can have negative consequences, increasing psychological strain and potentially triggering or exacerbating depressive symptoms [22]. Additionally, studies have shown that sensation seeking is significantly associated with higher risks of mental health issues, such as depression, anxiety, and suicide [23].

Sleep quality is a multidimensional construct encompassing several key components, including sleep latency (the time taken to fall asleep), wakefulness after sleep onset, the frequency and duration of nocturnal awakenings, and subjective reports of feeling rested and refreshed upon waking [24]. Poor sleep quality, specifically characterized by disruptions in sleep duration, continuity, and depth, has been consistently associated with impaired emotional regulation and an increased susceptibility to depression [25]. Adolescence is characterized by heightened emotional volatility, marked by rapid and intense fluctuations in mood and emotional reactivity [26]. Emotional volatility refers to the increased sensitivity and variability in emotional responses during adolescence, driven by ongoing neurodevelopmental changes, particularly in the prefrontal cortex [27]. This emotional instability may make adolescents particularly vulnerable to the negative effects of poor sleep quality, which can impair emotional regulation and increase the risk of depressive symptoms [28]. Among individuals with an E-type, whose delayed sleep patterns often conflict with societal demands such as early school start times, this misalignment can lead to insufficient sleep [29]. Academic pressures frequently compel E-type adolescents to adopt irregular sleep schedules, including late bedtimes and early wake times, which will degrade sleep quality [16]. Empirical evidence indicates that, compared to their peers, E-type adolescents are more likely to experience poor sleep quality, heightened sleep disturbances, and more severe depressive symptoms [30]. Collectively, the interaction between sensation seeking and these sleeprelated issues may establish a self-reinforcing cycle, further amplifying the susceptibility of E-type adolescents to depression.

Existing research suggests a significant potential link between high sensation seeking and poor sleep quality [31]. High sensation seekers are more likely to engage in activities that disrupt sleep, such as irregular sleep patterns, excessive stimulant use, and late-night stimulating activities [32]. These behaviors often lead to difficulties in sleep recovery, which are indicative of deteriorating sleep quality. Research has highlighted the role of sleep in the relationship between sensation seeking and risk-taking behaviors [31], showing that insufficient sleep among adolescents is positively correlated with increased risktaking [33]. The relationship between sensation seeking and sleep quality is an emerging area of study, influenced by common neurobiological mechanisms, including arousal regulation [34] and reward processing mechanisms [35]. High sensation seekers are inclined to pursue heightened stimulation, which may prevent relaxation and hinder the attainment of quality sleep. Furthermore, risk behaviors associated with sensation seeking, such as substance use, can exacerbate sleep disturbances [33]. Understanding the interaction between sensation seeking and sleep quality is critical for identifying high-risk individuals and developing targeted interventions to improve their sleep.

Therefore, this study aims to explore the complex relationship between chronotype, sensation seeking, sleep quality and adolescent depression, and examine the potential mediating roles of sensation seeking and sleep quality on the relationship between chronotype and adolescent depression. Based on the theories and literature above, we proposed the following hypotheses:

Hypothesis 1: Sensation seeking mediates the relationship between chronotype and adolescent depression.

Hypothesis 2: Sleep quality mediates the relationship between chronotype and adolescent depression.

Hypothesis 3: Chronotype indirectly associates the severity of depression in adolescent depression patients through the chain mediation effect of sensation seeking and sleep quality (Fig. 1).

# Materials and methods

## Participants

A total of 216 adolescents diagnosed with depression by licensed psychiatrists with senior professional titles were

recruited from the psychiatric outpatient clinic. Inclusion criteria were: (1) adolescents aged 12–18 years; (2) diagnosed with a depressive episode according to DSM-5 diagnostic criteria; (3) normal hearing and vision; and (4) informed consent from patients and their families. Exclusion criteria include: (1) diagnoses of schizoaffective disorder in DSM-V; (2) serious physical illness or psychoactive substance abusers; (3) communication or consciousness disorders; (4) serious suicidal ideation, agitation, impulsive or uncooperativeness; (5) history of head trauma with loss of consciousness over minutes; and (6) unwillingness to participate or withdrew in the middle of the study.

#### Measures

#### Descriptive information

The descriptive information form includes six questions about the participant's age, gender, educational status, and only-child status.

