



ORIGINAL ARTICLE

# Excessive daytime sleepiness mediates the relationship between insomnia symptoms and suicidal behavior in adolescents

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## Abstract

**Study Objectives:** Insomnia symptoms, excessive daytime sleepiness (EDS), and suicidal behavior are prevalent among adolescents. Growing studies have shown that both insomnia symptoms and EDS are associated with suicidal behavior. However, little is known about the pathways between insomnia symptoms, EDS, and suicidal behavior. This study aimed to examine the longitudinal mediating effect of EDS on insomnia-suicidal behavior link in a large sample of Chinese adolescents.

**Methods:** Participants were 7072 adolescents (Mean age = 14.58 years, 50.0% males) who were surveyed at baseline and were followed up 1 year later in the Shandong Adolescent Behavior and Health Cohort study. A self-administered questionnaire was used to measure insomnia symptoms, daytime sleepiness, sleep duration, social jetlag, suicidal behavior, and adolescent and family demographics.

**Results:** The prevalence of insomnia symptoms and EDS at baseline were 14.3% and 21.1%, respectively. Adolescents with insomnia symptoms or EDS at baseline were more likely to report suicidal behavior at 1-year follow-up compared to adolescents without insomnia symptoms or EDS. Path analyses showed that EDS played a significant mediation role between insomnia symptoms and suicidal behavior (including any suicidal behavior, suicidal thought, suicide plan, and suicide attempt) before and after adjusting for adolescent and family factors, sleep duration, social jetlag, and prior suicidal behavior.

**Conclusion:** Insomnia symptoms and EDS were associated with increased risk of subsequent suicidal behavior. The association between insomnia symptoms and suicidal behavior was mediated by EDS. These findings highlight the importance of assessment and treatment of insomnia and daytime sleepiness for suicide prevention in adolescents.

## Statement of Significance

Although growing studies have demonstrated that insomnia and EDS are significant risk factors of suicidal behavior, the mechanisms of their relationship are not well established. The current study from a large sample of community adolescents demonstrated that both insomnia symptoms and EDS were associated with increased risk of subsequent suicidal behavior and that EDS mediated the link between insomnia symptoms and suicidal behavior. These findings stress the importance of screening and treatment of insomnia and EDS for potentially effective prevention of adolescent suicide.

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## Graphical Abstract

## Excessive daytime sleepiness mediates the relationship between insomnia symptoms and suicidal behavior in adolescents

### Background

- Insomnia symptoms (IS) and excessive daytime sleepiness (EDS) are significant risk factors of suicidal behavior.
- Little is known about the pathways between IS, EDS, and suicidal behavior.

### Aim

To examine the mediation effect of EDS between IS and suicidal behavior.

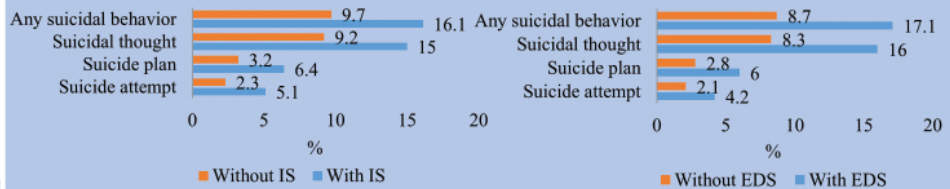
### Methods

● 7,072 adolescents from the Shandong Adolescent Behavior and Health Cohort study were resurveyed 1 year later

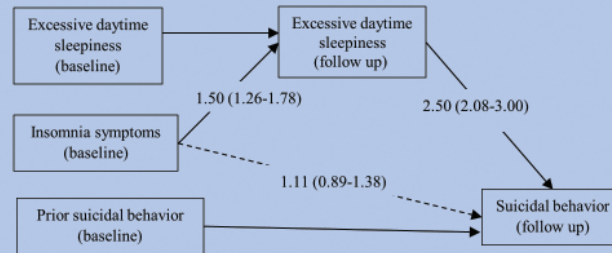
- Questionnaire survey
  - ✓ Suicidal behavior
  - ✓ Sleep problems
  - ✓ Adolescent and family factors

### Findings

- Adolescents with IS or EDS were more likely to report suicidal behaviors at 1-year follow-up (all  $P < 0.001$ ).



- EDS played a significant mediation role between insomnia symptoms and suicidal behavior [OR (95%CI)]



### Conclusions

- The association between IS and suicidal behavior was mediated by EDS.
- Assessment and treatment of insomnia and daytime sleepiness are important for suicide prevention in adolescents.

**Key words:** insomnia; daytime sleepiness; suicidal behavior; mediation; adolescent; longitudinal study

## Introduction

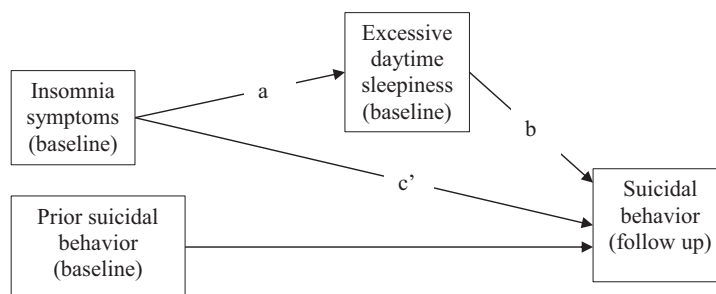
Suicide is the fourth leading cause of death among people aged 15–29 in the world [1]. Non-fatal suicidal behavior including suicidal thought (ST), suicide plan (SP), and suicide attempt (SA) has been identified as the strongest predictor of suicide death [2, 3] and is prevalent among adolescents [4]. Non-fatal suicidal behavior is multifactorial. Numerous studies have shown demographical, biological, and psychosocial factors (i.e. female gender, age, parental separation, or divorce, serotonin activity, and mental disorders) are associated with non-fatal suicidal behavior [5, 6].

