



Association between adverse childhood experiences and sleep quality, emotional and behavioral problems and academic achievement of children and adolescents

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Abstract

The impact of adverse childhood experiences (ACEs) on adult health has been extensively examined, but the association between ACEs and sleep, emotion, behavior and academic outcomes of children and adolescents is not well known. A total of 6363 primary and middle school students were included to examine the effect of ACEs on sleep quality, emotional and behavioral problems and academic achievement and further explore the mediation role of sleep quality and emotional and behavioral problems. Children and adolescents with ACE exposure had 1.37 times risk of poor sleep quality (adjusted odds ratio [OR] = 1.37, 95% confidence interval [CI]: 1.21–1.55), 1.91 times risk of emotional and behavioral problems (adjusted OR = 1.91, 95%CI: 1.69–2.15) and 1.21 times risk of self-reported lower academic achievement (adjusted OR = 1.21, 95%CI: 1.08–1.36). Most types of ACEs were significantly associated with poor sleep quality, emotional and behavioral problems and lower academic achievement. There were dose-response relationships between cumulative ACE exposure and risk of poor sleep quality, emotional and behavioral problems, and lower academic achievement. Sleep quality and emotional and behavioral performance mediated 45.9% of the effect of ACEs exposure on math scores and 15.2% of the effect of ACEs exposure on English scores. Early detection and prevention of ACEs among children and adolescents are urgent and essential, and targeted interventions for sleep and emotional and behavioral performance as well as early educational interventions are recommended for children with ACEs exposure.

Keywords Adverse childhood experiences · Sleep quality · Emotional and behavioral problem · Academic achievement

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Introduction

Adverse childhood experiences and its hazards on human health

Adverse childhood experiences (ACEs) are defined as series of traumatic events experienced before adulthood, such as abuse and neglect. Increasing efforts have been made worldwide tend to uncover consequences of ACEs and its potential mechanisms since ACEs were originally identified by Felitti et al [1]. Numerous studies have already documented the impact of adverse childhood experiences on human health, involving somatic disorders [2], psychopathological diseases [3], and even premature death [4]. Early screening for various health hazards of ACEs can help identify high-risk groups and implement interventions. However, evidences of these positive associations were mostly drawn from adult population, and little is known about how ACEs affect

pediatric population. Children and adolescents are in an important period of growth and development, during which various behavioral or mental problems will affect their future growth or long-term development. Consequently, interventions during this period can have a lasting impact on lifelong health [5]. Unfortunately, however, the healthy developments of various psychological status and social behaviors in childhood including sleep and emotional and behavioral problems are implied to be affected by the adverse experiences during growth. Additionally, sleep problems and emotional and behavioral problems are the most common mental problems in children and adolescents, but the relationship between them and ACEs is not exact and needs further examination.

Adverse childhood experiences and sleep problems

Sleep is a natural physiological phenomenon conserved across all animal species. Adequate and superior sleep is critical for somatic and cerebral neural development in adolescent and children [6, 7]. Sleep problems not only disturb the normal development and function, but also are closely associated with a variety of adverse physical and mental outcomes in later life [8–11]. Over the past few decades, although a few studies have identified the negative association between ACEs and sleep health such as short sleep duration, poor sleep quality, night awakenings and nightmare, most have focused on adults [12–14]. Despite the fact that the evidence linking ACEs and insomnia, sleep duration, and social jetlag (defined as a sleep-timing misalignment between school nights and weekend nights) of adolescents is emerging [15, 16], there is a gap that the evidence of the effect of childhood adversity on sleep quality of children and adolescents is extremely rare. Considering closely relationship between sleep problems and later medical or psychiatric conditions [10], exploring how ACEs affect sleep is an important first step in providing targeted sleep interventions to these vulnerable populations.

Adverse childhood experiences and emotional and behavioral problems

Emotional and behavioral problems are also common in children and adolescents. In the United States, approximately 10.8 million children aged 3–17 years old had current depression, anxiety or behavioral problems [17]. In addition, emotional and behavioral problems in early childhood can trigger health risk behaviors in later childhood and also increase the risk of clinical mental illness and physical health problems in the future [18, 19]. Thus, extensively exploring factors affecting the genesis of emotional and behavioral problems in childhood are important and meaningful. Currently, the evidence on associations between ACEs and emotional and behavioral outcomes of youth is growing but the

conclusions are inconsistent. Findings from cohort studies have identified that ACEs' exposure in early life was strongly associated with later externalizing and internalizing behaviors [20, 21]. A meta-analysis of studies in mainland China has demonstrated that physical abuse, emotional abuse, and neglect are linked to a wide range of behavioral problems in childhood [22]. Nevertheless, a previous longitudinal study has found that compared to children who were exposed to fewer ACEs in early childhood, children exposed to higher numbers of early ACEs significantly show more externalizing but not internalizing problems [23]. However, a previous meta-analysis has found that some types of early life adversities such as poverty and natural disaster are not associated with depression in childhood and adolescence [24]. These inconsistent findings imply that more researches are encouraged to be conducted to examine the accurate association between ACEs and emotional and behavioral problems.

