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Loneliness mediates the association between sleep deficiency and fighting in school-aged adolescents: a 2-year longitudinal study

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Sleep deficiency is becoming increasingly common among adolescents and may lead to aggressive behaviour. This study investigated the association between sleep deficiency and fighting among 1946 school-aged adolescents (mean age: 12.2 ± 0.47 years) in Ningbo city through a two-year longitudinal study and explored the mediating roles of loneliness, sadness, and nervousness. A total of 552 (28.3%) reported sleep deficiency at baseline. During the follow-up period, 347 (17.8%) adolescents engaged in fighting. Sleep deficiency was significantly associated with an increased likelihood of fighting (OR: 1.91, 95% CI: 1.45–2.52) after adjusting for confounders. Compared with boys, girls with sleep deficiency presented a greater risk of fighting (OR: 2.61, 95% CI: 1.44–4.73 for girls; OR: 1.74, 95% CI: 1.27–2.39 for boys). This association persists among adolescents with unhealthy lifestyles. Loneliness partially mediated this relationship (indirect effect $\beta = 0.013$, $P < 0.05$, effect ratio = 12.26%), whereas sadness and nervousness had no significant mediating effect. Studies have shown that sleep deficiency independently predicts adolescent fighting behaviour, with loneliness playing a key mediating role. Interventions that improve sleep hygiene, reduce loneliness, and address lifestyle likelihood factors may help reduce violent behaviour in adolescents.

Keywords Sleep deficiency, Fighting, Adolescents, Loneliness, Mediation effect

Adolescent sleep deficiency has emerged as a critical public health challenge, marked by increasing global prevalence and multifaceted health consequences¹. Epidemiological studies have revealed that approximately 40% of adolescents in Europe and Asia experience sleep-related problems, with 20% meeting the criteria for chronic sleep deficiency^{2,3}. Alarming, sleep deprivation (< 8 h/night) affects more than 75% of senior high school students in some regions^{4,5}, with emerging evidence linking such deficits to impaired neurocognitive function⁶, academic underperformance⁷, and compromised social adaptation⁸. Sleep deficiency, encompassing both insufficient sleep duration and poor sleep quality⁹, defined as the AASM criteria (Pittsburgh Sleep Quality Index [PSQI] ≥ 5 or sleep duration < 8 h for adolescent)¹⁰, is further associated with behavioural dysregulation, including heightened aggression and violence^{11,12}. Notably, physical fighting—a prevalent manifestation of adolescent aggression—has been reported in 23.7% of youth populations¹³, with longitudinal data suggesting its predictive value for adult violence and suicidality^{14,15}.

The neurobiological mechanisms underlying the association between sleep deficiency and aggression involve prefrontal cortex dysfunction and dysregulated cortisol/serotonin activity, which may exacerbate impulsivity and reduce behavioural inhibition. Sleep deficiency has been shown to impair prefrontal cortex function, which plays a key role in behavioural regulation and executive control. This impairment is associated with increased

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levels of cortisol and serotonin, both of which have been implicated in the modulation of aggression and violent behaviour, including fighting^{16,17}. Moreover, sleep deficiency reduces inhibitory control, thereby increasing the likelihood of impulsive and aggressive responses¹⁸. Evidence from animal models further supports this association. In one study, mice subjected to forced wakefulness via a rotating drum exhibited fatal outcomes within 3 to 14 days. Notably, the cause of death was not solely attributable to sleep deficiency itself but rather to heightened aggression and fighting behaviour among the animals. These findings suggest that sleep deficiency may directly promote aggressive tendencies¹⁶.

Sleep deficiency, characterized by insufficient sleep duration and poor sleep quality, adversely affects daytime functioning and is influenced by multiple biological, psychological, and social factors^{9,19}. Previous studies have demonstrated that insufficient sleep duration can contribute to psychological and emotional disturbances, which may in turn mediate the relationship between sleep deficiency and aggressive behaviour. Interventions targeting psychological and emotional well-being have been shown to mitigate the aggression associated with sleep deficiency²⁰. Furthermore, other studies have reported a significant association between poor sleep quality and increased involvement in physical fights among adolescents, with psychological stress identified as a key mediating variable¹³. Sleep deficiency has also been linked to heightened vulnerability to negative emotional states, including depression, loneliness, anxiety, anger, confusion and fatigue^{21,22}. These findings highlight the importance of identifying specific mediating factors that may help explain the mechanisms underlying the association between sleep deficiency and aggressive behaviours such as fighting.

Cross-sectional studies posit that psychological states such as loneliness, sadness, and nervousness may bridge sleep deficits and aggression^{13,20,22,23}, although causal inferences remain constrained by methodological limitations. For example, sleep deprivation has been shown to amplify perceived loneliness, potentially creating a cyclical pattern of social withdrawal and reactive aggression^{13,23,24}. Despite these insights, longitudinal investigations controlling for lifestyle confounders (e.g., screen time, alcohol use) and evaluating the temporal mediating effects of psychological factors (such as loneliness, sadness, and nervousness) remain conspicuously absent from the literature. This two-year prospective cohort study addresses three primary objectives: (1) quantifying longitudinal associations between sleep deficiency and physical fighting in Chinese adolescents; (2) examining gender-specific vulnerability patterns; and (3) evaluating parallel temporal mediation effects of loneliness, sadness, and nervousness. We used social emotional learning theory²⁵ to construct a mediation model of psychological factors (such as loneliness, sadness, and nervousness) and proposed the following hypotheses (see Fig. 1):

H1 Baseline sleep deficiency independently predicts the incidence of fighting behaviour.

