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ORIGINAL RESEARCH

Association Between Daytime Sleepiness and Quality of Life in Chinese Adolescents: A Moderated Mediation of Cognitive Dysfunction and Depressive Symptoms

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Background: Daytime sleepiness is prevalent among Chinese adolescents and has been associated with increased depressive symptoms, impaired cognitive function, and reduced quality of life. However, the interrelationships among these variables remain unclear, particularly regarding whether cognitive function moderates the association between daytime sleepiness and quality of life.

Methods: A large-scale cross-sectional survey was conducted among 52,964 students (grades 7–12) across five geographically diverse regions of China. Data were collected on daytime sleepiness, depressive symptoms, cognitive dysfunction, and quality of life using standardized self-report measures.

Results: 1) Among the Chinese adolescents, excessive daytime sleepiness (13.87%) and poor quality of life were prevalent. 2) Quality of life was negatively correlated with daytime sleepiness ($r = -0.277$), depressive symptoms ($r = -0.416$), and cognitive dysfunction ($r = -0.217$), all p-values < 0.001. 3) Depressive symptoms played a partially mediating role in the association between daytime sleepiness and quality of life (effect size = −0.232), accounting for 82.86% of the total effect. 4) In the moderated mediation model of daytime sleepiness → depressive symptoms → quality of life, cognitive dysfunction plays a moderating role. Specifically, cognitive dysfunction significantly moderated the association between daytime sleepiness and depressive symptoms (a = 0.100, $SE = 0.003$, $t = 34.618$), the association between depressive symptoms and quality of life (b = −0.014, $SE = 0.005$, $t = -2.929$), and the direct effect of daytime sleepiness on quality of life (c' = −0.048, $SE = 0.005$, $t = -9.996$), all p-values < 0.001.

Conclusion: Depressive symptoms partially mediate the relationship between daytime sleepiness and quality of life, while cognitive dysfunction plays a moderating role in both direct and indirect effects. Improving depressive symptoms and cognitive dysfunction may be potential strategies to mitigate the adverse effects of daytime sleepiness on adolescents' quality of life.

Keywords: daytime sleepiness, quality of life, cognitive dysfunction, depressive symptoms, adolescents

Introduction

Excessive daytime sleepiness (EDS) is a prevalent symptom among children and adolescents, characterized by an increased propensity to fall asleep during daytime hours.[1] Its consequences have been shown to affect the health, development, mood and cognitive function of children and adolescents,[2] which would further contribute to the reduced academic performance and poor quality of life (QoL).[1] However, the recommended sleep duration of 9–10 hours per night for school-aged children,

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particularly adolescents, is often not met in practice.[3,4] This insufficient sleep and eveningness chronotype have the direct impact on daytime activity and may lead to EDS in children and adolescents.[5,6] In recent years, growing evidence has indicated that reduced sleep duration may significantly impact cognitive function. For example, a study using accelerometer-measured sleep duration found that shorter sleep time was associated with decreased executive function in the Stroop task and revealed related neural activity changes through functional near-infrared spectroscopy (fNIRS).[7] Furthermore, another study integrating population-based research and mouse experiments further explored the potential mechanisms between insufficient sleep and cognitive impairment, emphasizing the crucial role of inflammatory biomarkers and cellular signaling pathways.[8] These findings suggest that insufficient sleep may affect individual cognitive ability through neurophysiological and immune-inflammatory mechanisms, further deepening our understanding of the relationship between sleep and brain health. Given the significant negative impact of EDS on mood, cognitive function and QoL,[1] to clarify the psychological pathways through which daytime sleepiness causes poor QoL and manage modifiable risk factors would be valuable in improving the well-being of the adolescents.

Depression is among the most prevalent psychiatric disorders in adolescents globally and has been consistently linked to excessive daytime sleepiness (EDS).[9,10] In China, a recent nationwide epidemiological survey reported a point prevalence of depression of 2.004% among children and adolescents.[11] Individuals exhibiting depressive symptoms are more likely to experience EDS.[12] Among patients with major depressive disorder, the prevalence of EDS can reach as high as 50.8%.[13] Importantly, EDS has also been identified as a contributing risk factor for the development of depression.[10,14] Conversely, baseline levels of daytime sleepiness have been shown to predict the subsequent onset of depressive symptoms.[15–17] One study revealed a strong association between daytime sleepiness and depressive symptoms among rural Chinese adolescents.[15] Collectively, these studies suggest a potentially complex and bidirectional relationship between EDS and depressive symptoms. Notably, depression is associated not only with EDS but also with impaired QoL. Both evidences from epidemiological and clinical studies found the significant association between severity of depression and poor QoL,[18] and depression could significantly predict QoL outcomes.[19–21] Recent studies have demonstrated this association across diverse populations.[22–24] Therefore, given the strong associations between EDS and depression, and between depression and QoL, it is plausible that depression serves as a key psychological pathway linking EDS to QoL.

A growing body of evidence has established a robust association between EDS and cognitive dysfunction.[25–28] Even one week of partial sleep deprivation in adolescents has been shown to impair various domains of cognitive function.[29] Studies in older populations have consistently demonstrated that EDS is closely associated with cognitive decline and increased risk of dementia.[30,31] Meanwhile, numerous studies have also revealed a significant relationship between depressive symptoms and cognitive dysfunction.[32–34] Mehta et al found that individuals with depression are at a significantly higher risk of cognitive impairment.[35] Another study reported that depression-related cognitive impairments may persist over extended periods.[36] A meta-analysis showed that the effect size of cognitive dysfunction in patients with depression, compared to healthy controls, ranged from −0.34 to −0.65.[37] MacKenzie et al provided compelling evidence of cognitive impairment in first-degree relatives of individuals with depression, suggesting a potential shared genetic vulnerability for both conditions.[38] These findings collectively suggest that EDS is related to cognitive dysfunction, which, in turn, is strongly associated with depressive symptoms.