Insomnia disorder, manifested as recurrent and chronic perceived sleep dissatisfaction occurring several times per week, is one of the common sleep problems among adolescents [7]. Insomnia symptoms are very common among adolescents [8]. Growing studies have demonstrated that insomnia is a significant risk factor of adolescent suicidal behavior [9–11]. The link between insomnia and suicidal behavior is complicated and may be mediated and/or moderated by multiple factors. Anxiety and depression have been considered the most common factors that mediate the association between insomnia and suicidal behavior [12, 13]. However, in a meta-analysis involving 39 studies,

the authors found that insomnia, nightmares, and other sleep disturbances were significantly associated with suicidal behaviors, independent of depression and anxiety (adjusted risk ratio ranging from 1.66 to 3.00) [14]. That is, in the absence of depression and anxiety, the experience of insomnia also increases the risk of suicidal behavior. Recent studies have examined other mediators, such as defeat and entrapment [15, 16], hopelessness [17], perceived burdensomeness and thwarted belongingness [18], and nightmares [19]. However, all these factors were mostly examined in cross-sectional studies and these factors could only explain part of the association between insomnia and suicidal behavior. To develop effective prevention and intervention programs of suicidal behavior, it is important to identify modifiable factors that mediate the association between insomnia and suicidal behavior in adolescents.

Excessive daytime sleepiness (EDS) is also prevalent in adolescents [20]. EDS may be a potential mediator of the insomnia-suicidal behavior link because EDS is one of the most common consequences of insomnia and because EDS is associated with increased risk of suicidal behavior. For example, in a cross-sectional study of 36 743 adults, the risk of EDS was

Model A: Insomnia symptoms at baseline was associated with increased risk of subsequent suicidal behavior and mediated by excessive daytime sleepiness at baseline.



Model B: Insomnia symptoms at baseline was associated with increased risk of subsequent suicidal behavior and mediated by excessive daytime sleepiness at follow-up.

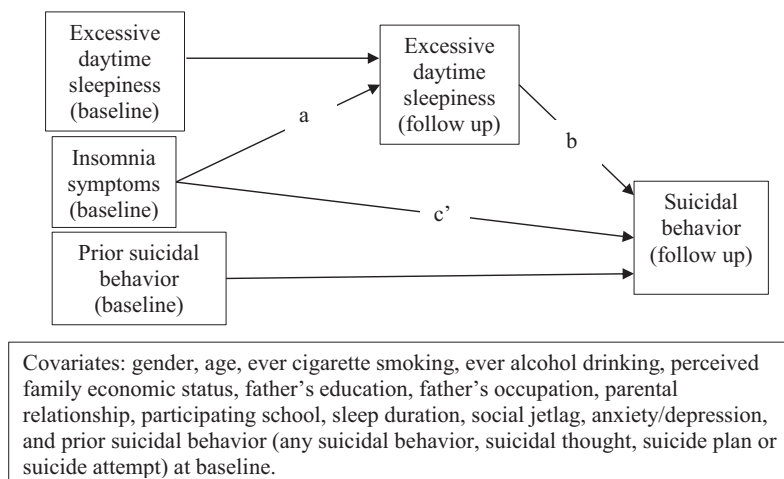


Figure 1. Hypothesized mediation models.

three times as high for individuals with insomnia as for those without EDS [21]. Another cross-sectional study of 1667 Chinese adolescents reported that insomnia symptoms was independently associated with EDS (adjusted OR = 3.8) [22]. In a 3-year longitudinal study, Chen et al. [23] found adolescents with persistent insomnia (adjusted OR = 3.06) or incident insomnia (adjusted OR = 2.20) had a greater risk of EDS. Besides, a recent meta-analysis reported prospective positive associations between EDS and SA/suicide death [24]. However, to our knowledge, no studies have specifically examined the mediating effects of EDS on the link between insomnia and suicidal behavior in adolescents.

To address this gap, we aimed to examine the mediation effect of EDS between insomnia symptoms and suicidal behavior based on baseline and 1-year follow-up data of the Shandong Adolescent Behavior and Health Cohort (SABHC) study among community adolescents ( $n = 7072$ ). Mediation requires time precedence from the cause to the mediator to the outcome and the effect depends on the time interval between variables, so two hypothesized models were proposed: (1) insomnia symptoms at baseline would increase the risk of EDS at baseline, and in turn, the elevated risk of EDS at baseline would predict suicidal behavior at 1-year follow-up (model A of Figure 1); (2) insomnia symptoms at baseline would increase the risk of EDS at 1-year follow-up, which in turn increases the risk of suicidal behavior at 1-year follow-up (model B of Figure 1).

## Methods

### Participants and procedure

Data for this prospective analysis were derived from the SABHC study, which was conducted in Shandong province, China. Detailed sampling and data collection have been described in our previous publications [25–27]. In brief, the baseline survey was conducted in November–December of 2015, and 12301 7th–11th graders from 5 middle and 3 high schools were sampled with consideration of the representativeness of adolescent students in the region, prior study collaboration, convenience, and budget for at least three waves of data collection. All 7th, 8th, and 10th graders at baseline ( $n = 8629$ ) were resurveyed 1 year later. A self-administered adolescent health questionnaire (AHQ) was used to assess suicidal behavior, sleep problems, mental health, and psychosocial factors.

Before the survey, we obtained permission to conduct the study from the principals in the target schools and informed consent from participants. Trained public health workers administered AHQ to participants in target classrooms during regular school hours. Before filling out the questionnaire, participants were asked to read the instructions carefully and informed that the survey was anonymous, and their participation was voluntary. It took about 45 min to fill out the questionnaire. The study was approved by the research ethics committee of Shandong University School of Public Health and target schools.

## Measures

### Suicidal behavior

Lifetime ST, SP, and SA at baseline were assessed by “Have you ever seriously thought about killing yourself?” “Have you ever made a specific plan for killing yourself?” and “Have you ever tried to kill yourself?” respectively. Similar questions were used to assess ST, SP, and SA in the past year at 1-year follow-up. All of the questions had a “yes/no” answer. Participants who responded positively to ST, SP, or SA were considered as having any suicidal behavior. These questions are commonly used in suicidality studies in adolescents [28, 29].