#### Chronotype

The Reduced Morningness-Eveningness Questionnaire (rMEQ), developed by Adan and Almirall, is a widely used tool for assessing chronotype [36]. The rMEQ scores range from 4 to 25, with 4–11 as indicating E-type, 12–17 as I-type, and 18–25 as M-type. Weixia Li et al. confirmed the Chinese rMEQ's validity and reliability [37]. In this study, the Cronbach's alpha for the MEQ scale was 0.648. This may be related to the few items on the scale.

#### Sensation seeking

The Sensation Seeking Scale (SSS), developed by Lina Chen et al., has shown reliability and validity [38]. It includes two scales: Thrill and Adventure Seeking (TAS) and Disinhibition (DIS). The SSS is scored on a 3-point Likert scale from 0 (want to do it) to 2 (will definitely do it if given the chance). In this sample, the Cronbach's  $\alpha$  of the SSS was 0.937.



Fig. 1 Research model

#### Sleep quality

The Pittsburgh Sleep Quality Index (PSQI), developed by D. J. Buysse, is used to assess sleep quality over the past month, including seven dimensions: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction [39]. The Chinese version of the PSQI has been proven to have good reliability and validity [40]. The scale is rated using a 4-point Likert scale, ranging from 0 (not in the past month) to 3 (three or more times per week). The total score of the PSQI is 21 points, with higher scores indicating greater difficulty in sleep. The Cronbach's  $\alpha$  coefficient for the PSQI was 0.803 in this study.

#### **Depression symptoms**

The Beck Depression Inventory (BDI), developed by Beck AT in 1974, consists of 13 items to assess depressive symptoms [41]. The scale is rated on a 4-point Likert scale from 0 to 3 and can be used for clinical diagnosis. Scores are categorized as 0–4 for no depression, 5–7 for mild depression, 8–15 for moderate depression, and 16–39 for severe depression, with higher scores indicating more severe symptoms. The Cronbach's alpha was 0.867 in this study.

#### Procedure

The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University. Participants who agreed to take part in the survey were recruited after receiving detailed information about the study. All participants and their guardians volunteered to take the survey and provided written informed consent before data collection began. Consistent verbal and written instructions about the questionnaire were provided by two trained assistants to ensure that all participants fully understood and completed the questionnaire. The questionnaire was completed during the clinic visit to ensure sufficient time for assessment.

#### Statistical analysis

Data analysis was performed using IBM SPSS 27 software. Continuous data were expressed as mean (M) and standard deviation (SD), while categorical data were presented as frequencies and percentages. The univariate normality of the data was tested using the Shapiro–Wilk analysis. Spearman's correlation test was used to examine the associations between continuous and categorical variables, specifically analyzing the relationships among chronotype, sensation-seeking, sleep quality, and depressive symptoms. Structural equation modeling (SEM) was then conducted using Amos 27.0. To test the hypothesis that sensation-seeking and sleep quality mediate the relationship between chronotype and adolescent depressive symptoms, we conducted a chained mediation analysis using SEM. Previous research has indicated that SEM analysis is appropriate when the sample size is  $\geq 200$  [42]. Thus, the sample size in this study meets the basic requirements for model validation. The non-standardized coefficients of direct and indirect effects within the model were estimated using bias-corrected bootstrap techniques (5,000 iterations). An effect was considered significant when the 95% confidence interval did not include zero.

#### Results

#### General characteristics of participants

Table 1 presents the socio-demographic characteristics of the 216 adolescents with depression included in the final analysis. The sample comprised 69 males (31.9%)

Table 1	Characteristics (	of the study	population	(N = 216)
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Characteristics	N(%)	Mean(SD)
Age(years)		15.60 (1.65)
Gender		
Male	69 (31.9%)	
Female	147 (68.1%)	
Education		
Suspend school	1 (0.5%)	
Primary school	3 (1.4%)	
Middle school	83 (38.4%)	
High school	119 (55.1%)	
College	10 (4.6%)	
Only chid		
No	120 (55.6%)	
Yes	96 (44.4%)	
rMEQ score		10.70 (3.58)
rMEQ subtypes		
M-type	12 (5.6%)	
l-type	73 (33.8%)	
E-type	131 (60.6%)	
Sleep Quality		10.16 (4.08)
Subjective sleep quality		1.65 (0.80)
Sleep latency		1.98 (1.07)
Sleep duration		1.07 (1.01)
Habitual sleep efficiency		0.92 (1.15)
Sleep disturbance		1.56 (0.69)
Use of sleep medication		1.12 (1.34)
Daytime dysfunction		1.86 (0.94)
SSS		20.79 (13.73)
TAS		12.18 (9.23)
DIS		8.62 (6.56)
BDI- 13		20.06 (7.14)