Adverse childhood experiences and academic achievement

Academic achievement is an important element for school-age children and closely correlated with their future and employment. Poor academic achievement during childhood has been demonstrated to be a significant risk factor for subsequent series problem behavior [25, 26] and psychological problems [27, 28]. Academic achievement of children is easily affected by multiple factors including external social and environmental factors and internal biological factors. In recent years, the association between ACEs and academic performance or achievement (e.g, lower educational achievements, grade retention) has been revealed by few studies [29–31], but the evidence on Chinese adolescents is rare. Although two studies in Chinese children and adolescent have revealed the association between psychological abuse and neglect and academic outcomes [30, 31], the consequence of other types of ACEs on academic achievements is not clear. In addition, the pathway of how ACEs affect the academic level is still unclear, and the mediating effect of potential intermediate factors deserves further exploration.

The potential mediation roles of sleep problems and emotional and behavioral problems on the association between ACEs and academic achievement

As described above, it has been demonstrated that both sleep and behavior can be affected by ACEs. Moreover, poor sleep quality and emotional and behavioral problems are also indicated to be correlated with poor academic performance of adolescents. In terms of sleep, some epidemiological studies have already identified that sleep pattern and sleep problems are closely associated with academic performance of children and adolescents [32, 33]. Similarly, previous

longitudinal studies have also demonstrated that emotional and behavioral problems are significant inducements for poor academic outcomes [34, 35]. Therefore, synthesizing relevant evidence, it can be properly speculated that sleep quality and emotional and behavioral problems may play a mediation role on association between ACEs exposure and academic achievement. However, it is a gap that whether these potential mediation roles exist has not been elucidated yet.

Study hypothesis and the current study

A series of epidemiological studies have examined the association between sleep quality and emotional and behavioral problems of children and adolescents, and some findings have been identified that poor sleep quality can significantly affect emotion (e.g. anxiety or depression) and behavior of children, but non obvious reverse correlation existed [36, 37]. Thus, based on the evidence presented above, we proposed the following hypotheses: (1) ACEs can significantly and negatively affect the academic achievement of children and adolescents; (2) poor sleep quality and emotional and behavioral problems are potential consequences of ACE exposure and can further negatively affect academic achievement. Concisely, poor sleep quality and emotional and behavioral problems can mediate the adverse effect of ACE exposure on academic achievement; (3) poor sleep quality can positively affect emotional and behavioral problems of children, which plays an indirect role in the association between ACEs exposure and academic achievement. This study was, therefore, conducted in order to reveal the association between ACE exposure and sleep quality, emotional and behavioral problems, academic achievement of children and adolescents, and further explore the mediation role of sleep quality and emotional and behavioral problems on the association between ACEs exposure and academic achievement. The findings of this study will additionally provide evidence of the path how ACEs affect sleep, emotion, behavior and academic achievement of children and adolescents, and theoretical basis for prevention and intervention of ACEs hazards.

Methods

Participants

This study was a cross-sectional survey of mental and physical health of primary and middle school students in Anhui Province of China from October to December 2020 (During this period, the epidemic of COVID-19 had been completely under controlled in China, and all schools in our study sites had been open for several months and implemented

consistent the policies and measures for COVID epidemic). Briefly, fourth to ninth grade students from two to four schools in the north, middle and south of Anhui Province were selected as the potential participants. Students were selected according to pre-designed inclusion and exclusion criteria. After obtaining informed consent of eligible students, the information about mental and physical health of students was collected through a standard structured questionnaire. All questions of measurements were presented in Chinese without any translations. The survey initially recruited 7012 students, and a total of 6494 questionnaires were finally collected. With excluding the questionnaires with missing information on both ACE exposure and mental health, data for 6363 children were finally retained. The detailed recruitment and selection of participants were described in our previous study [38]. In this study, information of 6363 students was used for data analysis. The flow chart of participants' selection is presented in Fig. 1. Of 6363 students, the mean age was 12.31 ± 1.83 years and 54.6% were boys. The detailed information about participants is presented in Table 1. This study was approved by the institutional ethics board of Anhui Medical University. This study was performed and reported in accordance with Strengthening the Reporting of Observational Studies in Epidemiology guideline for cross-sectional studies.

Measurement

Adverse childhood experiences

In our study, 11 items of ACEs were measured. Emotional, physical and sexual abuse and emotional and physical neglect were assessed by Chinese version of Childhood Trauma Questionnaire-Short Form (CTQ-SF). Six items of family dysfunction (family members were addicted to gambling, drugs or alcohol; parents had been separated or divorced; mother suffered from domestic violence; family members had mental disorders; family members jailed for crimes; Family economy was extremely hard) were assessed through self-designed questions. If one item of ACEs was assessed as positive, it counted as one score. In our study, both binary outcome and cumulative scores of ACEs were used. The detailed description of ACEs measurement was presented in our previous study [38].