In addition to the established framework involving EDS, cognitive dysfunction, and depression, previous studies have also highlighted the interrelationship among depression, cognitive impairment, and QoL in older adults.[39] Cognitive dysfunction has been used as a mediating variable to explore the link between emotional states and QoL, and has been shown to mediate the association between depressive symptoms and QoL.[40] Moreover, Poletti et al demonstrated that cognitive dysfunction may interact with depressive symptoms in influencing QoL during the COVID-19 pandemic.[41] From an intervention perspective, cognitive behavioral therapy (CBT) has been shown to significantly alleviate depressive symptoms and enhance QoL in individuals experiencing diabetes-related distress.[42] According to existing evidence, including a systematic review by Gil-Gonzalez et al,[43] depressive symptoms and cognitive dysfunction have consistently been identified as significant risk factors for reduced QoL. However, the precise interplay among these variables remains poorly understood. Therefore, further investigation is warranted to clarify the interrelationships among depressive symptoms, cognitive dysfunction, and QoL in adolescents.

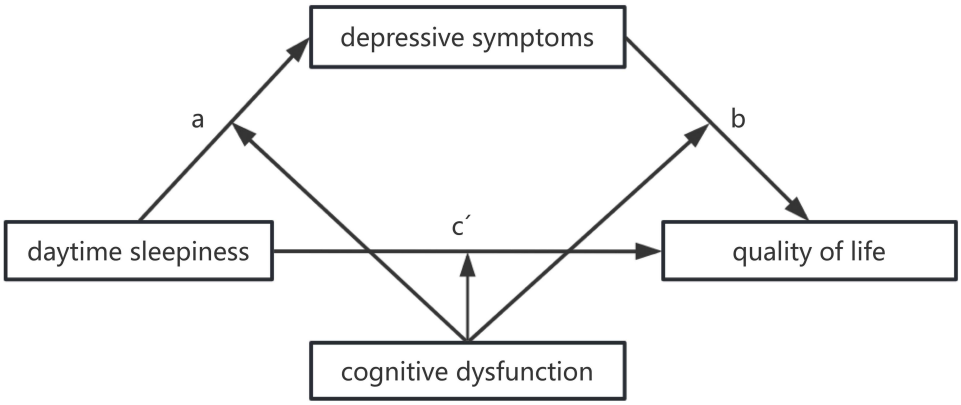

Figure 1 Hypothesized schematic model of cognitive deficits as the moderator of the mediation model of depressive symptoms between daytime sleepiness and quality of life Notes: a: daytime sleepiness → depressive symptoms path; b: depressive symptoms → quality of life path; c': daytime sleepiness → quality of life path.

Despite growing evidence linking daytime sleepiness to depressive symptoms, cognitive dysfunction, and QoL,[44] no studies to date have examined whether depressive symptoms mediate the association between daytime sleepiness and QoL, or whether cognitive dysfunction moderates the relationships between daytime sleepiness and depressive symptoms, and between depressive symptoms and QoL, particularly in Chinese adolescents. Therefore, this study first aimed to examine whether depressive symptoms mediate the relationship between daytime sleepiness and QoL in adolescents. In addition, it aimed to explore the moderating role of cognitive dysfunction in both the direct and indirect pathways linking daytime sleepiness and QoL via depressive symptoms (Figure 1). Based on a review of the literature and in light of the complex interrelations among these variables, we proposed two hypotheses: Hypothesis 1: Depressive symptoms mediate the relationship between daytime sleepiness and QoL. Hypothesis 2: Cognitive dysfunction moderates both the direct and indirect effects of daytime sleepiness on QoL, with depressive symptoms as a mediator.

Methods

Participants

This cross-sectional epidemiological study, conducted in China in January 2023, evaluated a sample of students selected from five independent regions, stratified by urbanization level and geographic location. All students enrolled in grades 7 through 12 in the five selected regions - Shandong Province, Inner Mongolia Autonomous Region, Hebei Province, Guangxi Zhuang Autonomous Region, and Xinjiang Uygur Autonomous Region - were eligible for inclusion. The sampling strategy was designed to ensure representativeness of the adolescent population in China. Inner Mongolia and Hebei were selected to represent northern China. Shandong, Xinjiang, and Guangxi were selected to represent eastern, western, and southern China, respectively. Inclusion criteria for participation were: (1) Chinese nationality; (2) aged between 12 and 18 years; and (3) provision of informed consent via an online platform. The study was approved by the Ethics Committee of Beijing Huilongguan Hospital. Informed consent was obtained from both the participants and their parents after they were fully informed about the purpose, procedures, and confidentiality of the study.

A total of 56696 questionnaires were collected for this study through the Wenjuanxing online platform (www.wjx.com). After excluding questionnaires that were not between the ages of 12–18, had missing answers, had the same answers for all items, or had a completion time of less than 270 seconds, we obtained a total of 50072 valid questionnaires with an effective response rate of 88.32%.

Measurement and Instruments

The Chinese Adolescent Daytime Sleepiness Scale (CADSS)

The Chinese Adolescent Daytime Sleepiness Scale (CADSS) was used to evaluate daytime sleepiness.[45] While the Pediatric Daytime Sleepiness Scale (PDSS) remains the cornerstone of daytime sleepiness research,[46] our choice of the CADSS was in line with the target population of this research, Chinese adolescents, a population with distinct cultural

and environmental factors influencing sleep patterns. The CADSS was selected due to its cultural adaptation and validation for this demographic. The CADSS consists of seven questions that ask adolescents about their shared feelings of sleepiness and dozing in different situations during the day over the past month. All the seven items are rated on a 5-point scale from 1 = never, 2 = rarely (<1 times week), 3 = sometimes (1–2 times/week), 4 = often (3–5 times/week), to 5 = almost every day (6–7 times/week). The total score of these seven items equals the total CADSS score, which ranges from 7 to 35 points. The Cronbach's alpha value of the CADSS was 0.89 and the test-retest reliability coefficient was 0.77. The higher the CADSS score, the greater the tendency to experience daytime sleepiness in the past month. A total score of 23 has been proposed as a cutoff value for identifying individuals with (or moderate or severe daytime sleepiness) over the past month.[45,47]