### Insomnia symptoms

Youth Self-Rating Insomnia Scale (YSIS) [30] with eight items was used to measure insomnia severity during the past month. Participants were asked to score each item that describes difficulty initiating sleep (DIS), difficulty maintaining sleep (DMS), early morning awakening (EMA), unrefreshing sleep, poor sleep quality, sleep insufficiency, sleep dissatisfaction, and interference of sleep difficulties with daytime functioning. All items are rated on a 5-point scale from 1 to 5. Summing the 8-item scores yields a total YSIS score, with a higher score indicating a higher level of insomnia severity. Cronbach’s alpha of the scale was 0.80 with the current sample. For the purpose of the study, we used DIS, DMS, and EMA to define insomnia symptoms [31]. Clinical insomnia symptoms were defined by the presence of DIS, DMS, or EMA at least 3 times/week.

### Daytime sleepiness

Chinese Adolescent Daytime Sleepiness Scale (CADSS) [32] was used to measure daytime sleepiness during the past month at baseline and 1-year follow-up. The CADSS consists of seven items that ask adolescents about their general feelings of drowsiness and dozing off in different situations during the daytime. All the items are rated on a 5-point scale from 1 = never, 2 ≤ 1 time/week, 3 = 1–2 times/week, 4 = 3–5 times/week, to 5 = 6–7 times/week. Summing the 7 item scores yields a total score, with a higher score indicating greater daytime sleepiness. A total CADSS score ≥23 was recommended to define excessive daytime sleepiness (EDS) [32]. Cronbach’s alpha of the scale was 0.89 with the current sample.

### Covariates

The following covariates were selected based on literature [33–35] and their associations with insomnia, EDS, and suicidal behavior in the current study.

Baseline adolescent and family factors included in this study were age, gender, ever cigarette smoking (yes or no), ever alcohol drinking (yes or no), perceived family economic status (excellent, good, fair, poor, very poor), father’s education (primary school, middle school, high school, professional school, college, or above), father’s occupation (farmer or non-farmer), parental relationships (excellent, good, fair, poor, separated/ divorced/widowed), and participating school (7 dummy variables for 8 schools).

Bedtime and wake-up time on weekdays were asked by “During the past month, what time do you usually go to bed on

a typical school day?” and “During the past month, what time do you usually get up on a typical school day?” Similar questions were asked to assess bedtime and wake-up time on weekends during the past month. Based on bedtime and wake-up time, social jetlag (SJL) was estimated according to Roenneberg’s formula [36]. Sleep duration on weekdays during the past month was assessed by the question: “During the past month, how many hours of actual sleep did you get at night on a typical school day?” Anxious/depressive symptoms during the past 6 months were measured by the anxious/depressed subscale of Chinese Youth Self-Report of the Child Behavior Checklist [37, 38]. The subscale comprises 16 items with a 3-point response (0 = not true, 1 = sometimes true, and 2 = often true). Cronbach’s alpha of the subscale was 0.88 with the current sample. Two items concerning suicidal behavior were not included when calculating the subscale score in the study. A total score was calculated by summing the 14 item scores, with a higher score indicating more severe anxious/depressive symptoms. The 90th percentile of the scale score at baseline survey of the entire cohort ( $n = 11\,831$ ) was used as the cutoff to define clinically relevant anxious/depressive symptoms.

### Statistical analyses

Means (standard deviation, SD) and frequency (percentage) were used to describe continuous and categorical variables, respectively. Chi-square tests and t-tests were used for categorical variables and continuous variables respectively to examine differences in sample characteristics by insomnia symptoms and EDS and between participants with and without 1-year follow-up. Differences in the prevalence of suicidal behaviors at 1-year follow-up by insomnia symptoms and EDS were examined by  $\chi^2$  tests. Based on insomnia and EDS status at baseline, participants were categorized into four groups: insomnia only, EDS only, insomnia + EDS, and none of them. Multiple logistic regression models were conducted to examine the adjusted associations of insomnia and/or EDS with suicidal behavior at 1-year follow-up controlling for covariates in Table 1, participating schools, and prior suicidal behavior. Interaction effects of insomnia symptoms and EDS for suicidal behavior were tested. Stratification analyses by sleep duration ( $\geq 7$  h vs.  $< 7$  h) were followed to examine if the associations differed by sleep duration. 7 h was used as cutoff point to stratify participants because median sleep duration of the total sample at baseline was 7 h.  $p < 0.05$  was used for the statistical significance threshold. The above statistical analyses were performed by IBM SPSS 24 (Armonk, NY: IBM Corp, USA).

Path analyses [39] were applied to test the hypothetical logistic mediation models (Figure 1) by Mplus 8.3 [40]. Specifically, the following paths were examined in the unadjusted model A: (1) the direct effect of insomnia symptoms at baseline on EDS at baseline (indicated by the path coefficient  $a$ ); (2) the direct effect of EDS at baseline on suicidal behavior at 1-year follow-up (path coefficient  $b$ ), with adjusting for insomnia symptoms at baseline and prior suicidal behavior at baseline to control the autoregressive effect; and (3) the direct effect of insomnia symptoms at baseline on suicidal behavior at 1-year follow-up (path coefficient  $c$ ), with adjusting for EDS and prior suicidal behavior at baseline. Similarly, three paths were tested for the unadjusted model B: (1) path  $a$ : the direct effect of insomnia symptoms at baseline on EDS at 1-year follow-up with adjusting for EDS at