Sleep quality

The sleep quality of children and adolescents was assessed using the Pittsburgh Sleep Quality Index (PSQI) which is a self-rated questionnaire assessed seven components of sleep: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction [39]. PSQI

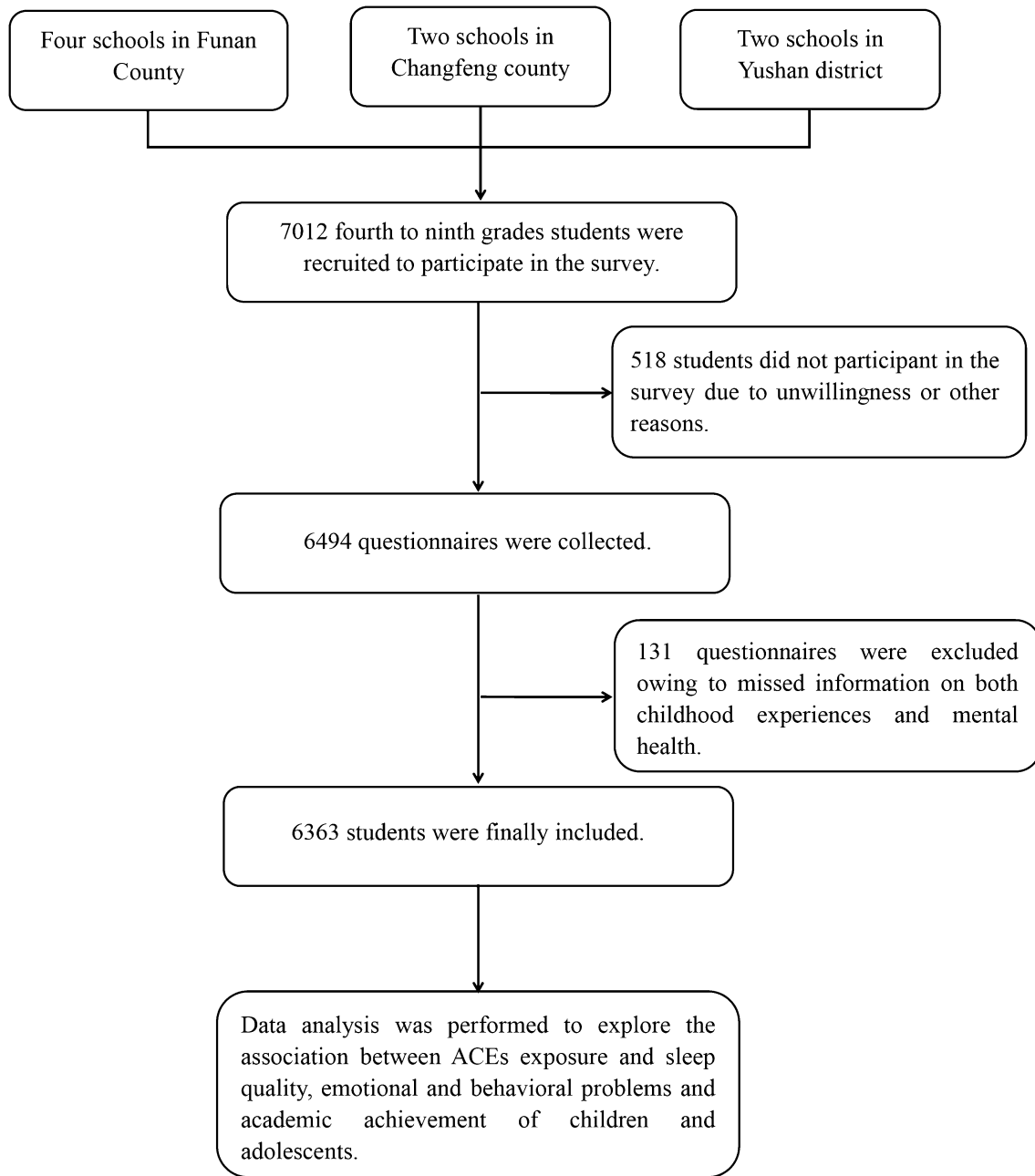


Fig. 1 The flow chart of this study

contained 19 items which rated on 0 to 3 scores and total scores of PSQI ranged from 0 to 21. Poor sleep quality was defined as PSQI score > 5 [39]. Good reliability and validity of PSQI in Chinese adolescents and young adults have been demonstrated in previous studies [40, 41]. In our study, the Cronbach's alpha of PSQI was 0.802.