The Patient Health Questionnaire-9 (PHQ-9)

The scale was developed according to the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders.[48] It is used to screen for depression in primary care and other medical Settings.[49] We used the Chinese version of this scale. The scale consists of 9 items, each with a 0–3 scale. The severity of symptoms is determined by a total score of 5 to 9 mild, 10 to 14 moderate, 15 to 19 moderate and 20 to 27 severe. The Cronbach's alpha value of PHQ-9 in the Chinese population was 0.86, and the retest reliability was 0.86, indicating that this scale has good reliability and validity.[50]

Screening for and Promotion of Health-Related QoL in Children and Adolescents-10 Items (KIDSCREEN-10)

The KIDSCREEN-10 was designed to be a cross-national tool for measuring Health-Related Quality of Life. This instrument was developed by Ravens-Sieberer et al in Germany.[51] It is employed for the assessment of health-related QoL in children and adolescents between the ages of 8 and 18 years. And the Cronbach's Alpha value of KIDSCREEN-10 in the Chinese population was 0.847, and the retest reliability was 0.842, indicating that the Chinese version of KIDSCREEN-10 has good reliability, and validity.[52] All the seven items are rated on a 5-point scale from 1 = never, 2 = almost never, 3 = sometimes, 4 = almost always, to 5 = always. The total score of all the 10 items in Chinese version of KIDSCREEN-10 was calculated to assess the health-related QoL. A lower total score indicates a lower level of health-related QoL.

Perceived Deficits Questionnaire for Depression-5-Items (PDQ-5-D)

The Perceived Deficits Questionnaire for Depression-5-items scale (PDQ-5-D) was used to record the severity of self-reported cognitive dysfunction in the past 7 days.[53] It consists of 5 questions and 4 subscales: Attention/concentration, prospective memory, planning/organization, and retrospective memory. The frequency of these symptoms was rated using a scale from 0 to 4 (0 = "not at all" to 4 = "very often, more than once a day"). The scale has a total score of 0–20, with higher scores indicating greater cognitive dysfunction. We used the Chinese version of PDQ-5-D. The Cronbach's alpha value of Chinese version PDQ-5-D was 0.704,[54] which was acceptable.[55] And the test-retest reliability of Chinese version PDQ-5-D was good (intraclass correlation coefficient = 0.841).[54]

Covariates

The adolescents were asked to provide self-reported data on their age, place of residence (1 = urban/town, 2 = rural), gender (1 = male, 2 = female), grade (Grades 7–12), primary caregivers. Primary caregivers were categorized as parents, grandparents (father's side), grandparents (mother's side), and others.

Statistical Analyses

Continuous variables are expressed as mean and standard deviation and categorical variables are reported as frequency (percentage). Significance testing was conducted using either a *t*-test or analysis of variance (ANOVA). Pearson correlation analysis was performed to examine associations between daytime sleepiness, depressive symptoms, quality of life, and cognitive dysfunction. Mediation analysis was conducted using the PROCESS macro in SPSS.[56] Hayes PROCESS estimates model coefficients and produces bias-corrected bootstrap confidence intervals for conditional indirect effects and tests of moderated or conditional mediation. The proportion mediated was calculated as the ratio of the indirect effect to the total effect, and statistical significance was determined using bootstrapped 95% confidence

intervals. This robust method, widely applied in previous epidemiological studies, avoids assumptions of normality and provides reliable estimates of mediation effects.[57,58] In our study, we used Model 4 (simple mediated model) and Model 59 (direct and indirect pathways mediated by one variable). First, we used model 4 to examine whether the association between daytime sleepiness and quality of life was mediated by depressive symptoms. Second, Model 59 was used to examine whether cognitive dysfunction moderated the direct (path c': daytime sleepiness-quality of life) and indirect (path a: daytime sleepiness -depressive symptoms and path b: depressive symptoms-quality of life) effects of daytime sleepiness on quality of life. At the same time, demographic variables (gender, age, grade, place of residence, primary caregivers) were controlled for mediating and moderating effects. Simple slopes are then plotted to explore the significant interactions associated with low/high levels of cognitive dysfunction. Based on 5000 random samples, the bootstrap confidence interval (CI) determines whether the effect in model 4 and Model 59 is significant. In this study, all the data was standardized. All of the tests were two-tailed, and the significance level was set at $p < 0.05$. All of the analyses were performed using SPSS for Windows 24.0.

Results

Characteristics of the Participants

The mean age of 50,072 participants included in the analysis was 15.69 ± 1.57 years, as presented in Table 1, approximately 46.9% (n = 23497) were males and 53.1% (n = 26575) were females. The majority of participants resided in urban or town areas (61.1%) and lived with their parents (92.1%). The EDS, depressive symptoms, quality of life, and cognitive dysfunction of the participants were significantly different among gender, grade, place of residence, and primary caregivers (Table 2).