H2 Loneliness mediates the relationship between adolescent sleep deficiency and fighting behaviour.

H3 Sadness mediates the relationship between adolescent sleep deficiency and fighting behaviour.

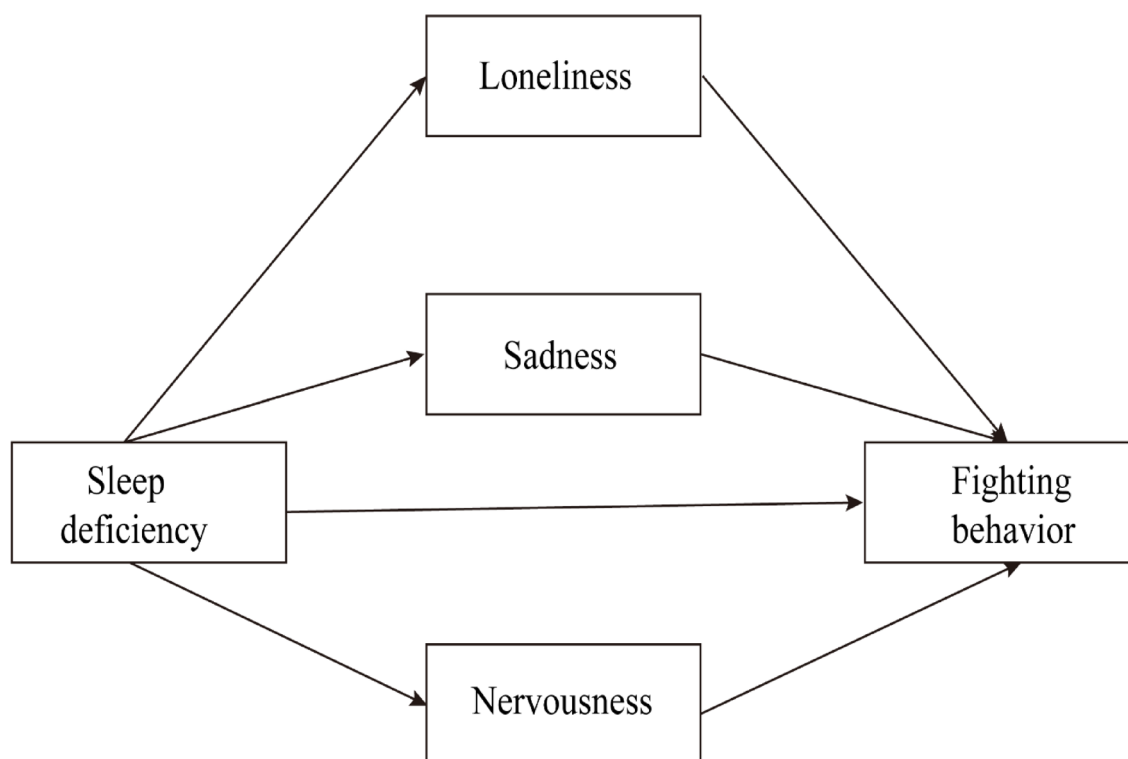


Fig. 1. Parallel mediation hypothesis model.

H4 Nervousness mediates the relationship between adolescent sleep deficiency and fighting behaviour.

By employing a rigorous mediation framework and controlling for key lifestyle covariates, this research advances the understanding of modifiable risk pathways for adolescent violence. These findings have direct implications for the development of sleep hygiene interventions and targeted mental health support to mitigate aggression in youth populations.

Methods

Sampling procedure and participants

This school-based prospective cohort study was conducted by the Ningbo Centers for Disease Control and Prevention (CDC) in Ningbo, China. The baseline survey was administered from October–November 2016, and subsequent evaluations were conducted in October 2017 and October 2018. The study adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the Ethics Review Committee of the Ningbo CDC (No. 201703). To ensure standardization of data collection, strict training was provided to all researchers before the project began to maintain consistency in survey management. Prior to participation, written informed consent from parents or legal guardians was obtained, and all the adolescents participated voluntarily. Before the questionnaire was distributed, detailed explanations about the research objectives were provided to the participants. The collected data will only be used for scientific research purposes and will not be disclosed to the public. The participants were also informed that they had the right to withdraw from the investigation at any time without any consequences. Written informed consent was obtained from parents or legal guardians before participation. All the participants completed the questionnaire within one hour of normal class time.

This study used a school-based cluster random sampling method to select seventh-grade students from 13 middle schools across 10 districts of Ningbo City as study participants. This study targeted healthy adolescents, excluding those with major illnesses or value deficiencies. After the investigation was completed, the responses were reviewed, and questionnaires with incomplete or unreasonable answers were deemed invalid and excluded from analysis. Finally, 1946 valid questionnaires were obtained, for a response rate of 89.93%. There were 943 girls and 1003 boys, with an average age of 12.2 ± 0.47 years. The research flow chart is presented in Fig. 2.