Emotional and behavioral problem

Student version of Strengths and Difficulties Questionnaire (SDQ) was used to assess emotional and behavioral problems of students. SDQ contained 25 items which rating from 0 to 2 scores ("not true" = 0, "somewhat true" = 1, "certainly

Table 1 Characteristics of samples ($N=6363$)

Characteristics	N/Mean	Percent-age (%) / SD
Age, years	12.31	1.83
Age category, years		
8–11	2238	35.2
12–15	4024	63.2
16–18	101	1.6
Sex		
Male	3474	54.6
Female	2889	45.4
BMI, Kg/m ²	20.02	3.51
Resilience score	107.64	16.87
Family location		
Rural	2426	38.1
Town	2130	33.5
City	1807	28.4
Serious disease in the past year		
Yes	200	3.1
No	6163	96.9
The only child in family		
Yes	1592	25.0
No	4771	75.0
Paternal educational level		
Primary school and below	1136	17.9
High school	4396	69.1
College and above	831	13.1
Maternal educational level		
Primary school and below	1803	28.3
High school	3851	60.5
College and above	709	11.1
Adverse childhood experience		
Yes	3259	51.2
No	3104	48.8
Sleep quality		
Good	4228	66.4
Poor	2135	33.6
PSQI score	4.69	2.58
Emotional and behavioral problems		
Yes	2048	32.2
No	4315	67.8
Total difficulty score	11.39	5.34
Academic achievement		
Lower	2512	39.5
Higher	3851	60.5

true” = 2). SDQ contained four difficulty dimensions (emotional problems, conduct problems, hyperactivity or inattention, peer relationship problems) and prosocial behavioral problems dimension [42]. The score of five dimensions

ranges from 0 to 10 and corresponding cutoff value were 7, 5, 7, 6, and 4. In our study, the positive of emotional and behavioral problem was defined as the positive of any of five dimensions. The total scores of difficulty are the sum of four difficulty dimensions ranging from 0 to 40, and higher scores indicate the high degree of difficulty. In our study, the total scores of difficulty were used to reflect the severity of emotional and behavioral problems of students. The high levels of reliability and credibility of SDQ in Chinese children and adolescents have been demonstrated [43]. The Cronbach’ alpha of SDQ in this study was 0.784.

Academic achievement

In our study, academic achievement of adolescents was assessed by two methods that one was the self-rating grade of their academic performance (low-grade, below average grade, medium grade, above-average grade, high grade) and another one was self-reported their scores of the last examination of Chinese reading, math, and English language. In our study, the self-rating the grade of student’s academic performance was classified as lower academic achievement (low-grade and below average grade) or higher academic achievement (medium grade, above-average grade, and high grade).

Covariables

Demographic characteristics of students were collected through self-designed questionnaire including age, sex, BMI, serious disease in the past year (yes or no), family location (rural area, town, and city), and the only child in family (yes or no) of adolescents, paternal educational level and maternal educational level. It is well known that ACEs exposure is cumulative along with the age of children and there is sensitive and critical periods for the development of children [2], the ACEs exposure in different age of children may have different effects [23]. Physical health of children has been widely demonstrated to be closely associated with ACE exposure and psychology and behavior of children [2, 3, 44]. In addition, family structure has been identified as the factor associated with both the ACEs exposure and mental health of children [45]. Overall, all of above characteristics of students have been demonstrated to be closely associated with ACEs exposure and/or the physical and mental outcomes of children [2, 3, 44–46], which may confuse accurate associations between ACEs and interest outcomes. Therefore, these covariables were controlled in the adjusted models of statistical analysis. In addition, considering individual intrinsic attribute specificity that resilience was demonstrated to be an important factor against consequences of ACE exposure [47], resilience score of adolescents was, therefore, measured through Child Youth Resilience

Measurement (CYRM-28). CYRM-28 is a 5-point Likert scale which contained 28 items with response options ranging from “not at all” to “a lot” and higher sum score of CYRM-28 represent higher resilience [48].

Statistical analysis

Data analysis was performed using SPSS 23.0 software and Mplus 8.0 software. The missing values are filled by multiple interpolation. Continuous data were presented as mean and standard deviation (SD) and categorical data were described as number and percentage. Correlation coefficients of variables were calculated using Bivariate Pearson (for continuous data) and Spearman (for categorical data) correlation analyses. To examine the effect of ACEs on the presence of poor sleep quality, emotional and behavioral problems, and lower academic achievement (higher academic achievement as reference) of adolescents, logistic regressions were separately conducted and reported with odds ratios (OR) and 95% confidence interval (95%CI). In order to examine the mediating effects of sleep quality, emotional and behavioral problems on the association between ACEs exposure and academic achievement, path analyses were performed using cumulative ACEs exposure scores, PSQI scores, total difficulty scores and standardized self-reported academic examination scores. As suggested, model fit was identified by the comparative fit index (CFI) and standardized root mean square (SRMR) indexes that $CFI > 0.9$ and $SRMR < 0.05$ indicated acceptable model fit [49]. Sensitive analysis was performed by excluding children and adolescents who had serious disease in the past year to examine the stability of main results. All analyses were two-side tested and P value less than 0.05 indicated significance.

Results

Characteristics of participants

In this study, 6363 students were included and 200 (3.1%) reported serious disease in the past years. 51.2% ($n = 3259$) of students reported ACE exposure. For outcomes, 2135 (33.6%) were assessed with poor sleep quality, 2048 (32.2%) were assessed with emotional and behavioral problems and 2512 (39.5%) were reported with lower academic achievement (Table 1).