**Table 1.** Sample characteristics at baseline, stratified by insomnia symptoms and EDS

Characteristics	Total (n = 7072) <sup>a</sup>	Insomnia symptoms				EDS			
		No (n = 5737)	Yes (n = 960)	$\chi^2/t$	P	No (n = 5247)	Yes (n = 1402)	$\chi^2/t$	P
Female gender	3536 (50.0)	2925 (51.0)	473 (49.3)	0.97	0.326	2632 (50.2)	747 (53.3)	4.31	0.038
Age, mean (SD)	14.58 (1.45)	14.61 (1.44)	14.57 (1.47)	0.80	0.462	14.39 (1.46)	15.44 (1.05)	30.39	<0.001
Cigarette smoking, yes	1339 (18.9)	1021 (17.8)	244 (25.4)	31.17	<0.001	809 (15.4)	431 (30.7)	171.23	<0.001
Alcohol drinking, yes	2417 (34.2)	1899 (33.1)	401 (41.8)	27.42	<0.001	1568 (29.9)	729 (52.0)	239.26	<0.001
Anxiety/depression, yes	866 (12.2)	574 (10.0)	258 (26.9)	215.11	<0.001	461 (8.8)	355 (25.3)	280.96	<0.001
Sleep duration (h)				3.27	0.070			444.50	<0.001
<7	3323 (48.0)	2710 (48.1)	486 (51.3)			2175 (42.2)	1019 (74.2)		
≥7	3603 (52.0)	2919 (51.9)	461 (48.7)			2983 (57.8)	365 (25.8)		
Social jetlag (h), mean (SD)	1.24 (0.89)	1.21 (0.87)	1.38 (1.01)	4.77	<0.001	1.18 (0.85)	1.46 (1.01)	9.39	<0.001
Family economic status				50.29	<0.001			43.12	<0.001
Excellent	181 (2.6)	132 (2.3)	26 (2.7)			138 (2.7)	21 (1.5)		
Good	1263 (18.0)	1054 (18.5)	146 (15.3)			995 (19.1)	197 (14.1)		
Fair	4719 (67.4)	3884 (68.2)	603 (63.3)			3495 (67.1)	958 (68.8)		
Poor	746 (10.6)	561 (9.9)	153 (16.1)			520 (10.0)	186 (13.4)		
Very poor	96 (1.4)	62 (1.1)	24 (2.5)			58 (1.1)	31 (2.2)		
Father's education				39.07	<0.001			16.69	0.002
Primary school	966 (13.8)	725 (12.8)	176 (18.4)			708 (13.6)	183 (13.1)		
Middle school	3784 (54.1)	3062 (53.9)	523 (54.8)			2875 (55.3)	705 (50.6)		
High school	1303 (18.6)	1083 (19.1)	159 (16.7)			944 (18.2)	278 (20.0)		
Professional school	523 (7.5)	463 (8.1)	40 (4.2)			372 (7.2)	134 (9.6)		
College or above	419 (6.0)	349 (6.1)	56 (5.9)			301 (5.8)	93 (6.7)		
Father's occupation: nonfarm	4380 (61.9)	3622 (63.1)	534 (55.6)	19.69	<0.001	3235 (61.7)	903 (64.4)	3.57	0.059
Inter-parental relationship				86.84	<0.001			73.69	<0.001
Excellent	2997 (42.8)	2502 (44.0)	324 (34.0)			2336 (44.9)	492 (35.3)		
Good	1838 (26.3)	1533 (27.0)	216 (22.7)			1383 (26.6)	354 (25.4)		
Fair	1732 (24.8)	1329 (23.4)	323 (33.9)			1191 (22.9)	430 (30.8)		
Poor	193 (2.8)	133 (2.3)	49 (5.1)			120 (2.3)	63 (4.5)		
Separated/divorced/ widowed	235 (3.4)	184 (3.2)	40 (4.2)			167 (3.2)	55 (3.9)		

EDS, excessive daytime sleepiness.

<sup>a</sup>n Differs due to missing values.

baseline; (2) paths *b* and *c*: the effects of EDS at 1-year follow-up and insomnia symptoms at baseline on suicidal behavior at 1-year follow-up, with adjusting for prior suicidal behavior at baseline. Because the outcomes (any suicidal behavior, ST, SP, and SA) and mediator (EDS) were all binary variables, the estimations and significance of indirect effects of insomnia symptoms on suicidal behavior via EDS were calculated and tested by the Delta method [41]. Odds ratios (OR) and 95% confidence intervals (CIs) of the path coefficients were reported. Effect size of mediation effect was quantified as  $a^*b/(a^*b + c')$  if the mediation effect ( $a^*b$ ) was significant [42]. Missing data were handled by full information maximum likelihood [43]. Adjusted mediation models were then performed to adjust for covariates in Figure 1.

## Results

### Sample characteristics

Among 12 301 students who were sampled for the SABHC study, 11 831 (96.2%) returned their questionnaires. Of 8629 7th–8th and 10th graders who participated in the baseline survey, 7072 (82.0%) participated in the follow-up survey and were included in the current study. Male gender, age, ever cigarette smoking, ever alcohol drinking, sleep duration (>7 h), social jetlag, family economic status, father's education, and non-farming

occupation of father were associated with attrition (all  $ps < 0.05$ ). See Appendix Table 1 for details. Compared with participants who participated in the baseline survey and those who participated in 1-year follow-up revealed no significant differences in all covariates (all  $ps > 0.05$ ) except age ( $\chi^2 = 3.26$ ,  $p = 0.001$ ). The main reasons for attrition were transferring to another school or being absent from school on the day of follow-up survey.

Among 7072 participants, the mean age was 14.58 (SD = 1.45) and half were female. Detailed sample characteristics by insomnia and EDS are presented in Table 1. Ever cigarette smoking, ever alcohol drinking, anxiety/depression, social jetlag, poor perceived family economic status, lower father's education, farming occupation of father, and poor parental relationship were related to insomnia symptoms (all  $ps < 0.05$ ). Age, ever cigarette smoking, ever alcohol drinking, anxiety/depression, sleep duration (<7 h), social jetlag, poor perceived family economic status, higher father's education, and poor parental relationship were related to EDS at baseline (all  $ps < 0.05$ ).

A total of 22.3% ( $n = 1577$ ) participants reported a history of suicidal behavior at baseline and the prevalence of lifetime ST, SP, and SA were 18.8% ( $n = 1323$ ), 8.8% ( $n = 609$ ), and 3.6% ( $n = 247$ ), respectively. At 1-year follow-up, 10.6% ( $n = 750$ ) reported having suicidal behavior during the past 12 months and the 12-month prevalence of ST, SP, and SA were 10.0% ( $n = 707$ ), 3.6% ( $n = 258$ ), and 2.7% ( $n = 190$ ), respectively.