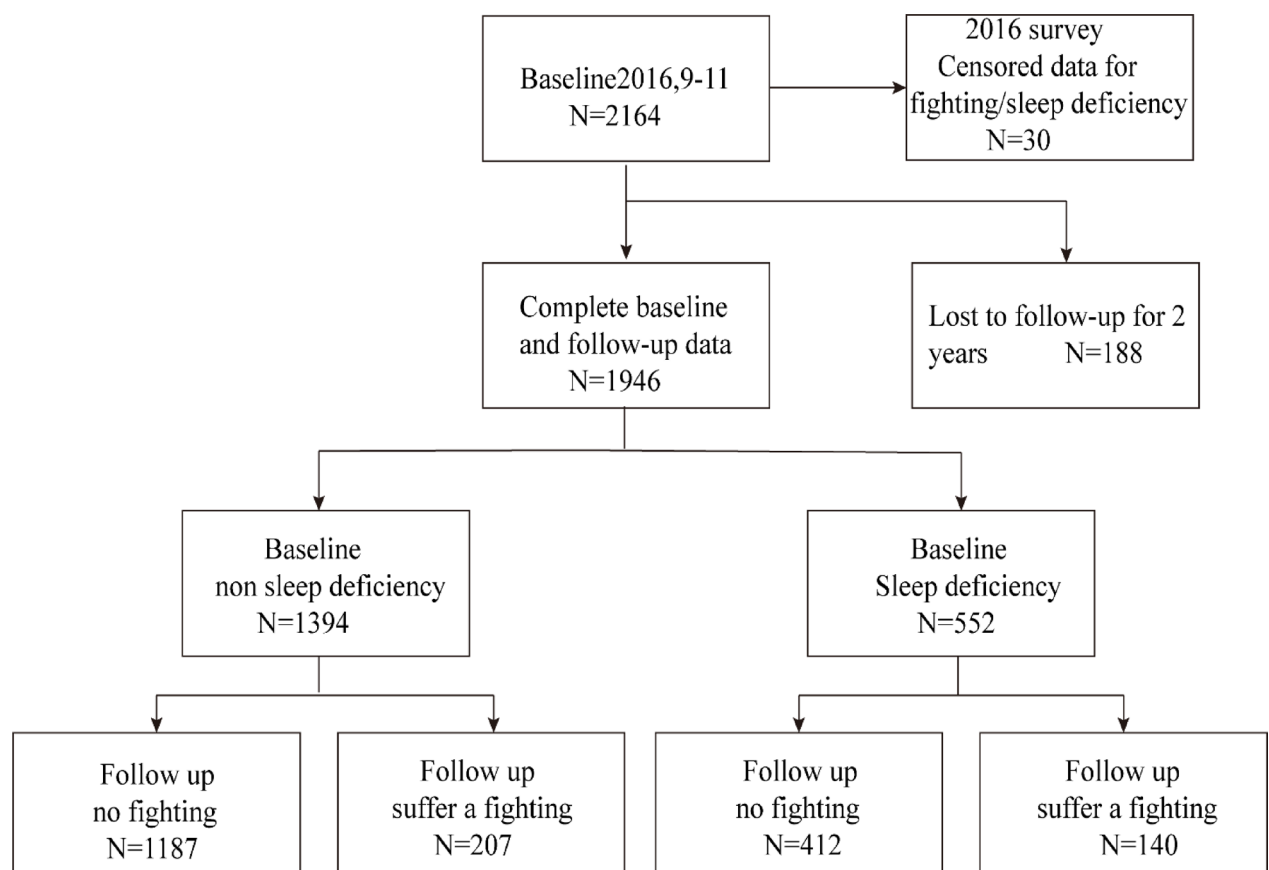


Fig. 2. The flow chart of this study.

Research tools

Data collection utilized a standardized, self-report questionnaire adapted from the U.S. Youth Risk Behaviour Survey (YRBS) developed by the CDC^{26–28}. The questionnaire assesses, among other things, sleep duration and quality, physical activity, screen time, smoking, alcohol use, and mental health. It is scored via self-reported multiple-choice or dichotomous classification, with higher scores indicating a greater prevalence of health risk behaviours. In addition, a demographic survey was included in this study. The YRBS questionnaire has good reliability and cultural adaptability and is widely used for adolescent health surveillance^{29,30}. Trained investigators distributed and collected the questionnaires onsite, ensuring completeness.

Measures

Sleep deficiency

Sleep quality was assessed at baseline via the Pittsburgh Sleep Quality Index (PSQI). A PSQI score ≥ 5 indicated poor sleep quality^{31,32}. Sleep duration was classified into three categories on the basis of the National Sleep Foundation's recommendations for adolescents (12–13 years): <8 h, 8–9 h, and ≥ 9 h. Sleep deprivation was defined as <8 h of sleep per night, whereas ≥ 9 h indicated sufficient sleep²⁸. According to the American Academy of Sleep Medicine (AASM), insufficient sleep and poor sleep quality are collectively categorized as sleep deficiency^{33,34}.

Fighting behaviour

Fighting behaviour was assessed with the following question: “In the past 12 months, how many times have you been in physical fighting?”. Fighting behaviour was defined as engaging in at least one fight (1 = yes, 0 = no)³⁵. Adolescents who reported at least one fight during the 2017 and 2018 follow-ups were classified as having engaged in fighting.

Mental health factors

Baseline mental health factors included loneliness, sadness, and nervousness³⁶. Loneliness was measured by the following question: “In the past 12 months, how often did you feel lonely?” with responses ranging from 0 (never) to 4 (always). Sadness and nervousness were assessed by asking “In the past 12 months, have you ever felt sad?” (1 = Yes, 0 = No). “In the past 12 months, have you ever felt nervous?” (1 = Yes, 0 = No). These measures are widely validated for assessing adolescent emotional well-being³⁷.

Lifestyle factors and behaviours

Lifestyle behaviours, including physical activity, screen time, smoking, and alcohol use, are assessed at baseline^{38,39}. Physical activity was defined as engaging in moderate to vigorous exercise or muscle-strengthening activities at least once a week (1 = yes, 0 = no). Excessive screen time was defined as more than 2 h per day of TV or computer use (1 = yes, 0 = no). Smoking and drinking were assessed by asking whether the adolescents smoked or consumed alcohol at least once in the past month (1 = yes, 0 = no).