Association between ACEs exposure and sleep quality

As shown in Table 2, overall, ACEs exposure was positively associated with poor sleep quality that children and adolescents with ACEs exposure had 1.37 times risk of poor

sleep quality (adjusted OR = 1.37, 95%CI: 1.21–1.55). Most types of ACEs, except for sexual abuse, emotional neglect, and extremely hard family economy, were significantly positively associated with poor sleep quality. Specially, adolescents with emotional abuse had the highest risk of poor sleep quality (adjusted OR = 4.02, 95%CI: 2.89–5.62) and children and adolescents with other types of ACE exposure had 1.12–2.31 times risk of poor sleep quality. For the risk of cumulative ACE exposure on poor sleep quality, adolescents with higher cumulative counts of ACE exposure showed higher risk of poor sleep quality and with each point increase of ACE exposure, the risk of poor sleep quality increased 22% (adjusted OR = 1.22, 95%CI: 1.16–1.28). In addition, except for sleep medication, ACE exposure was significantly positively associated with other six components of sleep and the risk was increased with the cumulative ACEs level (Table S2–S8). Among all dimensions of sleep quality, sleep disturbances of adolescents was most affected by ACE exposure (adjusted OR = 8.70, 95%CI: 2.97–25.46) (Table S6). Similarity, children and adolescents with emotional abuse had highest risk of poor subjective sleep quality, sleep latency, sleep disturbances, sleep medication and daytime dysfunction.

Association between ACE exposure and emotional and behavioral problems

ACE exposure showed significantly positively association with adolescents' emotional and behavioral problems (adjusted OR = 1.91, 95%CI: 1.69–2.15) (Table 2). As for specific type of ACE types, except for gambling, drugs or alcohol addiction of family members, other types of ACE were positively associated with emotional and behavioral problems and the odds ratios ranged from 1.28 to 3.65 (Table 2). With regard to the risk of cumulative ACE level, we found that risk of emotional and behavioral problems was gradually increased with cumulative ACE counts and the risk of behavioral problems increased by 32% with each additional ACE exposure (Table 2). In addition, we also found that ACE exposure was positively associated with all five dimensions of behavioral problems and there was a dose–response relationship (Table S9).

Association between ACE exposure and academic achievements.

Children and adolescents with ACE exposure showed higher risk of self-reported lower academic achievement (adjusted OR = 1.21, 95%CI: 1.08–1.36) (Table 2). Among all types of ACE exposure, only emotional neglect, physical neglect and extremely hard family economy were significantly associated with lower academic achievement. Cumulative ACE exposure also showed positive association with lower academic

Table 2 Association between adverse childhood experiences and risk of poor sleep quality, emotional and behavioral problems, and lower academic achievement

	Poor sleep quality			Emotional and behavioral problems			Lower academic achievement		
	Adjusted OR [#]	95%CI	P	Adjusted OR [#]	95%CI	P	Adjusted OR [§]	95%CI	P
ACEs exposure (binary variable)	1.37	1.21–1.55	<0.001	1.91	1.69–2.15	<0.001	1.21	1.08–1.36	0.001
ACEs type									
Emotional abuse	4.02	2.89–5.62	<0.001	3.65	2.63–5.07	<0.001	1.06	0.79–1.43	0.696
Physical abuse	1.68	1.29–2.18	<0.001	2.17	1.69–2.79	<0.001	1.03	0.80–1.31	0.845
Sexual abuse	1.12	0.87–1.46	0.381	2.58	2.03–3.29	<0.001	1.04	0.82–1.32	0.729
Emotional neglect	0.99	0.85–1.16	0.902	1.65	1.42–1.91	<0.001	1.22	1.05–1.41	0.009
Physical neglect	1.29	1.23–1.49	<0.001	1.45	1.27–1.65	<0.001	1.23	1.08–1.40	0.002
Family members were addicted to gambling, drugs or alcohol	1.62	1.30–2.04	<0.001	1.16	0.93–1.44	0.188	0.98	0.79–1.21	0.846
Parents had been separated or divorced	1.47	1.25–1.72	<0.001	1.47	1.26–1.72	<0.001	1.14	0.98–1.32	0.099
Mother suffered from domestic violence	1.58	1.33–1.89	<0.001	1.28	1.07–1.52	0.006	0.86	0.73–1.02	0.085
Family members had mental disorders	2.31	1.59–3.36	<0.001	2.28	1.59–3.28	<0.001	1.02	0.71–1.45	0.930
Family members jailed for crimes	1.90	1.32–2.75	0.001	1.99	1.39–2.84	<0.001	1.14	0.81–1.62	0.444
Family economy was extremely hard	1.06	0.83–1.36	0.623	1.45	1.14–1.84	0.002	1.27	1.01–1.60	0.039
ACEs counts*									
1	1.16	1.01–1.34	0.042	1.66	1.44–1.91	<0.001	1.21	1.06–1.38	0.004
2–3	1.52	1.30–1.78	<0.001	2.02	1.73–2.35	<0.001	1.19	1.03–1.38	0.022
≥4	2.55	1.95–3.33	<0.001	3.58	2.76–4.65	<0.001	1.36	1.06–1.75	0.016
ACEs scores	1.22	1.16–1.28	<0.001	1.32	1.26–1.38	<0.001	1.06	1.01–1.11	0.010

*None ACEs as reference

[#]Adjusted for age, sex, BMI, resilience score, serious disease in the past year, family location, the only child in family, paternal educational level, maternal educational level[§]Adjusted for age, sex, BMI, resilience score, serious disease in the past year, family location, the only child in family, paternal educational level, maternal educational level, emotional and behavioral problem, and poor sleep quality

achievement and the risk of poor academic achievement increased by 6% with each additional ACE score (adjusted OR = 1.06, 95%CI: 1.01–1.11) (Table 2).