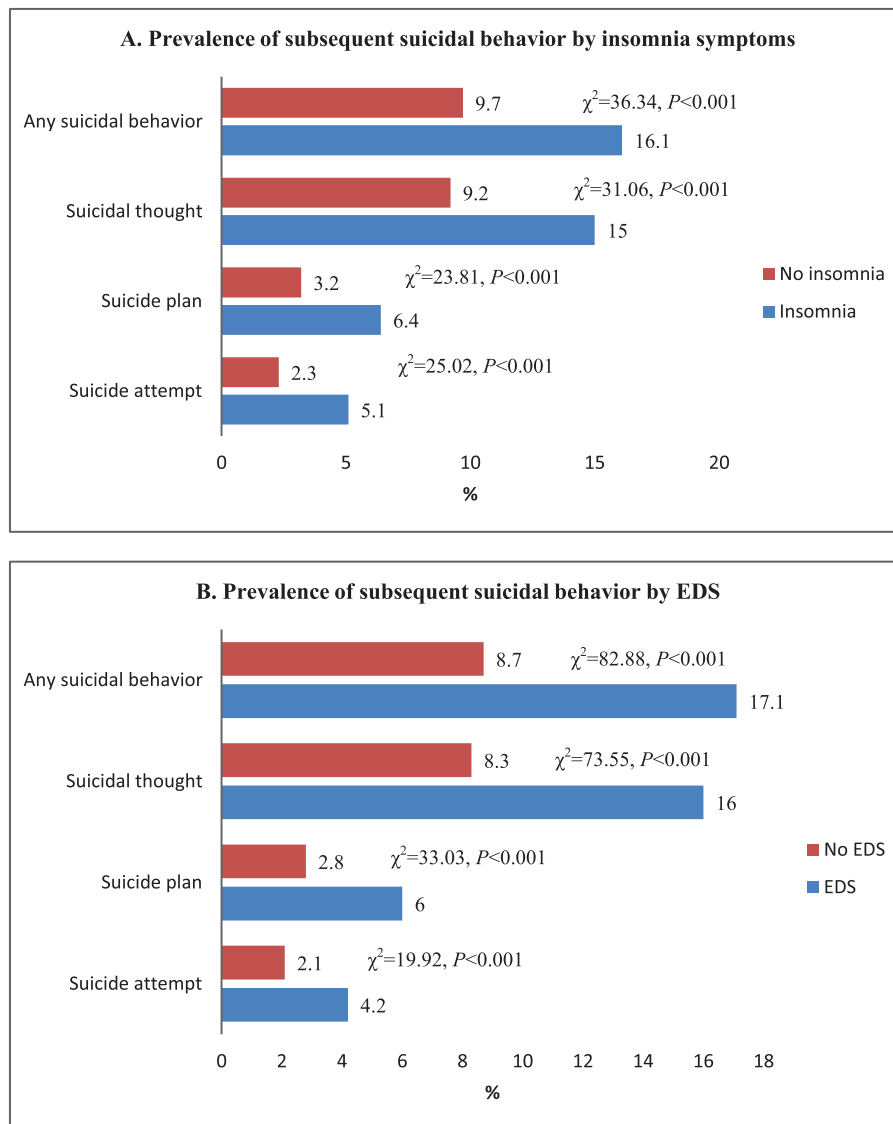


Figure 2. Prevalence of subsequent suicidal behavior during 1-year follow-up by insomnia symptoms and EDS at baseline. EDS, excessive daytime sleepiness.

#### Associations of insomnia symptoms and EDS with suicidal behavior

At baseline, the prevalence of insomnia symptoms and EDS were 14.3% ( $n = 960$ ) and 21.1% ( $n = 1402$ ), respectively, including 9.3% with insomnia symptoms only, 16.5% with EDS only and 4.8% with both insomnia symptoms and EDS. Besides, among participants who reported insomnia symptoms ( $n = 960$ ), the prevalence of EDS was 34.1% ( $n = 311$ ).

As shown in Figure 2, compared to adolescents without insomnia symptoms or EDS at baseline, adolescents with insomnia symptoms or EDS were more likely to report all suicidal behaviors at 1-year follow-up (all  $ps < 0.001$ ). Illustratively, the prevalence of subsequent suicidal behavior was 9.7% in adolescents without insomnia symptoms at baseline, and 16.1% with insomnia symptoms ( $\chi^2 = 36.34$ ,  $p < 0.001$ ). The prevalence of subsequent suicidal behavior was 8.7% in adolescents without EDS, and 17.1% with EDS ( $\chi^2 = 82.88$ ,  $p < 0.001$ ).

Table 2 shows the associations of insomnia and EDS with subsequent suicidal behavior at 1-year follow-up. Of the total sample, insomnia only, EDS only, and insomnia + EDS were significantly associated with 39–169% increased odds of subsequent

insomnia symptoms after adjusting for prior suicidal behavior. After adjusting for covariates in Table 1 and participating schools, EDS only and insomnia + EDS were significantly associated with 39–129% increased odds of subsequent suicidal behavior. Insomnia only was no longer statistically significant. Although the OR were numerically increased from insomnia only to EDS only to insomnia + EDS, there are no significant interactions between insomnia and EDS on suicidal behavior (all  $ps > 0.05$ ).

Separate analyses by sleep duration showed similar trends. Illustratively, for adolescents with sleep duration  $\geq 7$  h, OR of subsequent any suicidal behavior were 1.15 (95% CI = 0.77–1.69) for insomnia only, 1.57 (95% CI = 1.04–2.39) for EDS only, and 2.17 (95% CI = 1.23–3.84) for insomnia + EDS, respectively. For adolescents with sleep duration  $< 7$  h, OR were 1.18 (95% CI = 0.75–1.86) for insomnia only, 1.40 (95% CI = 1.05–1.88) for EDS only, and 1.58 (95% CI = 1.02–2.44) for insomnia + EDS, respectively. Although the odds ratio was numerically higher in adolescents with insomnia + EDS and sleep duration  $\geq 7$  h than that in those with insomnia + EDS and sleep duration  $< 7$  h, there were no significant interactions between sleep duration and insomnia/EDS on suicidal behavior (all  $ps > 0.05$ ).