Covariates

Demographic information, including gender, age, parental marital status, and parental education level, was collected at baseline. These covariates are known to influence sleep patterns and behavioural outcomes²⁰.

Statistical analysis

Descriptive statistics were used to summarize the characteristics of the adolescents by sleep deficiency and fighting behaviour status. The Kolmogorov-Smirnov test was used to assess data normality. Normally distributed continuous data are expressed as the mean \pm standard deviation (SD), whereas nonnormally distributed data are presented as the median and interquartile range (IQR). Categorical data are expressed as frequencies (percentages).

Between-group comparisons were conducted via independent t tests or analysis of variance (ANOVA) for continuous variables and chi-square tests for categorical variables. Logistic regression models were applied to assess the association between sleep deficiency and fighting behaviour, with the results reported as adjusted odds ratios (ORs) and 95% confidence intervals (CIs) after adjusting for the confounders of age, parental marital status, education level, physical activity, screen time, smoking status and alcohol use.

Subgroup analyses were performed to examine the moderating effects of physical activity, screen time, smoking, and alcohol use on sleep deficiency and fighting behaviour, and forest plots were used to visualize ORs and interactions. The mediating effects explored the indirect effects of loneliness, sadness, and nervousness on the relationship between sleep deficiency and fighting. The “lavaan” package in R was used for parallel mediation effects analysis, and bootstrap resampling was used to estimate the indirect effect. The bias-corrected 95% CI was calculated via bootstrap resampling to ensure the robustness of the inference. If the confidence interval did not contain zero, the mediation effect was considered statistically significant.

All analyses were conducted via R software (version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria). A two-tailed P value of <0.05 was considered statistically significant.

Results

Descriptive analysis

Of the 2164 students initially enrolled, 30 were excluded because of missing data, and 188 were lost to follow-up, resulting in a final sample of 1946 adolescents (Table 1; Fig. 2). The mean age of the participants was 12.2 ± 0.47 years. Sleep deficiency was reported by 552 adolescents (28.3%), with similar prevalence rates among boys (28.31%) and girls (28.42%). Significant differences were detected between adolescents with and without sleep

Characteristics	Total (n = 1946)	No (n = 1394)	Yes (n = 552)	P value
Age, years, mean (SD*)	12.2 (0.47)	12.2 (0.48)	12.2 (0.45)	0.335
Gender, n (%)				0.999
Girls	943 (48.46%)	675 (71.58%)	268 (28.42%)	
Boys	1003 (51.54%)	719 (71.68%)	284 (28.31%)	
Parents' marriage status, n (%)				0.198
Divorced/widowed/separated	144 (7.40%)	96 (66.67%)	48 (33.33%)	
Married	1776 (91.26%)	1280 (72.07%)	496 (27.93%)	
Parents' education at college level, n (%)				0.554
Both had college degree	260 (13.36%)	180 (69.23%)	80 (30.77%)	
Only one of them had college degree	248 (12.74%)	176 (70.97%)	72 (29.03%)	
None of them had college	1327 (68.19%)	961 (72.42%)	366 (27.58%)	
Moderate physical activity (≥ 1 day/wk), n (%)				0.094
No	144 (7.40%)	94 (65.28%)	50 (34.72%)	
Yes	1801 (92.55%)	1300 (72.18%)	501 (27.82%)	
Mild physical activity (≥ 1 day/wk), n (%)				0.023
No	125 (6.42%)	78 (62.40%)	47 (37.60%)	
Yes	1819 (93.47%)	1315 (72.29%)	504 (27.71%)	
Muscle strengthening activity (≥ 1 day/wk), n (%)				0.037
No	753 (38.69%)	519 (68.92%)	234 (31.08%)	
Yes	1192 (61.25%)	875 (73.41%)	317 (26.59%)	
TV screen (≥ 2 h/day), n (%)				< 0.001
No	1486 (76.36%)	1100 (74.02%)	386 (25.98%)	
Yes	460 (23.64%)	294 (63.91%)	166 (36.09%)	
Internet screen (≥ 2 h/day), n (%)				< 0.001
No	1556 (79.96%)	1158 (74.42%)	398 (25.58%)	
Yes	388 (19.94%)	236 (60.82%)	152 (39.18%)	
Cigarette use, n (%)				0.016
No	1814 (93.22%)	1312 (72.33%)	502 (27.67%)	
Yes	132 (6.78%)	82 (62.12%)	50 (37.88%)	
Alcohol use, n (%)				< 0.001
No	1154 (59.30%)	877 (76.00%)	277 (24.00%)	
Yes	792 (40.70%)	517 (65.28%)	275 (34.72%)	
Loneliness, n (%)				< 0.001
Never	1011 (51.95%)	827 (81.80%)	184 (18.20%)	
Occasion	645 (33.14%)	438 (67.91%)	207 (32.09%)	
Sometime	197 (10.12%)	96 (48.73%)	101 (51.27%)	
Regularly	50 (2.57%)	17 (34.00%)	33 (66.00%)	
Always	43 (2.21%)	16 (37.21%)	27 (62.79%)	
Sadness, n (%)				< 0.001
No	1661 (85.35%)	1253 (75.44%)	408 (24.56%)	
Yes	285 (14.65%)	141 (49.47%)	144 (50.53%)	
Nervousness, n (%)				< 0.001
No	1326 (68.14%)	1037 (78.21%)	289 (21.79%)	
Yes	619 (31.81%)	356 (57.51%)	263 (42.49%)	

Table 1. Baseline and follow-up characteristics by baseline sleep deficiency.

deficiency in terms of mild physical activity, muscle-strengthening activity, screen time, smoking, and alcohol use ($P < 0.05$). Adolescents with sleep deficiency reported higher levels of loneliness, sadness, and nervousness ($P < 0.05$).