The mediation effects of emotional and behavioral problem and sleep quality

The mediation effects of emotional and behavioral problem and sleep quality on the association between ACE exposure and academic achievement were examined and a good model fit was demonstrated in outcomes of Chinese reading (CFI: 0.909/SRMR: 0.038), math (CFI: 0.922/SRMR: 0.032), and English (CFI: 0.921/SRMR: 0.033). The coefficients of all paths showed statistical significance (Fig. 2 and Table S10). ACE score was positively associated with sleep quality and total difficulty score. Total difficulty score was negatively associated with Z-score of Chinese reading, math, and English, but

positive correlation was found for sleep quality. Table 3 shows standardized coefficients for total, indirect and direct effects of ACEs exposure on academic achievement. For the outcome of Chinese reading score, sleep quality (indirect effect: 0.029, 95% CI: 0.022 ~ 0.036) and emotional and behavioral problems (indirect effect: -0.025, 95% CI: -0.038 ~ -0.017) showed significant indirect effect. Furthermore, ACEs exposure had significant indirect effects on Chinese reading performance through sleep quality and emotional and behavioral problems (indirect effect: -0.008, 95% CI: -0.011 ~ -0.005). However, the total indirect effect was not significant ($P = 0.467$). For the outcome of math score, all indirect path showed statistical significance ($P < 0.001$) and total difficulty score was the strongest mediator. Total indirect effect of ACE exposure on math score via sleep quality and emotional and behavioral problems was -0.034 (95%CI: -0.046 ~ -0.024), accounting for 45.9% of total effect (total effect: -0.074,

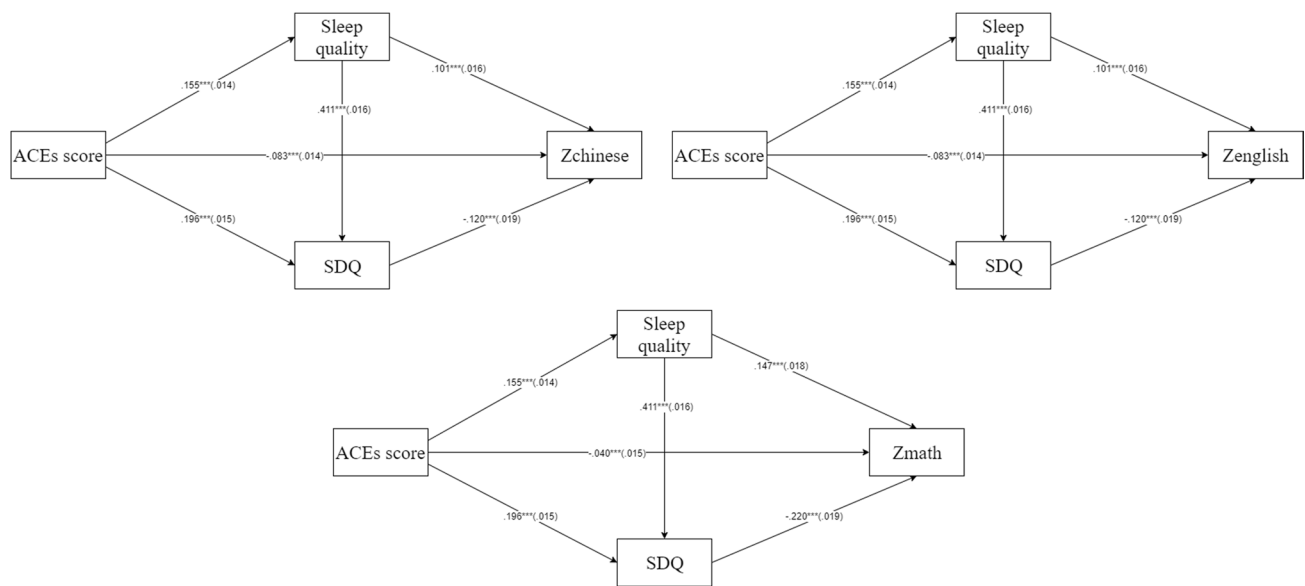


Fig. 2 Path coefficients of adverse childhood experiences on academic achievements through sleep quality and emotional and behavioral performance. ***represent for $P < 0.001$

Table 3 Effect decomposition of adverse childhood experiences on academic achievement