**Table 2.** Associations of insomnia symptoms and EDS at baseline with subsequent suicidal behavior at 1-year follow-up, stratified by sleep duration

	Total		By sleep duration					
	AOR <sup>1</sup>	95% CI	AOR <sup>2</sup>	95% CI	AOR <sup>3</sup>	95% CI	AOR <sup>3</sup>	95% CI
<b>Insomnia symptoms or EDS status</b>								
<b>Any suicidal behavior</b>								
No	1.00		1.00		1.00		1.00	
Insomnia only	1.46 <sup>***</sup>	1.12–1.91	1.16	0.86–1.55	1.15	0.77–1.69	1.18	0.75–1.86
EDS only	1.45 <sup>***</sup>	1.18–1.79	1.47 <sup>***</sup>	1.16–1.87	1.57 <sup>*</sup>	1.04–2.39	1.40 <sup>*</sup>	1.05–1.88
Insomnia + EDS	1.93 <sup>***</sup>	1.42–2.63	1.75 <sup>***</sup>	1.24–2.47	2.17 <sup>***</sup>	1.23–3.84	1.58 <sup>*</sup>	1.02–2.44
<b>Suicidal thought</b>								
No	1.00		1.00		1.00		1.00	
Insomnia only	1.46 <sup>**</sup>	1.11–1.92	1.15	0.85–1.55	1.23	0.83–1.82	1.06	0.66–1.69
EDS only	1.39 <sup>**</sup>	1.13–1.73	1.39 <sup>**</sup>	1.09–1.78	1.37	0.88–2.13	1.36 <sup>*</sup>	1.01–1.84
Insomnia + EDS	1.89 <sup>***</sup>	1.37–2.59	1.71 <sup>**</sup>	1.21–2.43	2.36 <sup>***</sup>	1.32–4.21	1.47	0.94–2.29
<b>Suicide plan</b>								
No	1.00		1.00		1.00		1.00	
Insomnia only	1.69 <sup>*</sup>	1.11–2.56	1.32	0.83–2.11	1.25	0.67–2.33	1.40	0.67–2.92
EDS only	1.74 <sup>**</sup>	1.24–2.42	1.77 <sup>**</sup>	1.21–2.60	2.42 <sup>**</sup>	1.32–4.42	1.50	0.91–2.44
Insomnia + EDS	2.17 <sup>**</sup>	1.35–3.47	1.99 <sup>**</sup>	1.19–3.35	1.98	0.86–4.56	1.98 <sup>*</sup>	1.00–3.91
<b>Suicide attempt</b>								
No	1.00		1.00		1.00		1.00	
Insomnia only	1.99 <sup>**</sup>	1.25–3.16	1.51	0.90–2.57	1.39	0.70–2.74	1.80	0.78–4.18
EDS only	1.76 <sup>**</sup>	1.19–2.61	1.87 <sup>**</sup>	1.21–3.02	2.25 <sup>*</sup>	1.08–4.69	1.69	0.92–3.09
Insomnia + EDS	2.69 <sup>***</sup>	1.60–4.55	2.29 <sup>**</sup>	1.25–4.17	2.92 <sup>*</sup>	1.21–7.06	1.84	0.79–4.27

AOR, adjusted odds ratios; CI, confidence intervals.

<sup>1</sup>AOR, adjusted for prior suicidal behavior.

<sup>2</sup>AOR, adjusted for covariates in Table 1 + participating schools and prior suicidal behavior.

<sup>3</sup>AOR, adjusted for covariates in Table 1 except sleep duration + participating schools and prior suicidal behavior.

\* $p < 0.05$ ;

\*\* $p < 0.01$ ;

\*\*\* $p < 0.001$ .

### Path analyses

Tables 3 and 4 present the OR and 95% CIs of path coefficients ( $a$ ,  $b$ ,  $c'$ , and  $a^*b$ ) and the mediation effect sizes [ $a^*b/(a^*b + c')$ ] from the hypothesized models A and B for any suicidal behavior, ST, SP, and SA at 1-year follow-up, respectively.

For unadjusted model A (Table 3), all the path coefficients were significant (all the 95% CIs did not include the value of 1). The mediation effect sizes ranged from 0.375 to 0.431. For example, for any suicidal behavior,  $a = 2.19$  (95% CI = 1.88–2.55),  $b = 1.45$  (95% CI = 1.21–1.74),  $c' = 1.40$  (95% CI = 1.14–1.71),  $a^*b = 1.06$  (95% CI = 1.03–1.09), and  $a^*b/(a^*b + c') = 0.431$ . After adjusting for covariates in Figure 1, all the indirect effects ( $a^*b$ ) remained significant although they were slightly reduced, and all the direct effects ( $c'$ ) were no longer statistically significant. The mediation effect sizes ranged from 0.420 to 0.468.

For model B (Table 4), the results were similar to model A. All the path coefficients were significant in the unadjusted models. After adjusting for covariates, all the indirect effects ( $a^*b$ ) remained significant and all the direct effects ( $c'$ ) were no longer statistically significant. The mediation effect sizes for unadjusted and adjusted models B ranged from 0.375 to 0.495.

## Discussion

To our knowledge, this study represents the first longitudinal study to examine the mediating role of EDS in the insomnia-suicidal behavior link. The results reinforce previous evidence

indicating that insomnia and EDS are associated with an increased risk of suicidal behavior [24]. The identified mediation effect of EDS in the insomnia-suicidal behavior link may have important implications for further research on adolescent sleep and for intervention and prevention of suicide.

Consistent with previous studies [7, 44, 45], this study demonstrated that insomnia and EDS were prevalent in adolescents. Insomnia and EDS often co-occur. In our study, about 5% of participants had both insomnia symptoms and EDS. Based on clinical data of 553 Hungarian children with depression, Liu and colleagues found approximately 10% of depressed children had insomnia plus hypersomnia [46]. Besides, the prevalence of EDS among adolescents with insomnia symptoms was high (34.1%) in this study. Previous studies had come to a similar conclusion, although the prevalence was not comparable due to the criteria used to define insomnia symptoms and EDS or study population are different. For example, in a study conducted among 1311 insomnia sufferers with age  $\geq 18$  years, Hein et al. [47] found that 45.61% of participants reported EDS. In an international study with 5293 outpatients complaining of sleep disturbances in primary care practice, 85.4% of insomnia sufferers reported daytime impairments [48]. The high comorbidity supported the notion that EDS is a common consequence of insomnia, and insomnia may affect physical and mental health via EDS.