and 147 females (68.1%), with a mean age of 15.60 years (SD = 1.65, range = 12–18 years). According to the survey, 55.6% of participants were not only children, 55.1% were attending high school. The mean chronotype score was 10.70 (SD = 3.58), with 60.6% identified as E-type, 33.8% as I-type, and 5.6% as M-type. The mean scores for SSS and PSQI were 20.79 (SD = 13.73) and 10.16 (SD = 4.08), respectively. The mean scores for BDI- 13 were 20.06 (SD = 7.14).

#### **Correlation analysis**

As shown in Table 2, the results of the Spearman rho correlation analysis revealed a significant correlation between rMEQ scores, SSS scores, PSQI scores and BDI-13 scores. Specifically, E-type was associated with higher levels of sensation seeking (r = -0.134, p < 0.05), poorer sleep quality (r = -0.303, p < 0.01), and more severe depressive symptoms (r = -0.376, p < 0.01). Additionally, higher sensation seeking was associated with poorer sleep quality (r = 0.193, p < 0.01) and more severe depressive symptoms (r = -0.446, p < 0.01). Poorer sleep quality was also associated with more severe depressive symptoms (r = 0.176, p < 0.01).

#### Model fit test results analysis

A preliminary test was conducted on the structural equation model, and based on modification indices, the correlations between the error terms of different dimensions of sleep quality were added. According to the model fit test results shown in Table 3, the chi-square to degrees of freedom ratio (CMIN/DF) is 1.481, which falls within the good range of 1 to 3; the RMSEA is 0.047, within the excellent range of less than 0.05. Additionally, GFI = 0.955, AGFI = 0.920, IFI = 0.960, TLI = 0.938, and CFI = 0.958, all of which exceed 0.9, and RFI is 0.830, indicating a high model fit. Therefore, based on the overall analysis, it can be concluded that the revised chained mediation model has an acceptable level of fit.

<b>Table 3</b> Fit indices of measurement and structural mod
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Netrics	Judgment Criteria	Value	Model Fit Results
CMIN/DF	1 ~ 3, good; 3 ~ 5, acceptable	1.481	Good
RMSEA	< 0.05, good; < 0.08, acceptable	0.047	Good
GFI	> 0.8,acceptable; > 0.9, good	0.955	Good
AGFI	> 0.8,acceptable; > 0.9, good	0.920	Good
RFI	> 0.8,acceptable; > 0.9, good	0.830	Acceptable
IFI	> 0.8,acceptable; > 0.9, good	0.960	Good
TLI	> 0.8,acceptable; > 0.9, good	0.938	Good
CFI	> 0.8,acceptable; > 0.9, good	0.958	Good

*CMIN/DF* Chi-square to Degrees of Freedom Ratio, *RMSEA* Root Means the Square Error of Approximation, *GFI* Goodness-of-Fit Index, *AGFI* Adjusted Goodness-of-Fit Index, *RFI* Normed Fit Index, *IFI* Incremental Fit Index, *TLI* Tucker-Lewis's index, *CFI* Comparative Fit Index

#### Path hypothesis testing

Based on the analysis results presented in Table 4, it can be seen that in the hypothesis testing of this study, rMEQ significantly negatively associated with SSS ( $\beta = -$ 0.376, p < 0.01), PSQI ( $\beta = -$  0.050, p < 0.001), and BDI ( $\beta = -$  0.318, p < 0.05). SSS significantly positively associated with PSQI ( $\beta = 0.021$ , p < 0.05), but its prediction of BDI was not significant ( $\beta = 0.071$ , p = 0.401). PSQI significantly positively associated with BDI ( $\beta = 6.593$ , p <0.001).

#### **Mediation analysis**

To examine the effect of the independent variable on the dependent variable through mediators, we used 5,000 bootstrap samples to compute percentile bootstrapping and bias-corrected percentile bootstrapping with a 95% confidence interval (CI).