Likelihood of fighting behaviour during follow-up

During the two-year follow-up, 347 adolescents (17.8%) engaged in fighting. Fighting was significantly associated with gender, parental marital status, mild physical activity, internet screen use, smoking, alcohol use, and mental health outcomes (loneliness, sadness, and nervousness) ($P < 0.05$, Table 2). Boys were more likely to fight (28.41%) than girls were (6.57%). Adolescents from households with divorced, widowed, or separated parents were more likely to fight. Additionally, adolescents who reported fighting were more prone to feelings of loneliness, sadness, and nervousness ($P < 0.05$).

Characteristics	Total (n = 1946)	No (n = 1599)	Yes (n = 347)	P value
Age, years, mean (SD*)	12.2 (0.47)	12.2 (0.48)	12.2 (0.46)	0.802
Gender, n (%)				<0.001
Girls	943(48.46%)	881(93.43%)	62(6.57%)	
Boys	1003(51.54%)	718(71.59%)	285(28.41%)	
Parental marriage status, n (%)				0.008
Divorced/widowed/separated	144 (7.40%)	106 (73.61%)	38 (26.39%)	
Married	1776(91.26%)	1470(82.77%)	306(17.23%)	
Parental education at college level, n (%)				0.910
Both had college degree	260 (13.36%)	216 (83.08%)	44 (16.92%)	
Only one of them had college degree	248 (12.74%)	203 (81.85%)	45 (18.15%)	
None of them had college	1327(68.19%)	1088(81.99%)	239(18.01%)	
Moderate physical activity (≥ 1 day/wk), n (%)				0.123
No	144 (7.40%)	111 (77.08%)	33 (22.92%)	
Yes	1801(92.55%)	1487(82.57%)	314(17.43%)	
Mild physical activity (≥ 1 day/wk), n (%)				0.025
No	125 (6.42%)	93 (74.40%)	32 (25.60%)	
Yes	1819(93.47%)	1505(82.74%)	314(17.26%)	
Muscle strengthening activity (≥ 1 day/wk), n (%)				0.232
No	753 (38.69%)	629 (83.53%)	124(16.47%)	
Yes	1192(61.25%)	969 (81.29%)	223(18.71%)	
TV screen (≥ 2 h/day), n (%)				0.082
No	1486(76.36%)	1234(83.04%)	252(16.96%)	
Yes	460 (23.64%)	365 (79.35%)	95 (20.65%)	
Internet screen (≥ 2 h/day), n (%)				<0.001
No	1556(79.96%)	1303(83.74%)	253(16.26%)	
Yes	388(19.94%)	294(75.77%)	94(24.23%)	
Cigarette use, n (%)				<0.001
No	1814(93.22%)	1509(83.19%)	305(16.81%)	
Yes	132(6.78%)	90(68.18%)	42 (31.82%)	
Alcohol use, n (%)				<0.001
No	1154(59.30%)	1003(86.92%)	151(13.08%)	
Yes	792 (40.70%)	596 (75.25%)	196(24.75%)	
Loneliness, n (%)				<0.001
Never	1011(51.95%)	861 (85.16%)	150(14.84%)	
Occasion	645 (33.14%)	524 (81.24%)	121(18.76%)	
Sometime	197 (10.12%)	150 (76.14%)	47 (23.86%)	
Regularly	50 (2.57%)	35 (70.00%)	15 (30.00%)	
Always	43 (2.21%)	29(67.44%)	14 (32.56%)	
Sadness, n (%)				<0.001
No	1661(85.35%)	1390(83.68%)	271(16.32%)	
Yes	285 (14.65%)	209 (73.33%)	76 (26.67%)	
Nervousness, n (%)				<0.001
No	1326(68.14%)	1126(84.92%)	200(15.08%)	
Yes	619 (31.81%)	473 (76.41%)	146(23.59%)	

Table 2. Characteristics of the study subjects according to fighting behaviour.

Longitudinal associations between sleep deficiency and fighting behaviour

Multivariate logistic regression revealed that adolescents with sleep deficiency at baseline were significantly more likely to be fighting during follow-up (OR: 1.95, CI: 1.53–2.48; Table 3). After adjusting for age, parental marital status, education level, physical activity, screen time, cigarette use, and alcohol use, sleep deficiency remained an independent predictor of fighting (OR: 1.91, 95% CI: 1.45–2.52).

Among boys, sleep deficiency increased the likelihood of fighting (OR: 1.84, 95% CI: 1.37–2.46), with the association persisting after adjustment (OR: 1.74, 95% CI: 1.27–2.39). Girls with sleep deficiency presented a greater likelihood of fighting (OR: 3.13, 95% CI: 1.86–5.29), and although the adjusted OR decreased (OR: 2.61, 95% CI: 1.44–4.73), their likelihood remained greater than that of boys (girls OR: 2.61 vs. boys OR: 1.74).