Paths	Estimates	SE	95%CI	P
Chinese score				
Total effect	−0.122	0.015	−0.152 ~ −0.092	<0.001
Direct effect	−0.118	0.016	−0.148 ~ −0.088	<0.001
Total indirect effect	−0.004	0.005	−0.014 ~ 0.006	0.467
ACEs → Sleep → Zchinese (Indirect 1)	0.029	0.004	0.022 ~ 0.036	<0.001
ACEs → SDQ → Zchinese (Indirect 2)	−0.025	0.004	−0.038 ~ −0.017	<0.001
ACEs → Sleep → SDQ → Zchinese (Indirect 3)	−0.008	0.001	−0.011 ~ −0.005	<0.001
Math score				
Total effect	−0.074	0.014	−0.103 ~ −0.048	<0.001
Direct effect	−0.040	0.015	−0.070 ~ −0.012	<0.001
Total indirect effect	−0.034	0.006	−0.046 ~ −0.024	<0.001
ACEs → Sleep → Zmath (Indirect 1)	0.023	0.003	0.016 ~ 0.030	<0.001
ACEs → SDQ → Zmath (Indirect 2)	−0.043	0.005	−0.054 ~ −0.034	<0.001
ACEs → Sleep → SDQ → Zmath (Indirect 3)	−0.014	0.002	−0.018 ~ −0.011	<0.001
English score				
Total effect	−0.099	0.014	−0.125 ~ −0.068	<0.001
Direct effect	−0.083	0.001	−0.111 ~ −0.052	<0.001
Total indirect effect	−0.015	0.005	−0.024 ~ −0.006	0.001
ACEs → Sleep → Zenglish (Indirect 1)	0.016	0.003	0.010 ~ 0.021	<0.001
ACEs → SDQ → Zenglish (Indirect 2)	−0.024	0.004	−0.032 ~ −0.016	<0.001
ACEs → Sleep → SDQ → Zenglish (Indirect 3)	−0.008	0.001	−0.010 ~ −0.005	<0.001

Models were adjusted for age, BMI, resilience and serious diseases in the past year

95% CI: −0.103 ~ −0.048). Similar results of the medication effect of sleep quality and emotional and behavioral

problem on the outcome of English score were also found (Table 3). The mediation effect accounted for 15.2%

($-0.015/-0.099$) of total effect of ACEs exposure on English scores.

Sensitive analysis

After excluding children and adolescents with serious diseases in the past year, the association between ACEs exposure and risk of sleep problem, emotional and behavioral problem and poor academic achievement was consistent with main results (Table S11–S13). In addition, the results of sensitive analysis on the mediation effects of sleep quality and emotional and behavioral problem were similar to main results (Table S14–S15). All these indicated that main results of this study were stable.

Discussion

This study demonstrated that ACE exposure was positively associated with poor sleep quality, emotional and behavioral problems and lower academic achievement of adolescent, and there were significant positive dose–response relationships, which provides additional evidence of the effect of ACEs on health of children and adolescents. These findings in sleep quality are consistent with previous epidemiological studies showing that exposure to ACEs was associated with worse sleep duration [16, 50, 51], sleep efficiency [50], subjective and actigraphic sleep [13]. Similarly, the findings in the association between ACE exposure and emotional and behavioral problems are in line with the findings of studies conducted in children and adolescents that exposure to ACEs was strongly associated with externalizing and internalizing behaviors during childhood [20, 52, 53], but inconsistent with the findings of a previous longitudinal study which indicated that children exposed to higher numbers of early ACEs did not significantly show more internalizing problems [23]. The peculiar and unexpected findings in the previous longitudinal study had been explained that some investigated factors, such as qualities of violent homes, were associated with externalizing behavior problems when they co-occur and other factors that may have a greater influence on the development of internalizing patterns of behavior, such as maternal depression, may affect the authenticity of the results but were not investigated [23]. In terms of academic achievement, our findings are also in line with previous studies that showed +ACEs were significantly associated with lower academic achievement of children and adolescents [29–31, 54]. Our study also found that among all types of ACEs, emotional abuse had the strongest correlation with emotional and behavioral problems and sleep quality of children and adolescents, and the strength of the association between extremely hard family economy and academic achievement of adolescents was the greatest.

These are consistent with a previous study which indicated that the impact of different types of adversity varied [3]. Considering that poor sleep quality, lower academic achievement, and emotional and behavioral problems in childhood can significantly affect later mental and physical health, all these highlight the importance of detection and prevention of ACEs especially for abuse and poverty in early childhood.