Table 5 indicates that chronotype is significantly associated with adolescent depressive symptoms through both direct and indirect pathways. The total effect ( $\beta = -0.408$ , 95% CI [-0.632, -0.245], p < 0.001) and direct effect ( $\beta = -0.318$ , 95% CI [-0.602, -0.049], p < 0.05) are both statistically significant. This suggests that even after accounting for mediators, chronotype retains a

Table 2	2 Bivariate cor	rrelations among	chronotype	sensation see	kina slee	on quality and	depression
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	Age	Sex	Educational Level	Only Child	rMEQ	SSS	PSQI	BDI- 13
Age	1.000							
Sex	- 0.241**	1.000						
Educational Level	0.773**	- 0.135*	1.000					
Only Child	0.231**	- 0.130	0.196**	1.000				
rMEQ	- 0.135*	- 0.040	- 0.100	0.000	1.000			
SSS	0.190**	- 0.024	0.243**	0.014	- 0.134*	1.000		
PSQI	- 0.062	0.115	- 0.039	- 0.014	- 0.303**	0.193**	1.000	
BDI-13	- 0.030	0.110	0.040	- 0.090	- 0.376**	0.446**	0.176**	1.000

Path Relatio	nship		Unstad.	Stad.	S.E.	C.R.	Р
rMEQ	<	SSS	- 0.376	- 0.227	0.122	- 3.09	**
SSS	<	PSQI	0.021	0.232	0.010	2.128	*
rMEQ	<	PSQI	- 0.050	- 0.326	0.012	- 4.126	***
PSQI	<	BDI	6.593	0.505	1.092	6.039	***
rMEQ	<	BDI	- 0.318	- 0.159	0.127	- 2.501	*
SSS	<	BDI	0.071	0.059	0.084	0.841	0.401

#### Table 4 Path effect analysis

\*\*\*\*p < 0.001, \*\*p < 0.01, \*p < 0.05

Table 5 Mediation effect analysis

Effect	Path Relationship	Estimate	Lower	Upper	Р
Total Effect	rMEQ→BDI	- 0.408	- 0.632	- 0.245	***
Direct Effect	rMEQ→BDI	- 0.318	- 0.602	- 0.049	*
Mediation Path 1	rMEQ→SSS→BDI	- 0.027	- 0.122	0.030	0.235
Mediation Path 2	rMEQ→PSQI→BDI	- 0.328	- 0.530	- 0.167	***
Chain Mediation 3	rMEQ→SSS→PSQI→BDI	- 0.053	- 0.163	- 0.005	**
Mediation Proportion 1		0.065	- 0.083	0.281	0.245
Mediation Proportion 2		0.805	0.480	0.965	**
Chain Mediation Proportion 3		0.130	0.014	0.415	*

\*\*\*p < 0.001, \*\*p < 0.01, \*p < 0.05

direct link to depressive symptoms. The indirect effects were decomposed into three distinct pathways:

effect size aligns with prior evidence that sensation seeking primarily influences externalizing behaviors (e.g.,

Path 1 (Chronotype  $\rightarrow$  Sensation Seeking  $\rightarrow$  Depression):  $\beta = -0.027$ , 95% CI (-0.122, 0.030), p = 0.235.

This pathway was nonsignificant, failing to support Hypothesis 1. The lack of mediation through sensation seeking may reflect its limited relevance to depressive symptoms in our sample or measurement limitations (e.g., sensation seeking scales capturing adaptive rather than maladaptive traits). risk-taking) rather than internalizing symptoms like depression. The analytical framework is illustrated in Fig. 2.

#### Discussion

This study investigates the relationship between chrono-

Path 2 (Chronotype  $\rightarrow$  Sleep Quality  $\rightarrow$  Depression) :  $\beta = -0.328, 95\% CI (-0.530, -0.167), p < 0.001$ , Proportion Mediated = 80.5%.

This dominant pathway supports Hypothesis 2, indicating that poorer sleep quality in E-type adolescents largely explains their elevated depressive symptoms. types and depression symptoms in adolescents, with a focus on the mediating roles of sensation seeking and sleep quality. The results indicate that E-type is signifi-

Path 3 (Chronotype  $\rightarrow$  Sensation Seeking  $\rightarrow$  Sleep Quality  $\rightarrow$  Depression) :  $\beta = -0.053$ , 95% *CI* (-0.163, -0.005), p < 0.01, Proportion Mediated = 13%.