Among the participants, the prevalence of EDS was 13.87%. For females, the prevalence rate of EDS was 8.50%, which was higher than that for males at 5.38%. The difference in EDS between males and females was statistically significant ($\chi^2 = 215.728$, $p < 0.001$). Chi-square tests also revealed that the prevalence of EDS in high school (Grade 10–12) and middle school (Grade 7–9) was 9.43% and 4.45%, respectively. The significantly higher prevalence of EDS in high school students ($\chi^2 = 1549.233$, $p < 0.001$) suggests an increased burden compared to middle school students. We

Table 1 Characteristics of Study Participants and Stratified by Daytime Sleepiness (N = 50,072)

Variables	Total		Non-EDS Adolescents (43125)		EDS Adolescents (6947)	
	n / M	% / SD	*n* / M	% / SD	*n* / M	% / SD
Gender						
Male	23497	46.9	20,804	48.2	2693	38.8
Female	26575	53.1	22,321	51.8	4254	61.2
Age (y)	15.69	1.57	15.59	1.58	16.32	1.36
Education (y)						
Grade 7	10,343	20.7	9835	22.8	508	7.3
Grade 8	8840	17.7	8070	18.7	770	11.1
Grade 9	6543	13.1	5594	13.0	949	13.7
Grade 10	11,664	23.3	9431	21.9	2233	32.1
Grade 11	9884	19.7	8040	18.6	1844	26.5
Grade 12	2798	5.6	2155	5.0	643	9.3
Place of residence						
Urban/Town	30587	61.1	26,362	61.1	4225	60.8
Rural	19485	38.9	16,763	38.9	2722	39.2
Primary caregivers						
Parent	46128	92.1	39,847	92.4	6281	90.4
Grandparents (father's side)	2433	4.9	2060	4.8	373	5.4
Grandparents (mother's side)	627	1.3	510	1.2	117	1.7
Other	884	1.8	708	1.6	176	2.5

Abbreviation: EDS, excessive daytime sleepiness.

Table 2 Scores on Various Scales of Study Participants (N = 50,072)

Variables		N	Cognitive Dysfunctions M±SD	*t*/*F*	*p*	Daytime Sleepiness M±SD	*t*/*F*	*p*	Depressive Symptoms M±SD	*t*/*F*	*p*	Quality of Life M±SD	*t*/*F*	*p*
Gender	Male	23497	6.31±4.72	−30.555	0.000	13.95±6.83	−30.756	0.000	4.55±5.56	−32.754	0.000	35.26±9.02	6.012	0.000
	Female	26575	7.57±4.47			15.83±6.81			6.27±6.10			34.80±8.07		
Place of residence	Urban/ Town	30587	6.78±4.61	−12.349	0.000	14.81±6.93	−5.397	0.000	5.42±5.91	−1.992	0.000	35.53±8.57	17.194	0.000
	Rural	19485	7.30±4.64			15.15±6.81			5.53±5.92			34.19±8.41		
Grade	Grade 7	10,343	5.75±4.38	291.018	0.000	11.96±5.38	872.622	0.000	3.76±4.85	332.395	0.000	35.99±8.96	55.146	0.000
	Grade 8	8840	6.43±4.64			13.35±6.14			4.69±5.62			35.48±8.84		
	Grade 9	6543	7.13±4.73			15.32±6.87			5.81±6.09			34.28±8.39		
	Grade 10	11,664	7.76±4.57			16.64±7.14			6.28±6.20			34.81±8.19		
	Grade 11	9884	7.66±4.54			16.61±7.06			6.37±6.12			34.51±8.22		
	Grade 12	2798	7.22±4.68			17.15±7.43			6.72±6.35			34.28±8.36		
Primary caregivers	Parent	46128	6.93±4.61	23.004	0.000	14.89±6.85	17.184	0.000	5.39±5.85	36.727	0.000	35.15±8.51	54.761	0.000
	Grandparents (father's side)	2433	7.47±4.85			15.20±7.12			5.93±6.31			33.73±8.62		
	Grandparents (mother's side)	627	7.37±4.97			15.53±7.57			6.29±6.54			34.01±8.73		
	Other	884	7.86±4.96			16.43±7.48			7.20±7.17			32.31±8.68		

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also found that the prevalence of EDS in urban area and rural area was 8.44% and 5.44%, respectively. The majority of adolescents with EDS lived with their parents (12.54%), while 1.33% lived with grandparents or others ($\chi^2 = 45.852$, $p < 0.001$). The score of KIDSCREEN-10 in Chinese adolescents was 35.01 ± 8.53, which is lower than the optimal cut points (from 40.26 to 41.93 for adolescents) suggested by the study of Hirschfeld et al.[59] These results suggested that excessive daytime sleepiness and the poor quality of life are prevalent among adolescents.

Correlation Between Daytime Sleepiness, Depressive Symptoms, Quality of Life and Cognitive Dysfunction

Correlation analysis showed that daytime sleepiness was significantly positively correlated with depressive symptoms ($r = 0.601$, $p < 0.001$) and cognitive dysfunction ($r = 0.539$, $p < 0.001$), and significantly negatively correlated with QoL ($r = -0.277$, $p < 0.001$). Depressive symptoms were positively correlated with cognitive dysfunction ($r = 0.569$, $p < 0.001$) and negatively correlated with QoL ($r = -0.416$, $p < 0.001$). There was a significant negative correlation between and cognitive dysfunction and QoL ($r = -0.217$, $p < 0.001$) (Table 3). These results support further analysis of mediation effects.

Mediating Effects of Depressive Symptoms in the Association Between Daytime Sleepiness and Quality of Life

As shown in Table 4, the total effect ($c = -0.280$, $SE = 0.005$, $t = -62.382$, $p < 0.001$) of daytime sleepiness on quality of life was found to be statistically significant. Additionally, daytime sleepiness significantly positively predicted depressive symptoms ($a = 0.589$, $SE = 0.004$, $t = 157.806$, $p < 0.001$). Daytime sleepiness and depressive symptoms entered simultaneously into the regression equation, with daytime sleepiness significantly negatively predicting quality of life ($c' = -0.048$, $SE = 0.005$, $t = -9.232$, $p < 0.001$), and depressive symptoms negatively predicting quality of life ($b = -0.394$, $SE = 0.005$, $t = -77.601$, $p < 0.001$). Finally, to test the mediation model, the researchers employed the bias-corrected percentile bootstrap method. The present study generated 5,000 bootstrapping samples from the standardized data to estimate the indirect effects. The research findings indicate a significant mediating effect of depressive symptoms on the relationship between daytime sleepiness and quality of life ($ab = -0.232$, $SE = 0.003$, 95% CI: −0.239, −0.225). The

Table 3 Correlations for the Main Variables

Variables	M	SD	1	2	3	4	5
1 Age	15.69	1.57	1				
2 Cognitive dysfunctions	6.98	4.63	0.146***	1			
3 Daytime sleepiness	14.94	6.88	0.262***	0.539***	1		
4 Depressive symptoms	5.46	5.92	0.162***	0.569***	0.601***	1	
5 Quality of life	35.01	8.53	−0.080***	−0.217***	−0.277***	−0.416***	1

Note: ***$p < 0.001$.