Sleep deficiency	Fighting		Crude		Multi-adjusted	
	No	Yes	OR (95%CI)	P value	OR (95%CI)	P value
Total (<i>n</i> = 1946)						
No	1187	207	Ref		Ref	
Yes	412	140	1.95 (1.53–2.48)	<0.001	1.91 (1.45–2.52)	<0.001
Boys (<i>n</i> = 1003)						
No	541	178	Ref		Ref	
Yes	177	107	1.84 (1.37–2.46)	<0.001	1.74 (1.27–2.39)	<0.001
Girls (<i>n</i> = 943)						
No	646	29	Ref		Ref	
Yes	235	33	3.13 (1.86–5.29)	<0.001	2.61 (1.44–4.73)	0.001

Table 3. Association of sleep deficiency at baseline with fighting at follow-up.

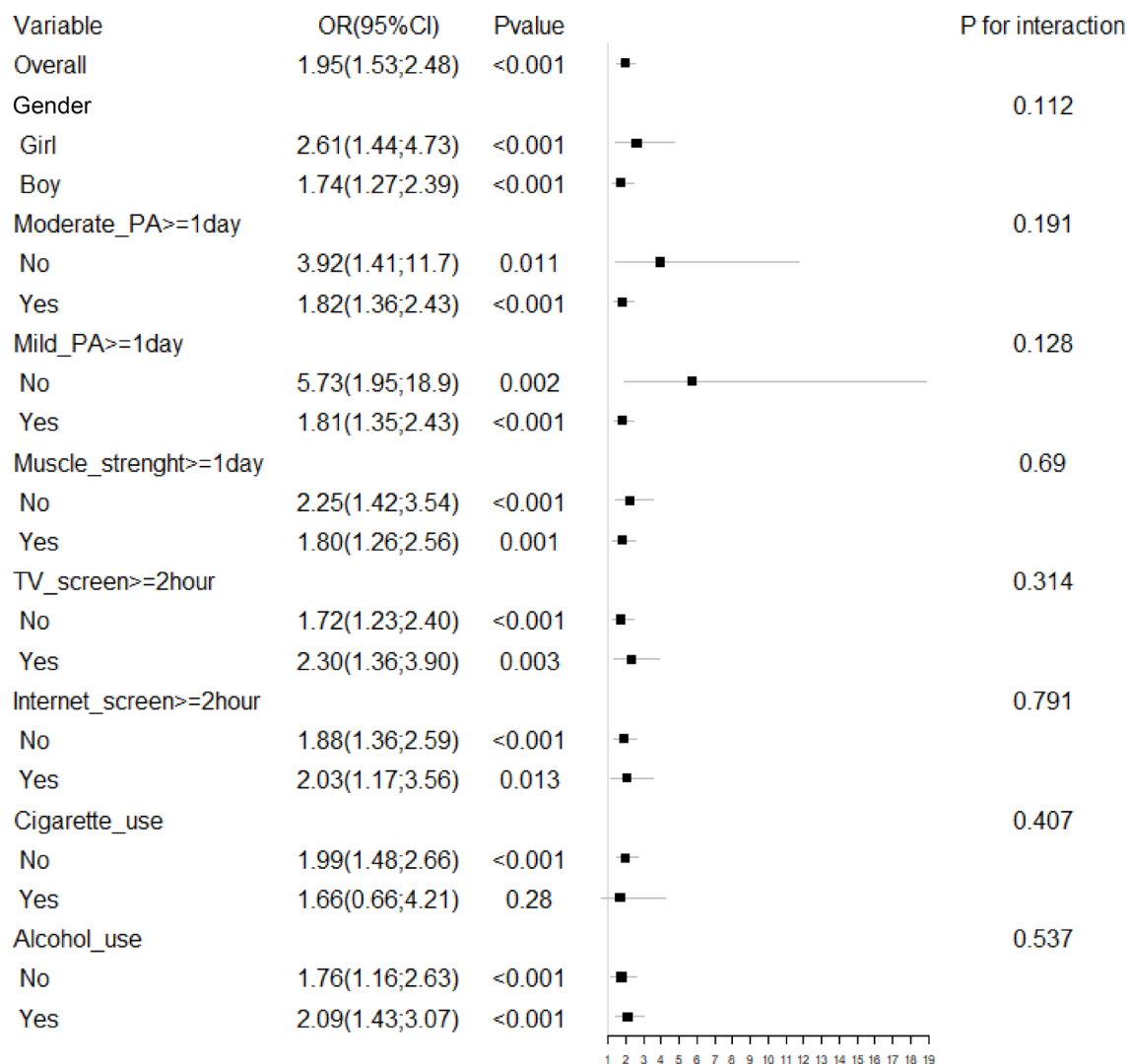


Fig. 3. Forest plot of subgroup analysis of the longitudinal association between sleep deficiency and fighting behaviour.

Subgroup analyses

As illustrated in Fig. 3, compared with their peers without sleep deficiency, adolescents with sleep deficiency were almost twice as likely to engage in fighting (OR: 1.95, 95% CI: 1.53–2.48, $P < 0.001$). Compared with boys, girls with sleep deficiency were more likely to fight (OR: 2.61, 95% CI: 1.44–4.73 for girls; OR: 1.74, 95% CI: 1.27–2.39 for boys). Adolescents with or without moderate physical activity and mild physical activity were more

Type of effect	Mediation pathway	Effect size	SE	Bootstarp 95% CI	P value	Ratio of effect
Direct effect	Sleep deficiency→Fighting behavior	0.076	0.022	0.035, 0.119	<0.001	71.70%
Mediation effect	Sleep deficiency→loneliness→Fighting behavior	0.013	0.007	0.001, 0.027	0.042	12.26%
	Sleep deficiency→sadness→Fighting behavior	0.007	0.005	-0.002, 0.017	0.156	6.60%
	Sleep deficiency→nervousness→Fighting behavior	0.009	0.005	0.000, 0.021	0.058	8.49%
Total mediation effect		0.030	0.007	0.016, 0.045	<0.001	28.3%
Total effect		0.106	0.021	0.064, 0.146	<0.001	

Table 4. Mediation analysis of psychological factors (loneliness, sadness, and nervousness).