Although small in magnitude, this significant chain mediation (Hypothesis 3 supported) suggests that sensation seeking may indirectly exacerbate depressive symptoms by further impairing sleep quality. The modest cantly associated with more severe depression symptoms (p < 0.05), with sleep quality playing a meaningful mediating role in this relationship. While sensation seeking alone did not show a mediating effect, a sequential



Fig. 2 The path coefficients of structural equation modeling. rMEQ, reduced Morningness–Eveningness Questionnaire. SSS, Sensation Seeking Scale. PSQI, Pittsburgh Sleep Quality Index. BDI, Beck Depression Inventory. These subscales of SSS are Thrill and Adventure Seeking (TAS) and Disinhibition (DIS). These subscales of PSQI are subjective sleep quality (Quality), sleep latency (Latency), sleep duration (Duration), habitual sleep efficiency (Efficiency), sleep disturbance (Disturbance), use of sleep medication (Medication), and daytime dysfunction (Dysfunction)

mediation pathway involving both sensation seeking and sleep quality emerged. This study found a higher proportion of E-type adolescents among those with depression. Specifically, 60.6% of the participants were classified as E-type, 33.8% as I-type, and only 5.6% as M-type. E-type was significantly associated with more severe depressive symptoms in adolescents, consistent with previous research [43, 44].

Several mechanisms may explain why E-type adolescents exhibit more severe depressive symptoms. First, circadian misalignment emerges as a central pathway. The conflict between adolescents'endogenous delayed sleep phase and early school schedules induces chronic social jetlag [18, 45]. Social jetlag-the misalignment between an individual's biological clock and social schedules-has been linked to increased mood disturbances with E-types [46, 47]. Tonon et al. identified circadian misalignment (like social jetlag) could mediate the association between chronotype and mental health [44]. Due to the misalignment between their delayed sleep patterns and societal demands-such as early school start times-E-types are more prone to circadian misalignment [16]. This misalignment may exacerbate sleep deprivation, impair emotional regulation, and increase susceptibility to depressive symptoms [15, 47]. And Carissimi et al. found that school time could influence the sleep deficit in children and adolescents, slight delays in school start times significantly reduced social jetlag in adolescents [48], implying that interventions targeting circadian alignment (e.g., adjusting school schedules) may disrupt the pathway from chronotype to depression. Future studies should examine the role of social jetlag in adolescent populations, as interventions aimed at reducing this misalignment (such as delaying school start times) could help mitigate the negative effects of E-type on mood [48]. Secondly, the behavior-environment interaction, the widespread use of electronic devices (e.g., cell phones, tablets, etc.) has also become a major obstacle to falling asleep, especially at night, when adolescents are often addicted to social media or video entertainment, further delaying sleep onset [49]. Blue light exposure from home lighting and electronic devices suppresses melatonin secretion, further exacerbating delayed sleep onset [44, 50, 51]. In addition, E-type adolescents may spend nights alone, lacking communication with family and friends, which could increase feelings of loneliness and the risk of depression [52]. Finally, certain characteristics identified in adult populations may also play a role in adolescents, influencing the relationship between chronotype and mood. For instance, emotional intelligence has been

shown to act as a protective factor against lowered mood in adults with E-types [53]. Emotional intelligence, which includes the ability to perceive, understand, and regulate emotions [54], may buffer the negative effects of evening chronotype on mood by enhancing adaptive coping strategies and reducing emotional distress [53]. Future research could explore whether emotional intelligence similarly moderates the relationship between E-type and depressive symptoms in adolescents, especially considering the emotional volatility characteristic of this developmental stage.