Table 4 The Mediating Role of Depressive Symptoms in the Relationship Between Daytime Sleepiness and Quality of Life

Variable	Path	β	SE	LLCI	ULCI
Total effect	Daytime sleepiness→Quality of life	−0.280	0.005	−0.288	−0.271
Direct effect	Daytime sleepiness→Depressive symptoms	0.589	0.004	0.582	0.596
	Depressive symptoms→Quality of life	−0.394	0.005	−0.403	−0.384
	Daytime sleepiness→Quality of life	−0.048	0.005	−0.058	−0.038
Indirect effect	Daytime sleepiness→Depressive symptoms→Quality of life	−0.232	0.003	−0.239	−0.225

Abbreviations: β, standardized coefficients; SE, the standard error of indirect effects estimated; LLCI, lower limit confidence interval; ULCI, upper limit confidence interval.

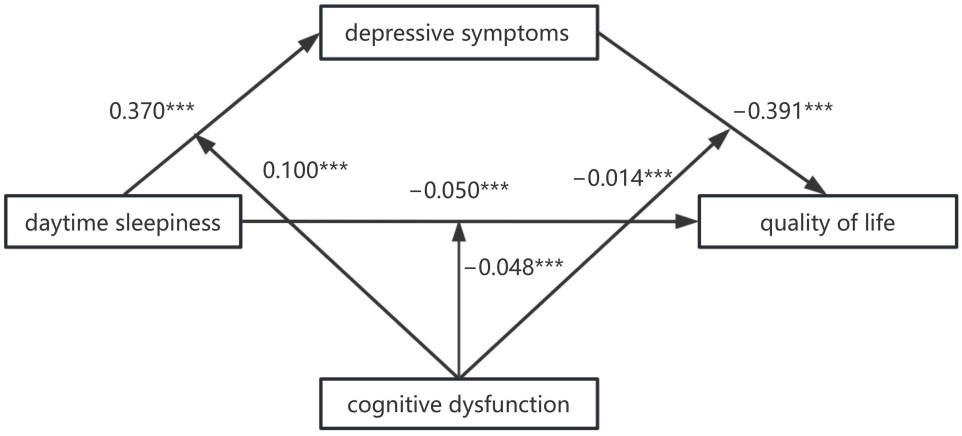

Figure 2 The moderated mediation model: cognitive deficits as moderators of the mediation model of depressive symptoms between daytime sleepiness and quality of life. (***$p < 0.001$).

mediating effect accounts for 82.86% of the total effect, while the direct effect size is −0.048, accounting for 17.14% of the total effect.

Moderation Effect of Cognitive Dysfunction on the Relationship Between Daytime Sleepiness and Quality of Life as Mediated by Depressive Symptoms

Using Model 59, moderated mediation model tests showed that the interaction between daytime sleepiness and cognitive dysfunction was a significant positive predictor of depressive symptoms through path a (daytime sleepiness * cognitive dysfunction: $\beta = 0.100$, $SE = 0.003$, $t = 34.618$, $p < 0.001$). The interaction between depressive symptoms and cognitive dysfunction through path b was a significant negative predictor of quality of life (depressive symptoms * cognitive dysfunction: $\beta = -0.014$, $SE = 0.005$, $t = -2.929$, $p < 0.001$), and the interaction between daytime sleepiness and cognitive dysfunction through path c' was also a significant negative predictor of quality of life (daytime sleepiness * cognitive dysfunction: $\beta = -0.048$, $SE = 0.005$, $t = -9.996$, $p < 0.001$). As shown in Figure 2 and Table 5, cognitive dysfunction modulates the effects of day time sleepiness on quality of life through pathways a, b, and c'.

In addition, for path a, when cognitive dysfunction was low (M−1SD), daytime sleepiness positively predicted depressive symptoms ($\beta = 0.270$, $SE = 0.006$, $t = 47.737$, $p < 0.001$); when cognitive dysfunction was high (M+1SD), daytime sleepiness also positively predicted depressive symptoms ($\beta = 0.470$, $SE = 0.004$, $t = 106.881$, $p < 0.001$). As cognitive dysfunction worsens, the predictive effect of daytime sleepiness on depressive symptoms showed a gradual increasing trend ($\beta = 0.100$, $SE = 0.003$, $t = 34.618$, $p < 0.001$) (Figure 3A).

For path b, when cognitive dysfunction was low (M−1SD), depressive symptoms negatively predicted quality of life ($\beta = -0.377$, $SE = 0.009$, $t = -40.980$, $p < 0.001$); when cognitive dysfunction was high (M+1SD), depressive symptoms negatively predicted quality of life ($\beta = -0.405$, $SE = 0.006$, $t = -69.625$, $p < 0.001$). As cognitive dysfunction worsens,

Table 5 The Moderated Mediating Effect of Daytime Sleepiness on Quality of Life by Depression Symptoms and Cognitive Dysfunctions

	Depressive Symptoms						Quality of Life					
	β	SE	t	p	LLCI	ULCI	β	SE	t	p	LLCI	ULCI
Daytime sleepiness	0.370	0.004	88.980	<0.001	0.362	0.378	−0.050	0.006	−8.943	<0.001	−0.061	−0.039
Depressive symptoms							−0.391	0.006	−63.807	<0.001	−0.403	−0.379
Cognitive dysfunction	0.343	0.004	87.693	<0.001	0.335	0.351	0.044	0.005	8.534	<0.001	0.034	0.054
Daytime sleepiness*Cognitive dysfunction	0.100	0.003	34.618	<0.001	0.095	0.106	−0.048	0.005	−9.996	<0.001	−0.057	−0.038
Depressive symptoms*Cognitive dysfunction							−0.014	0.005	−2.929	<0.001	−0.023	−0.005

Abbreviations: β, standardized coefficients; SE, the standard error of indirect effects estimated; LLCI, lower limit confidence interval; ULCI, upper limit confidence interval.