Insomnia symptoms and EDS were associated with higher risk of suicidal behavior compared with either insomnia or EDS only. A possible explanation is that individuals with both insomnia and EDS are more likely to suffer from circadian

**Table 3.** Associations of baseline insomnia symptoms on subsequent suicidal behavior via baseline EDS

Paths	Unadjusted model		Adjusted model	
	OR	95% CI	OR	95% CI
<b>Any suicidal behavior</b>				
W1 IS–W1 EDS (a)	2.19 <sup>***</sup>	1.88–2.55	1.99 <sup>***</sup>	1.65–2.40
W1 EDS–W2 SB (b)	1.45 <sup>**</sup>	1.21–1.74	1.42 <sup>**</sup>	1.15–1.75
W1 IS–W2 SB (c <sup>′</sup> )	1.40 <sup>*</sup>	1.14–1.71	1.18	0.95–1.47
W1 IS–W1 EDS–W2 SB (a <sup>*</sup> b)	1.06 <sup>***</sup>	1.03–1.09	1.04 <sup>**</sup>	1.01–1.06
$\frac{a+b}{a+b+c'}$	0.431		0.468	
<b>Suicidal thought</b>				
W1 IS–W1 EDS (a)	2.18 <sup>***</sup>	1.87–2.54	1.99 <sup>***</sup>	1.65–2.40
W1 EDS–W2 ST (b)	1.40 <sup>**</sup>	1.16–1.69	1.37 <sup>*</sup>	1.11–1.70
W1 IS–W2 ST (c <sup>′</sup> )	1.39 <sup>*</sup>	1.13–1.72	1.17	0.94–1.47
W1 IS–W1 EDS–W2 ST (a <sup>*</sup> b)	1.05 <sup>*</sup>	1.02–1.08	1.03 <sup>**</sup>	1.01–1.06
$\frac{a+b}{a+b+c'}$	0.430		0.468	
<b>Suicide plan</b>				
W1 IS–W1 EDS (a)	2.19 <sup>***</sup>	1.88–2.55	2.00 <sup>***</sup>	1.66–2.41
W1 EDS–W2 SP (b)	1.62 <sup>*</sup>	1.20–2.17	1.49 <sup>***</sup>	1.06–2.10
W1 IS–W2 SP (c <sup>′</sup> )	1.53 <sup>*</sup>	1.12–2.09	1.28	0.91–1.80
W1 IS–W1 EDS–W2 SP (a <sup>*</sup> b)	1.07 <sup>**</sup>	1.03–1.13	1.04 <sup>*</sup>	1.00–1.08
$\frac{a+b}{a+b+c'}$	0.412		0.448	
<b>Suicide attempt</b>				
W1 IS–W1 EDS (a)	2.18 <sup>***</sup>	1.87–2.54	1.99 <sup>***</sup>	1.65–2.40
W1 EDS–W2 SA (b)	1.66 <sup>*</sup>	1.18–2.33	1.57 <sup>***</sup>	1.03–2.40
W1 IS–W2 SA (c <sup>′</sup> )	1.80 <sup>*</sup>	1.26–2.56	1.45	0.99–2.14
W1 IS–W1 EDS–W2 SA (a <sup>*</sup> b)	1.08 <sup>*</sup>	1.02–1.14	1.05 <sup>*</sup>	1.00–1.10
$\frac{a+b}{a+b+c'}$	0.375		0.420	

Adjusted model: Adjusted for covariates described in [Figure 1](#).

IS, insomnia symptoms; EDS, excessive daytime sleepiness; SB, suicidal behavior; ST, suicidal thought; SP, suicide plan; SA, suicide attempt; W1, wave 1; W2, wave 2; OR, odds ratios; CI, confidence intervals.

<sup>\*</sup>*p* < 0.05;

<sup>\*\*</sup>*p* < 0.01;

<sup>\*\*\*</sup>*p* < 0.001.

<sup>\*\*\*\*</sup>*p* < 0.1.

rhythm dysregulation [49], daytime dysfunction [48, 50], emotional problems [46, 51], and abnormal serotonin [52], all of which can increase the risk of suicidal behavior [5, 53, 54]. It is notable that, after adjusting for covariates, the associations between insomnia only and subsequent suicidal behavior were no longer significant, but the effects of EDS only and insomnia + EDS were still significant. This finding is consistent with our previous study which demonstrated that EDS appears to be an independent predictor of subsequent suicidal behaviors in adolescents after adjusting for other sleep problems [27].

Longitudinal mediation analyses with different time intervals (W1 insomnia symptoms → W1 EDS → W2 suicidal behavior and W1 insomnia symptoms → W2 EDS → W2 suicidal behavior) demonstrated that EDS played significant mediating roles in the associations between insomnia symptoms and suicidal behavior (including any suicidal behavior, ST, SP, and SA) even when personal and family factors, sleep duration, social jetlag, anxiety/depression, and prior suicidal behavior were simultaneously considered as covariates. Although no research to date has connected insomnia symptoms to suicide risk through EDS, our findings are supported by the studies on the associations between insomnia and EDS and between EDS and suicidal behavior. For example, insomnia sufferers usually do not get enough sleep at night, often use hypnotic drugs, and may have circadian rhythm disturbance (i.e. social jetlag, delayed sleep phase, irregular bedtimes, and wake-up times) [49], all of which can lead to daytime sleepiness [55–57]. Besides, daytime sleepiness has been shown to have negative impacts on

self-regulation [58] and academic performance [59] and increases the risk of depression and anxiety [57], all of which in turn could increase the suicide risk of adolescents [27, 60, 61].

There is a growing interest in understanding the psychological processes driving the relationship between sleep disturbance and suicide. For example, based on interpersonal theory [62] and the integrated motivational–volitional model [63] of suicide, several studies examined hypotheses that insomnia may influence suicidal behavior indirectly through thwarted belongingness [64, 65], defeat and entrapment [15, 16]. Our finding that EDS mediated the effect of insomnia symptoms on suicidal behavior extends the limited literature by explaining their linkage from the physiological perspective. In the practice setting, compared with psychological problems, it is more comfortable to report sleep problems and more amenable to accepting treatment of sleep problems for adolescents, which may provide an additional avenue to reduce youth suicide risk. School-based programs should be designed to assess sleep state of students routinely and improve their knowledge of sleep, including awareness of the potential outcomes of poor sleep, keeping the sleeping environment quiet and comfortable, avoiding heavy meals, caffeine, and excessive digital media use before bedtime, or maintaining regular naps to avoid daytime sleepiness. For clinicians, it is necessary to timely assess and manage insomnia and EDS for the prevention of suicidal behavior in adolescents.