The correlation analysis revealed a significant relationship between sensation seeking, chronotype and depressive symptoms, which aligns with existing studies. Tonetti's research indicated that E-type individuals exhibit significantly higher levels of sensation seeking compared to other chronotypes [21]. Furthermore, sensation seeking behaviors are associated with various psychological health issues, particularly high-risk behaviors such as substance abuse and impulse control disorders [55]. However, in the mediation analysis, sensation seeking did not significantly mediate the relationship between chronotype and depressive symptoms, meaning Hypothesis 1 was not validated. This result may suggest that the effect of sensation seeking on depressive symptoms is indirect rather than direct, operating through other variables such as sleep quality. Seeking stimulation is defined as pursuing novelty or adventurous excitement to achieve thrill and exhilaration, representing an externalized behavior [56]. It may not directly result in a range of internalized symptoms, such as depression [57]; rather, it indirectly heightens the risk of these internalized symptoms by influencing adolescents'physiological and psychological states, including factors such as sleep quality [58]. For instance, individuals with high sensation seeking are more likely to delay sleep, leading to further misalignment of their circadian rhythms [59]. The consequences of this behavior ultimately affect sleep quality, which, by worsening sleep quality, exacerbates depressive symptoms [59]. Therefore, guiding and assisting depressed adolescents to fulfill their need for stimulation in appropriate ways is crucial. For instance, engaging depressed adolescents in organized vigorous physical activities, such as team sports (e.g., football, basketball), aerobic exercises (e.g., running, swimming), and extreme sports (e.g., rock climbing, skiing), has been shown to benefit adolescent both mental health and mental health [60, 61].

Sleep quality plays a significant mediating role between chronotype and depressive symptoms in adolescents, a finding that robustly supports Hypothesis 2 of this study. Research reveals that E-type adolescents consistently exhibit poorer sleep quality, which in turn markedly exacerbates the severity of depressive symptoms. This aligns with Horne's observations in healthy populations, where E-type was shown to influence depressive symptoms through partial mediation by sleep quality [62]. Furthermore, a recent study among young athletes has shown that sleep quality significantly mediates the relationship between chronotype and internalizing symptoms [63]. It is increasingly acknowledged that sufficient, high-quality sleep is crucial for mental health, as poor sleep quality is identified as a significant risk factor for the onset and persistence of mood disorders. E-type is more vulnerable to social interactions, social media use, and irregular sleep patterns, which negatively impact sleep quality, leading to a decline in sleep quality [59]. From a pathophysiological perspective, Sleep disturbances have been established as a critical risk modulator for mood disorders [44]. Clinical evidence from Tonon et al. underscores this mechanism, showing that adolescents with depression exhibit compromised sleep hygiene, particularly through erratic bedtimes and pre-sleep cognitive arousal. These findings underscore the preventive potential of targeted sleep interventions for E-type adolescents. For example, establishing a consistent sleep schedule can help stabilize their biological clocks and promote better sleep [64, 65]. Furthermore, creating a quiet, comfortable sleep environment and avoiding electronic devices before bedtime can prevent sleep disturbances [66]. Encouraging outdoor activities and daytime exercise can also improve nighttime sleep quality [67]. Additionally, practices like meditation or a warm bath before bed can help relax the body and mind, enhancing sleep quality [68].

Although sensation seeking did not independently serve as a mediator, the chain mediation analysis demonstrated that chronotype indirectly affects the severity of adolescent depression, validating Hypothesis 3. Sensation seekers typically have higher neural activation and sensitivity, making them more likely to stay up late or engage in sleep-depriving activities, thus leading to circadian rhythm disruptions (e.g., circadian misalignment). E-type adolescents, characterized by higher sensation-seeking tendencies, are more likely to participate in late-night social and entertainment activities. These activities frequently result in sleep deprivation, a condition strongly linked to increased depression [18]. Additionally, Killgore's research suggests that individuals who sleep late are typically sensation-seekers, which correlates with their propensity for engaging in risky behaviors, leading to poorer sleep quality and, consequently, exacerbating depression [69]. According to the dual systems theory of adolescent risk-taking, high levels of sensation seeking, combined with the still-developing cognitive control system in E-type adolescents, can lead to greater emotional dysregulation [70]. This emotional instability may further

disrupt sleep quality, exacerbating depressive symptoms. Our research findings suggest that sensation seeking should be understood from a more dynamic perspective. It is not only a stable personality trait but also influences an individual's life rhythms and mental health through behavioral choices and interactions with the environment. This implies that sensation seeking may serve as a long-term risk factor, whose effects need to be considered in conjunction with other variables, such as sleep quality. Furthermore, individuals with high sensation seeking tendencies may be more prone to developing unhealthy sleep patterns, necessitating interventions that focus on behavioral regulation. For example, sleep hygiene education or behavioral management targeted at high sensation seekers can effectively prevent the deterioration of sleep quality and reduce the risk of depression [58].