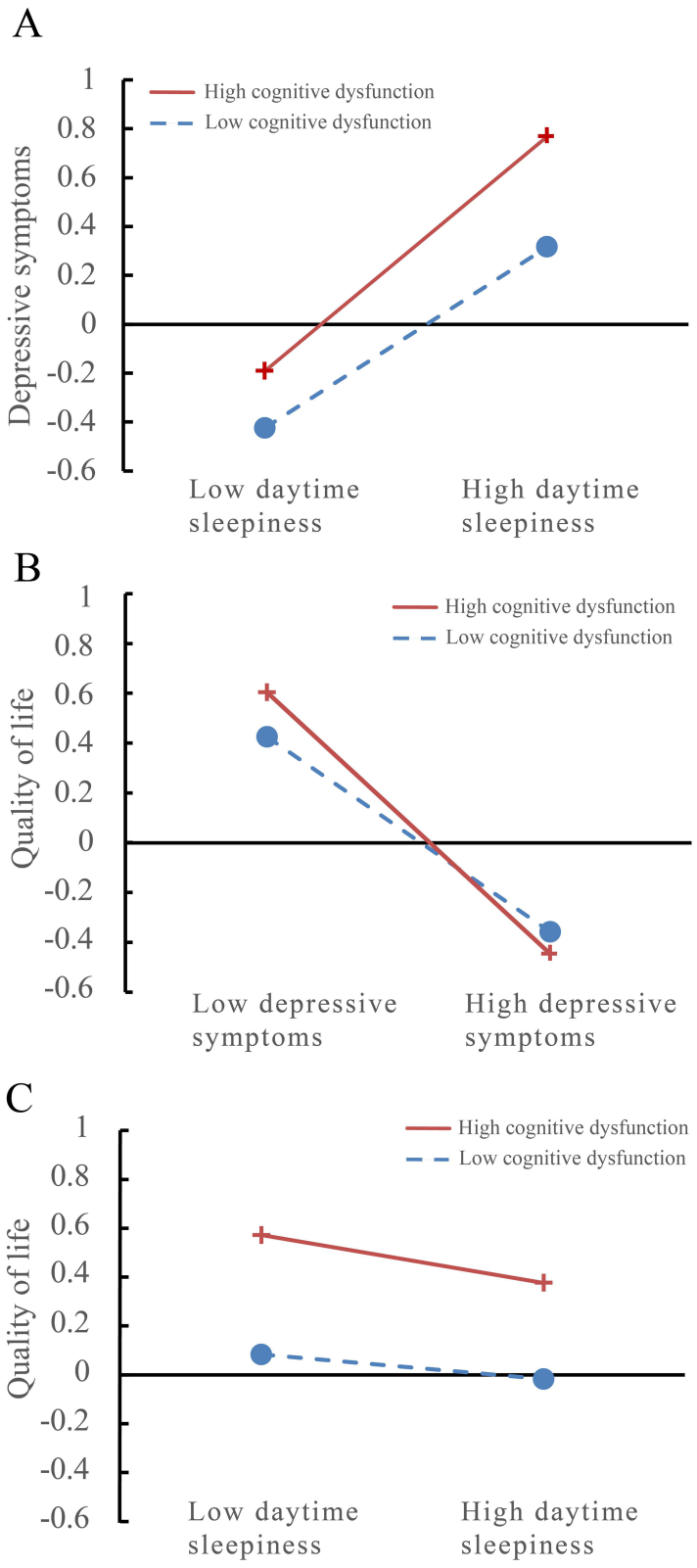

Figure 3 The simple plot of path (**A**–**C**) indicating the relationship between daytime sleepiness, depressive symptoms and quality of life among different levels of cognitive dysfunction.

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the predictive effect of depressive symptoms on quality of life showed a gradual increasing trend ($\beta = -0.014$, $SE = 0.005$, $t = -2.929$, $p < 0.001$) (Figure 3B).

For path c, when cognitive dysfunction was low (M−1SD), the relationship between daytime sleepiness and quality of life was not statistically significant ($\beta = -0.002$, $SE = 0.008$, $t = -0.295$, $p = 0.768$); when cognitive dysfunction was high (M+1SD), daytime sleepiness negatively predicted quality of life ($\beta = -0.098$, $SE = 0.006$, $t = -15.521$, $p < 0.001$). As cognitive dysfunction worsens, the predictive effect of daytime sleepiness on quality of life showed a gradual increasing trend ($\beta = -0.048$, $SE = 0.005$, $t = -9.996$, $p < 0.001$) (Figure 3C).

Discussion

In this cross-sectional epidemiological study of Chinese adolescents, the prevalence of EDS was approximately 13.87%, and poor quality of life was also widespread in this population. Our findings suggest that depressive symptoms play a crucial mediating role in the relationship between daytime sleepiness and QoL in adolescents. Additionally, cognitive dysfunction moderates the association between daytime sleepiness and QoL. Higher levels of cognitive dysfunction in adolescents amplify the impact of daytime sleepiness on QoL, strengthen the correlation between daytime sleepiness and depressive symptoms, and exacerbate the negative effects of depressive symptoms on QoL.