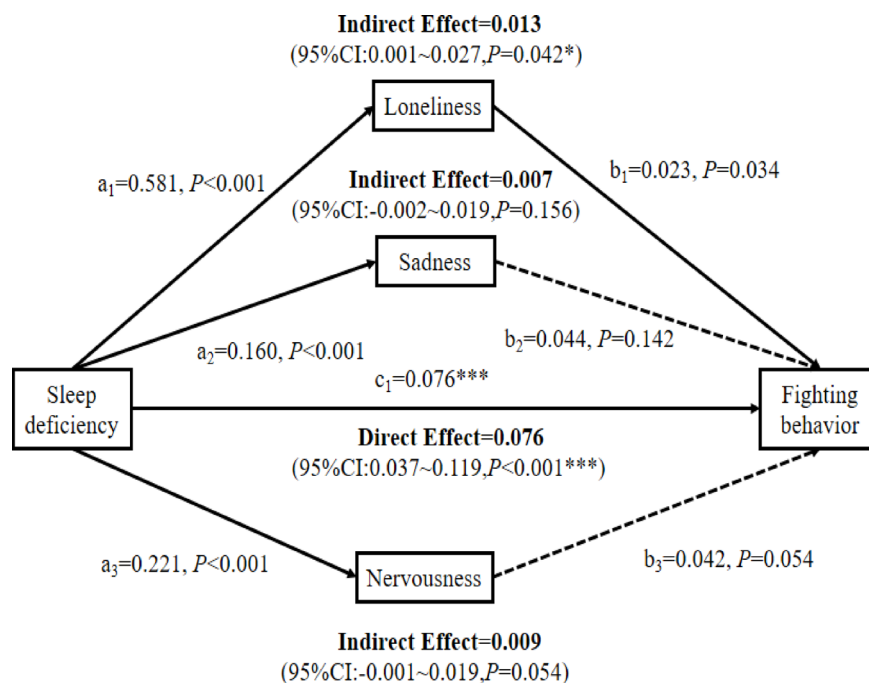


Fig. 4. Longitudinal associations between sleep deficiency and fighting behaviour are multiple parallel mediated by loneliness, sadness, and nervousness.

likely to fight (all $P < 0.01$). Excessive screen time and alcohol use were associated with a greater likelihood of fighting, although the interaction effects were not statistically significant.

Mediation analysis

Mediation analysis explored the roles of loneliness, sadness, and nervousness in the association between sleep deficiency and fighting (Table 4; Fig. 4). Sleep deficiency was positively correlated with fighting ($\beta = 0.076$, $P < 0.05$) and significantly predicted higher levels of loneliness, sadness, and nervousness. Loneliness, in turn, was positively associated with fighting.

Loneliness partially mediated the relationship between sleep deficiency and fighting (indirect effect $\beta = 0.013$, $P < 0.05$; effect ratio = 12.26%). However, sadness and nervousness exhibited no significant mediating effects ($P > 0.05$), suggesting that the influence of sleep deficiency on fighting is driven primarily by loneliness.

Discussion

Key findings

This 2-year prospective cohort study confirmed that sleep deficiency is an independent likelihood factor for fighting among adolescents (OR: 1.91, 95% CI: 1.45–2.52). Notably, girls with sleep deficiency were more likely to fight than boys were (girls; OR: 2.61 vs. boys; OR: 1.74). Subgroup analysis indicated that the relationship between sleep deficiency and fighting remained significant in adolescents with low physical activity, excessive screen time, and alcohol use (all $P < 0.05$). While sleep deficiency was associated with loneliness, sadness, and nervousness, only loneliness had a significant mediating effect on fighting.

Sleep deficiency and fighting: a complex relationship

Consistent with previous research, this study highlights the role of sleep deficiency in increasing aggressive and violent behaviour. Adolescents with poor sleep quality are up to 3.61 times more likely to exhibit aggressive

tendencies than those with sufficient, high-quality sleep^{18,20}. In our cohort, adolescents with sleep deficiency were twice as likely to fight as their peers were, underscoring the predictive value of sleep deficiency for adolescent aggression. The slightly lower odds observed in this study ($OR=2$) than in the literature may stem from the narrower classification of sleep deficiency, which focuses primarily on sleep duration and low sleep quality, whereas other studies included broader categories such as insomnia and sleep deprivation^{18,20}. The relationship between sleep deficiency and fighting may be explained by disruptions in neurocognitive and emotional mechanisms. Sleep deprivation impairs prefrontal cortex function, elevates cortisol and serotonin levels, and fosters antisocial and aggressive behaviours^{40,41}. Poor sleep quality may further exacerbate impulsivity and anger, contributing to aggressive outbursts^{42,43}.

Interestingly, this study revealed that while boys were more likely to fight overall, girls with sleep deficiency were more likely to fight than their boy counterparts were. This finding contradicts previous research suggesting that boys with sleep deficiency are at greater likelihood of violence^{44,45}. This discrepancy may reflect gender-specific emotional responses to sleep deficiency. Research by Short et al. (2015) suggests that adolescent girls are more emotionally vulnerable to sleep loss and exhibit greater susceptibility to depression and anxiety, which may heighten aggression⁴⁶. Hormonal differences and variations in the stress response may also contribute to this increased likelihood^{47,48}. Further investigations into the sex-specific effects of sleep deficiency on aggression are warranted.