In addition, mediation effect analysis indicated that sleep quality and emotional and behavioral problems of children and adolescent partially mediated 45.9% of ACEs on math scores and 15.2% of ACEs on English scores, but the total indirect effects of sleep quality and emotional and behavioral problem on Chinese reading scores were not obvious. Currently, how ACEs affect academic outcome has not been clearly clarified. These results of mediation effects fill the gap in the pathway of how ACE's exposure affect later academic outcomes. These findings also imply that improving sleep quality and emotional and behavioral problems of children and adolescents may reduce the risk of lower academic achievement for those with ACEs exposure. Possible mechanisms of the mediation role of sleep quality and emotional and behavioral problems on the association between ACEs and academic achievements may be explained as followings. A cross-sectional study has demonstrated that emotional/behavioral problems can partially mediate between abuse/neglect and school adjustment [55]. Along with the occurrence of emotional and behavioral problems, adolescents show more difficulty in building relationships, school performance, and in following school regulations [55, 56]. Therefore, it is clear that these difficulties in school performance may lead to lower academic achievement in the future. The reason why sleep quality can mediate the effect of ACEs and academic achievements may be attributed to changes in neuro and behavior. Poor sleep quality and sleep loss have been demonstrated to be correlated with daytime sleepiness, neurocognitive impairments and bad behavioral performance which are directly associated with a decline in academic performance [57]. The effects of ACEs on brain functions of humans have been extensively revealed. More importantly, neuroimaging changes in functional areas of the brain (including prefrontal cortex, the medial temporal lobe, and hippocampus) due to sleep problems have also been observed in several studies [57–60], and these changes are further closely related to the learning, cognitive and memory which are the basis of academic performance [57, 58]. Therefore, it can be speculated that ACEs and sleep problems may jointly aggravate the functional impairment of brain areas and lead to poor academic performance, which needs to be verified in the future.

This study is the first to comprehensively examine the association between ACEs exposure and sleep quality, emotional and behavioral problems, and academic outcomes of children and adolescents and further reveal their

interrelations. The findings of this study can provide additional suggestions and recommendations for public health practice. It is suggested that educators, social workers, and pediatricians should pay much attention to ACEs, the common early-life risk factors, and work together to address its hazards. From the aspect of prevention, first of all, as recommended, early and frequent screening for ACEs in children is essential considering its lasting and widespread damage on health [61]. Second, from an individual perspective, building up and strengthening the resilience of children can help them coping with adversity [62]. Third, to address the impact of ACEs, collaborative efforts with partners in the education, home visitation, and other social service sectors are also required [63]. In recent years, several organizations have proposed different programs to prevent the harm of ACEs and promote the optimal development of children. For example, the program “*Bright Futures*” is constructed to provide resources for pediatricians to detect both ACEs and adverse developmental outcomes of infants, children, and adolescents [64]. The program “*Help Me Grow*” can connect all needed resources to enhance the development of vulnerable children to provide early childhood services for at-risk children [65]. Actively taking the advantages of these programs in ACE intervention is useful for the health and academic success of children and adolescents. Furthermore, the findings in mediating effects also suggest that interventions on sleep, emotion and behavior of children may partially mitigate risks of ACEs in adolescents who are already exposed to ACEs. Studies have proved that active physical exercise and music therapy can reduce the impact of stress on academic performance, and these practices were demonstrated to be beneficial for sleep, emotion and behavior [66–69]. Therefore, interventions and prevention of sleep problem and emotional and behavioral problems from multiple perspectives are considered feasible to reduce the risk of ACE to academic outcomes in children and adolescents who have ACEs exposure.

Several limitations in our study need attention. Causal associations cannot be inferred for the cross-sectional design. Longitudinal studies are suggested to be conducted to verify and confirm findings of this study. Although all information was collected through structured questionnaire, data of academic achievements was self-reported by students causing that untruthfulness reports may exist and lead to bias. Future studies using a school-rated measure (e.g. the Grade Point Average (GPA)) to evaluate academic performance will be better to verify the findings of our study. Not only that, the measurement of ACEs is based on retrospective trauma experience; thus recall bias may influence the findings. Considering children and adolescents are in an important or sensitive period of growth and development, the time and frequency of ACE exposure are also important. However, given that it exists great difficulty for adolescents

to recall these information, we therefore did not collected information of time and frequency of ACEs exposure in childhood. Therefore, how and when ACEs exposure has the greatest impact on sleep, emotion, behavior and academic outcomes needs to be further explored.

Conclusions

ACE exposure is positively associated with poor sleep quality, emotional and behavioral problems, and lower academic achievement of adolescents, and there are significant dose–response relationships. Most types of ACEs are positively associated with these problems. Emotional abuse seems to show the strongest association with these problems of children and adolescents. Sleep quality and emotional and behavioral problems can mediate 45.9% of the effect of ACE exposure on math scores, and 15.2% of the effect of ACE exposure on English scores. Early detection and prevention of ACEs among children and adolescents are urgent and essential. For children already exposed to ACEs, targeted interventions for sleep, emotion, and behavior as well as early educational interventions may help improve their future academic achievement. Appropriate and collaborative programs are recommended to be constructed widely.

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Author contributions Sun Y conceived and designed the study. Qu G, Liu H, Sun L, Qin Q and Chen M supervised the study. Qu G and Liu H processed and guarded the data. Qu G performed the statistical analysis and wrote the main manuscript text. Han T, Zhang H and Ma S reviewed the draft and made revisions. All authors reviewed the final version of manuscript.

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Data availability Data used in this study will be provided by the corresponding author upon the reasonable request.

Declarations

Conflict of interest All authors declared that there was no conflict of interest.

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