Our findings revealed that adolescents experienced a high prevalence of EDS, reaching 13.87%. Notably, excessive daytime sleepiness among adolescents has been increasingly recognized as a significant public health concern.[60] This global issue is underscored by the high prevalence of daytime sleepiness among adolescents across various regions. International studies have reported that the prevalence of daytime sleepiness among adolescents ranges from 16% to 47%.[6,61–63] The discrepancies between our findings and previous studies may be attributable to differences in sample size. Chronic sleep deprivation, which varies by grade level, gender, and other factors, is a primary contributor to daytime sleepiness among adolescents.[64] Furthermore, our study demonstrated that the prevalence of daytime sleepiness significantly differed by grade, gender, and co-residency status. This finding aligns with previous research. A meta-analysis reported a decline in sleep duration among adolescents with increasing age, with gender also significantly influencing this trend.[65] Reduced sleep duration among adolescents is associated with more pronounced levels of daytime sleepiness. Moreover, a longitudinal study revealed that enhanced sleep quality and diminished daytime sleepiness were linked to superior family supervision and parent-child relationships,[66] suggesting that daytime sleepiness is influenced by different co-residents. In addition, we observed that the prevalence of EDS was higher among high school students compared to their middle school counterparts. In a follow-up study of 3736 adolescents from high schools in southern China, the 1-year persistence rate of excessive daytime sleepiness was 27.6% and the incidence rate was 9.3%,[15] indicating that the problem of daytime sleepiness is also very serious among high school adolescents. Sleep disturbances and associated EDS in adolescents may adversely impact quality of life and contribute to mood disorders, depressive symptoms, cognitive impairments, decreased academic performance, and safety risks.[3,67–69] These associations between daytime sleepiness, quality of life, depressive symptoms, and cognitive dysfunction underscore the importance of our investigation. Addressing excessive daytime sleepiness in adolescents is imperative, and developing effective intervention strategies should be prioritized.

In this study, we found that excessive daytime sleepiness (EDS) was negatively associated with quality of life (QoL) and positively correlated with depressive symptoms and cognitive dysfunction in adolescents. Further analysis indicated that all pairwise combinations among the four variables were significantly correlated, suggesting the presence of a potentially complex interrelationship. Although no prior studies have simultaneously examined the complex interactions among these four variables, existing research on pairwise relationships between daytime sleepiness and each of the other three variables supports our findings.[3,70–72]

In support of our first hypothesis, we found that the association between daytime sleepiness and QoL in adolescents is partially mediated by depressive symptoms. A previous study among Chinese college students reported a similar finding, indicating that sleep behaviors (including daytime sleepiness) indirectly affect physical and psychological health via negative emotions such as anxiety and depression.[73] Several potential mechanisms may explain this mediating relationship. Genetics, dysfunction of the HPA axis and dysfunction of the melatonergic system are possible mechanisms for the mediating relationship among sleep-wake cycle, depression and quality of life.[74–76] Multiple experimental studies have

confirmed a strong association between daytime sleepiness and the neural mechanisms underlying depressive symptoms.[77–79] A complex reciprocal relationship appears to exist between emotional processing on the preceding day, nighttime sleep, and emotional processing the following day.[80] Most importantly, growing evidence suggests that sleep disorders, which contribute to daytime sleepiness, may share common pathophysiological mechanisms with mental illnesses such as depression, contributing to their onset and maintenance.[81–83] From a biological perspective, brainstem cholinergic neurons are integral to the regulation of wakefulness, and dysfunction in these neurons can result in daytime sleepiness.[84] Moreover, both the cholinergic system and wake-promoting neurotransmitters, such as norepinephrine, dopamine, and serotonin, have been implicated in the pathophysiology of depressive symptom.[85–87] Therefore, the relationship between sleep behavior and depressive symptoms appears to be both complex and bidirectional.[77] Adolescents experiencing daytime sleepiness are more likely to suffer from insufficient nocturnal sleep, which may contribute to both the development and persistence of depressive symptoms.

Consistent with previous studies,[88,89] we also found that depressive symptoms were associated with poorer QoL. Previous research examining the relationship between psychological symptoms and QoL has identified depressive symptoms as the strongest predictor of diminished QoL.[90] Depression is associated with a range of negative societal and individual outcomes, including increased healthcare costs and elevated risk for comorbid psychological disorders.[91–93] These adverse effects consistently lead to reduced quality of life and diminished well-being.[94–96] For example, a cross-sectional study reveals that people with depression have worse quality of life than those without depression,[97] and some longitudinal studies confirm that depression at baseline predicts poorer quality of life at follow-up.[98–100] Furthermore, a meta-analysis demonstrated that QoL was already reduced prior to the onset of depression and declined further during the course of the disorder.[89] Taken together with our findings, the aforementioned studies suggest that the impact of daytime sleepiness on QoL is largely indirect, mediated through depressive symptoms. Therefore, comprehensive interventions targeting depressive symptoms in adolescents are warranted to improve QoL. And exercise therapy emerges as a particularly promising intervention for adolescent populations in depression prevention and management,[101] owing to its cost-efficiency, minimal spatial demands, and inherently engaging nature. Its therapeutic value extends beyond physiological improvements (eg, neuroendocrine regulation, cardiovascular adaptation) to encompass psychosocial benefits such as resilience development, identity formation, and restoration of interpersonal connectivity.

In line with our second hypothesis, we found that daytime sleepiness indirectly affects QoL, with depressive symptoms acting as a mediator and cognitive dysfunction serving as a moderator. Higher levels of cognitive dysfunction significantly amplified the mediating effect of depressive symptoms on the relationship between daytime sleepiness and QoL in adolescents. Additionally, daytime sleepiness exerted a direct negative impact on QoL, and this relationship was moderated by cognitive dysfunction. These findings suggest that adolescents with more severe cognitive dysfunction may be at heightened risk for poor QoL. Previous research has indicated that excessive daytime sleepiness is related to cognitive dysfunction,[25,26,102–104] and the relationship between cognitive dysfunction and depression has been confirmed.[105–110] A growing body of evidence indicates that cognitive functioning is a critical determinant of QoL.[111–113] Therefore, cognitive dysfunction may moderate the associations between daytime sleepiness and QoL, between daytime sleepiness and depressive symptoms, and between depressive symptoms and QoL. A study on obstructive sleep apnea/hypopnea syndrome (OSAHS) reported interactions among sleepiness, cognitive performance, and QoL in affected individuals,[114] findings that partially align with those of the present study.