Lifestyle factors and behavioural synergy

The link between sleep deficiency and fighting is modulated by lifestyle factors, with adolescents engaging in unhealthy behaviours being at heightened likelihood. Our findings align with those of previous studies demonstrating that adolescents who lack physical activity, spend excessive time on screens, and consume alcohol are more likely to experience both sleep deficiency and aggression. Physical inactivity is known to impair sleep quality in conjunction with emotional dysregulation and impulsivity, which in turn increase the likelihood of violent behavior⁴⁹. Moderate physical exercise can promote the mental health of adolescents, alleviate insomnia symptoms, and improve sleep quality^{50,51}. Excessive screen time further exacerbates sleep deficiency by disrupting melatonin secretion and interfering with circadian rhythms⁵². Adolescents who reported prolonged screen exposure were more likely to experience sleep deficiency and engage in fighting, supporting the need for interventions aimed at reducing screen use. Similarly, adolescents who consumed alcohol presented an increased likelihood of sleep deficiency and fighting, reinforcing the established link between substance use and aggression^{53,54}. Alcohol disrupts the sleep-wake cycle and impairs impulse control, increasing the likelihood of aggressive behaviours. This highlights the importance of addressing substance use as part of comprehensive interventions targeting adolescent violence and sleep problems.

The mediating role of loneliness

Mental health factors, particularly loneliness, have emerged as significant mediators of the association between sleep deficiency and fighting. Adolescents with higher levels of loneliness were more likely to engage in fighting, and loneliness partially mediated the relationship between sleep deficiency and aggression (indirect effect $\beta=0.013$, $P<0.05$; effect ratio = 12.26%). Conversely, sadness and nervousness did not exhibit a significant mediating effect.

These findings are consistent with those of previous studies indicating that sleep deprivation exacerbates loneliness, which in turn increases the likelihood of aggressive behaviour^{23,42,55,56}. Adolescents experiencing sleep deficiency often report elevated levels of psychological distress, which contributes to emotional dysregulation and impulsive behaviour. Addressing loneliness through psychological interventions may therefore reduce the likelihood of fighting in adolescents with sleep deficiency.

Previous studies have also demonstrated that states of loneliness and anxiety can negatively impact sleep quality, creating a bidirectional relationship that fuels aggression¹³. This underscores the importance of prioritizing adolescent mental health, as interventions targeting loneliness and emotional well-being may concurrently mitigate sleep deficiency and reduce aggressive tendencies.

This study revealed that not all mental health variables serve as significant mediators in the pathway between sleep deficiency and aggressive behaviour. Sadness and nervousness may lead to internalized behaviours such as withdrawal and avoidance rather than externalized fighting behaviours, which may explain why their mediating effect is not significant^{57,58}. Although both sadness and nervousness are correlated with sleep deficiency and fighting, their influence may be moderated by additional factors such as coping mechanisms and levels of social support^{59,60}. In contrast, loneliness appears to exert a more persistent and cumulative effect on aggressive behaviour, potentially making it a more stable and reliable mediator in the relationship between sleep deficiency and fighting.

Strengths and limitations

This study contributes valuable longitudinal evidence on the relationship between sleep deficiency and adolescent fighting, providing insight into the causal pathway and potential mediating factors involved. The prospective design enhances the robustness of the findings, shedding light on long-term associations that cross-sectional studies cannot capture.

However, several limitations should be acknowledged. The reliance on self-reported data introduces the possibility of recall bias and misreporting. Future studies should incorporate objective measures, such as actigraphy or polysomnography, to increase data accuracy⁶¹. Additionally, the study population was limited to a specific region, which may restrict the generalizability of the findings. Replication in diverse cultural and geographic contexts is essential to validate these results and explore potential variations.

Conclusion

This study highlights sleep deficiency as an independent likelihood factor for adolescent fighting, with the likelihood being greater among girls and adolescents with unhealthy lifestyles. Loneliness plays a critical mediating role in this relationship, emphasizing the need for comprehensive public health interventions to address sleep, lifestyle, and mental health. Early intervention strategies that promote better sleep hygiene, encourage physical activity, reduce screen time, and address alcohol use may reduce both sleep deficiency and aggressive behaviour. Additionally, psychological interventions aimed at alleviating loneliness and improving emotional well-being could further mitigate the likelihood of fighting but also improve overall mental health and promote healthier development among school-aged adolescents, thereby reducing the health burden and social costs associated with youth violence at a broader societal level.

Data availability

Upon reasonable request, the corresponding author will provide the dataset.

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Author contributions

Wei Wei: Writing – original draft, Data curation, Conceptualization. Lu Pan: Formal analysis, Data curation. Si-Jia Wang: Conceptualization, Investigation. Si-Xuan Li: Conceptualization, Investigation. Qing-Hai Gong: Resources, Methodology, Project administration, Funding acquisition. Xin Xiao: Methodology, Visualization, Software, Writing–review & editing, Funding acquisition.

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Ethics declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This study adhered to the ethical principles outlined in the Declaration of Helsinki and received approval from the Ethics Review Committee of the Ningbo CDC (No. 201703). All research procedures and data collection were performed in a manner compliant with the related legal requirements.

Informed consent

Written informed consent was obtained from parents or legal guardians before participation.

Additional information

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