The findings of this chain mediation model highlight the importance of addressing not only the direct impact of chronotype on the development of interventions for adolescent depressive symptoms but also the combined effects of mediating factors. The study conclusively demonstrates the complex interplay between chronotype, sensation seeking, and sleep quality in influencing adolescent depression. Intervention strategies should include guiding and assisting adolescents with depression in fulfilling their need for stimulation and improving sleep quality to effectively mitigate the association of chronotype with depressive symptoms. By addressing these interconnected factors, it may be possible to break the negative feedback loop, improve sleep quality, and enhance mental health. The results of this study provide preliminary insights that could inform future research on targeted interventions for adolescent depression. However, given the limitations of this study, including its cross-sectional design and small sample size, these findings should be interpreted as exploratory rather than definitive. Future research should aim to replicate these findings in larger, more diverse samples and explore the potential mechanisms underlying these associations.

The study has several limitations. First, its cross-sectional design limits the ability to establish the directionality of the relationships among chronotype, sensation seeking, sleep quality, and adolescent depression. Future research should employ longitudinal cohort studies to better establish causal links among these variables. Second, the reliance on self-report scales to assess chronotype and sleep quality introduces potential recall bias and subjective perceptions, which could distort the findings. Future studies should incorporate objective measures, such as actigraphy or polysomnography, for a more accurate assessment of sleep patterns. Third, excluding samples with missing values may introduce estimation bias and affect the generalizability of the results. Additionally, while depression was diagnosed by licensed psychiatrists using DSM- 5 criteria, structured clinical interviews were not employed, potentially compromising diagnostic precision. Although clinicianadministered scales were used to assess symptom severity and exclude bipolar disorder, a comprehensive evaluation of other comorbid mood disorders (e.g., generalized anxiety disorder, panic disorder) was not conducted, which limits the generalizability to adolescents with complex psychiatric comorbidities. Lastly, clinical characteristics, including medication use, duration of depressive episodes, and prior episode history, were not systematically collected, which should be addressed in future studies to provide a fuller context for interpreting the findings.

#### Conclusions

This study suggests that chronotype plays a significant role in adolescent depression, with E-type adolescents showing a higher risk for depressive symptoms. The findings highlight the potential importance of sleep quality as a mediating factor, indicating that sleep interventions could be a promising avenue for further exploration in alleviating depressive symptoms in adolescents. While sensation seeking did not emerge as a direct mediator in this relationship, it may still contribute to the behavioral patterns that affect depression, particularly in E-type adolescents. However, given the exploratory nature of this study and its limitations (e.g., small sample size, cross-sectional design), future research should explore other potential mediating factors, such as environmental and cultural influences, to develop a more comprehensive understanding of the complex interactions between chronotype, behavior, and mental health. Additionally, longitudinal studies with larger and more diverse samples are needed to confirm these findings and explore their generalizability. Early interventions focusing on improving sleep quality and regulating chronotype could be further investigated as potential strategies to reduce the risk of depression in adolescents, but their effectiveness should be validated through rigorous experimental designs.

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#### Authors' contributions

Fangyi Wang: Formal Analysis, Methodology, Visualization, Writing – original draft, Writing – review and editing. Ying Zhou: Formal Analysis, Methodology, Visualization, Writing – original draft, Writing – review and editing. Xiao Hou: Investigation, Writing – review and editing. Shifen Ni: Investigation, Writing – review and editing. Tanwei Zhang: Investigation, Writing – review and editing. Yunyan Zhang: Investigation, Writing – review and editing. Xiao Hou: Investigation, Writing – review and editing. Yunyan Zhang: Investigation, Writing – review and editing. Xiangyu Li: Data curation, Writing – review and editing. Keyi Wen: Resources, Writing – review and editing. Yutong Wang: Resources, Writing – review and editing. Yutong Wang: Resources, Writing – review and editing. Yutong Wang: review and editing. Yutong Wang: Resources, Writing – review and editing. Yutong Wang: Resources, Supervision, Writing – review and editing. Yixiao Fu: Conceptualization, Funding acquisition,

Project administration, Resources, Supervision, Writing – review and editing. All authors read and approved the final manuscript.

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#### Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

#### Declarations

#### Ethics approval and consent to participate

The research was conducted according to the Good Clinical Practice, National Medical Products Administration and the Declaration of Helsinki. The study procedures were reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University (2024 - 083 - 01).

#### **Consent for publication**

Not applicable.

#### **Competing interests**

The authors declare no competing interests.

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