This study has several strengths including the first study to examine the mediating role of EDS in the insomnia–suicidal behavior link, longitudinal data collection in a large community



**Table 4.** Associations of baseline insomnia symptoms on subsequent suicidal behavior via EDS at 1-year follow-up

Paths	Unadjusted model		Adjusted model	
	OR	95% CI	OR	95% CI
<b>Any suicidal behavior</b>				
W1 IS–W2 EDS (a)	1.56 <sup>***</sup>	1.33–1.84	1.50 <sup>***</sup>	1.26–1.78
W2 EDS–W2 SB (b)	2.44 <sup>***</sup>	2.06–2.88	2.50 <sup>***</sup>	2.08–3.00
W1 IS–W2 SB (c)	1.31 <sup>*</sup>	1.06–1.61	1.11	0.89–1.38
W1 IS–W2 EDS–W2 SB (a*b)	1.08 <sup>***</sup>	1.04–1.11	1.07 <sup>***</sup>	1.03–1.10
$\frac{a+b}{a+b+c}$	0.452		0.491	
<b>Suicidal thought</b>				
W1 IS–W2 EDS (a)	1.56 <sup>***</sup>	1.33–1.85	1.50 <sup>***</sup>	1.26–1.78
W2 EDS–W2 ST (b)	2.56 <sup>***</sup>	2.15–3.04	2.67 <sup>***</sup>	2.22–3.22
W1 IS–W2 ST (c)	1.29 <sup>*</sup>	1.04–1.59	1.09	0.87–1.37
W1 IS–W2 EDS–W2 ST (a*b)	1.08 <sup>***</sup>	1.04–1.12	1.07 <sup>***</sup>	1.04–1.11
$\frac{a+b}{a+b+c}$	0.456		0.495	
<b>Suicide plan</b>				
W1 IS–W2 EDS (a)	1.56 <sup>***</sup>	1.32–1.84	1.50 <sup>***</sup>	1.26–1.78
W2 EDS–W2 SP (b)	2.50 <sup>***</sup>	1.92–3.26	2.47 <sup>***</sup>	1.85–3.30
W1 IS–W2 SP (c)	1.45 <sup>°</sup>	1.06–1.97	1.23	0.88–1.72
W1 IS–W2 EDS–W2 SP (a*b)	1.06 <sup>***</sup>	1.04–1.12	1.07 <sup>***</sup>	1.03–1.11
$\frac{a+b}{a+b+c}$	0.422		0.465	
<b>Suicide attempt</b>				
W1 IS–W2 EDS (a)	1.56 <sup>***</sup>	1.32–1.84	1.50 <sup>***</sup>	1.26–1.79
W2 EDS–W2 SA (b)	1.96 <sup>***</sup>	1.42–2.69	1.94 <sup>**</sup>	1.36–2.76
W1 IS–W2 SA (c)	1.77 <sup>*</sup>	1.24–2.51	1.44	0.99–2.12
W1 IS–W2 EDS–W2 SA (a*b)	1.06 <sup>**</sup>	1.02–1.09	1.05 <sup>**</sup>	1.01–1.08
$\frac{a+b}{a+b+c}$	0.375		0.422	

Adjusted model: adjusted for covariates described in Figure 1.

IS, insomnia symptoms; EDS, excessive daytime sleepiness; SB, suicidal behavior; ST, suicidal thought; SP, suicide plan; SA, suicide attempt; W1, wave 1; W2, wave 2; OR, odds ratios; CI, confidence intervals.

<sup>°</sup>p < 0.1;

<sup>\*</sup>p < 0.05;

<sup>\*\*</sup>p < 0.01;

<sup>\*\*\*</sup>p < 0.001.

sample of adolescents, building two models with different time intervals to test the hypothesis, and controlling for multiple covariates. However, these findings need to be interpreted with the following limitations. First, all data including sleep problems and suicidal behavior were collected by self-report, which may lead to bias. This may be particularly true for suicidal behaviors, which were assessed by single items [66]. However, these questions have been used to assess adolescent suicidal behaviors by the Centers for Disease Control and Prevention [67], Global School-Based Health Survey [68] and in multiple studies of Chinese adolescents [26, 69, 70]. The rates of suicidal behaviors are comparable to those reported in previous studies in Chinese adolescents [70, 71]. Nevertheless, it is important to measure suicidal behaviors using valid scales with multiple items to reduce measurement bias in future studies. Second, baseline sleep problems used in the current study were measured once and these sleep problems were probably temporary or acute. Further research is needed to measure sleep problems at multiple time points to explore the effects of chronic sleep problems or the trajectories of sleep problems on suicidal behavior and related mechanisms. Third, insomnia and EDS were measured by screening scales in the study, which differ from DSM-V diagnostic criteria. Although these scales have acceptable psychometric properties, it is unknown to what extent sleep problems reported here are clinically meaningful. Fourth, although demographic variables, sleep duration, social jetlag,

anxiety/depression, and prior suicidal behavior were statistically controlled, other factors, such as life stress, use of sleep medicine, antidepressants, and school schedules, which may be associated with insomnia, EDS, and suicidal behavior were not included in the study. Fifth, although the follow-up rate was 82.0%, 18% of participants lost to follow-up should be taken into consideration when interpreting the findings. Furthermore, although the sample size is large, all participants were recruited from Shandong province of China. It is unknown whether the findings can be generalized to other adolescent samples. Further research with diverse samples is needed.

In conclusion, the current study demonstrated that both insomnia symptoms and EDS were associated with increased risk of subsequent suicidal behavior over 1-year follow-up and that EDS mediated the link between insomnia symptoms and suicidal behavior. These findings provide a novel insight into the mechanism linking insomnia and suicide risk and stress the importance of screening and treatment of insomnia and EDS for potentially effective prevention of adolescent suicide.

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