There is a lack of research examining cognitive dysfunction as a moderating factor in the associations between daytime sleepiness and QoL, or between depressive symptoms and QoL. However, our findings suggest that interventions targeting depressive symptoms and cognitive dysfunction may enhance QoL in adolescents experiencing daytime sleepiness. Notably, Drake et al systematically demonstrated the central therapeutic role of CBT-I,[115] proposing that behavioral interventions can restore sleep homeostasis by modifying maladaptive cognitive patterns—a mechanism theoretically aligned with the cognitive regulatory pathways in adolescents revealed in this study. Interventions addressing both cognitive dysfunction and depressive symptoms may exert a particularly strong influence on adolescents' quality of life and daily functioning. For instance, prior studies have shown that engagement in physical activity is a key strategy for enhancing adolescents' mental health and cognitive functioning.[116] These findings underscore the significance of our research and highlight the need for further investigation into the impact of cognitive therapies on QoL.

This cross-sectional epidemiological study presents several noteworthy strengths. To our knowledge, this is among the first studies to elucidate the mediating role of depressive symptoms and the moderating role of cognitive dysfunction in the relationship between daytime sleepiness and QoL among Chinese adolescents. Previous studies have primarily examined pairwise associations among these variables. Furthermore, the articulation of the moderated mediation model provides a concise and integrated framework capturing the complex interrelationships among daytime sleepiness, depressive symptoms, cognitive dysfunction, and QoL. Evidence on the psychological pathways linking daytime sleepiness and QoL may support the early identification of mental health concerns and inform timely interventions to mitigate poor QoL.

Limitations

It should be noted that the present study is not without limitations. Firstly, our study was based on a cross-sectional design and lacked a dynamic monitoring system to track changes, making it difficult to fully elucidate the temporal sequence among daytime sleepiness, depressive symptoms, cognitive dysfunction, and quality of life in adolescents. Also, the study's narrow timeframe precludes generalization to other seasonal or academic contexts. Seasonal variations in daylight exposure and school schedules (eg, exam periods, winter holidays) could affect sleep patterns, mood and cognitive function and could potentially influence the results, which warrants investigation in longitudinal designs. Secondly, we cannot rule out the possibility of the reverse relationship that cognitive dysfunction may act as the role of a mediator and depressive symptoms may act as the role of a moderator. Indeed, establishing a causal link between cognitive dysfunction and depressive symptoms is often challenging.

Thirdly, all variables in our study, including excessive daytime sleepiness, depressive symptoms, and cognitive dysfunction, were measured using self-reported questionnaires. Although these instruments have been validated and widely used in Chinese populations, self-reported data are inherently susceptible to recall bias and subjective interpretation. Moreover, considering the cultural diversity across different regions of China, participants may underreport or overreport symptoms due to social desirability bias or limited awareness of their own psychological or cognitive states. Additionally, the use of self-administered surveys limited our ability to monitor the response process, and there remains a possibility of careless or perfunctory answers, which could influence the accuracy and reliability of the findings. Future studies are recommended to incorporate clinical assessments or objective indicators to enhance the accuracy of the findings.

Fourthly, although we adjusted for several demographic variables (eg, age, gender, grade, residence, and primary caregiver), we acknowledge that other potential confounding factors, such as anxiety, socioeconomic status, academic stress, diet, physical activity, family dynamics, and undiagnosed medical conditions related to sleep (eg, insomnia or sleep apnea), were not measured or controlled for in our analyses. These factors may influence both sleep quality and psychological well-being, potentially biasing the associations observed in our study. In particular, it should be noted that these psychological and environmental factors—such as anxiety, academic workload, family dynamics, and sleep hygiene—may serve as critical mediators and moderators in shaping the relationship between EDS and QoL. Future research should consider incorporating a broader range of covariates to better isolate the effects of excessive daytime sleepiness and enhance the interpretability and robustness of the findings.

Conclusions

In conclusion, this study is the first to comprehensively examine the relationships among daytime sleepiness, depressive symptoms, cognitive dysfunction, and quality of life in Chinese adolescents. Our findings demonstrate that daytime sleepiness, a growing issue among adolescents, is significantly associated with poorer quality of life, highlighting the urgency of addressing this public health concern. Importantly, depressive symptoms were found to partially mediate the association between daytime sleepiness and quality of life, while cognitive dysfunction moderated this indirect effect, further exacerbating the impact. These results underscore the importance of early screening and psychological support for adolescents experiencing excessive daytime sleepiness. From a practical perspective, school-based mental health programs, exercise therapy, cognitive training interventions, and public health policies aimed at improving sleep hygiene and emotional well-being may serve as effective strategies to mitigate the adverse effects of daytime sleepiness on

adolescents' quality of life. This study contributes novel evidence by integrating both mediation and moderation mechanisms into the analysis of sleep-related quality of life in adolescents, an area that has been largely underexplored in previous Chinese studies. By doing so, it fills a critical gap in understanding the complex psychological pathways linking sleepiness to well-being in this vulnerable population.

Data Sharing Statement

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

Ethics Approval and Consent to Participate

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The study was approved by the Ethics Committee of Beijing Huilongguan Hospital. Informed consent was obtained from both the participants and their parents after they were fully informed about the purpose, procedures, and confidentiality of the study.

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Disclosure

All authors declare no competing financial interest.

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