Hindawi
Health & Social Care in the Community
Volume 2024, Article ID 1150608, 13 pages
https://doi.org/10.1155/2024/1150608

Research Article

Relationship between Anemia and Academic Performance in Chinese Primary School Students: Evidence from a Large National Survey

Yisong Hu, Yanxin Mao, and Weidong Wang

National Research Center, Renmin University of China, Beijing, China

Correspondence should be addressed to Weidong Wang; wwd@ruc.edu.cn

Received 27 June 2023; Revised 7 January 2024; Accepted 18 January 2024; Published 29 January 2024

Academic Editor: Gianpiero Greco

Anemia is a global public health problem, especially common among children in developing countries, which affects their physical and mental health development. However, there is currently a lack of research on the relationship between anemia and academic performance. The objective of this study was to explore the association between anemia and academic performance, and the possible factors mediating this association among Chinese children. The data for this study came from the baseline survey of the Chinese Education Panel Survey Elementary School Cohort. The cohort was conducted from September 2018 to June 2019 in 160 elementary schools, covering 20 provinces and 40 counties/districts throughout China. Paper-based questionnaires were used, completed by 4th grade students, parents, head teachers, main teachers, and principals. The data used included questionnaire responses, physical measurements, and academic performance of 17,695 students. Based on students' hemoglobin levels and school altitude data, we grouped them into anemia and nonanemia categories using WHO criteria. The anemia group had 1,154 individuals, while the nonanemia group had 16,541 individuals. An ordinary least squares regression and mediation effect analysis were conducted. Our findings found the prevalence of anemia was 6.52% among Chinese Grade 4 students. Students without anemia had a higher average test score for three academic subjects than students with anemia ($P < 0.001$); their test scores for Chinese, Mathematics, and English were also higher ($P < 0.05$). Multivariate regression analysis showed a negative association between anemia and average test scores as well as individual test scores for the three subjects. Mediation analysis found that anemia affected academic performance directly ($P < 0.05$), and indirectly by decreasing the cognition score ($P < 0.05$). The indirect effect was 19.9% of the total effect. Findings highlighted anemia affected academic performance both directly and indirectly. Nutrition-related interventions should be implemented to prevent a decrease in academic performance among students with anemia.

1. Introduction

Anemia is a worldwide public health problem and especially affects people in developing countries. The most susceptible populations are children and women[1, 2], with relatively few studies focusing on children with anemia. According to WHO estimates, the prevalence of anemia among children under 5 years old in China was 18.8% in 2019 [3], which is lower than the global prevalence of 39.8% for children under 5 [4]. However, this rate is lower compared to developing countries like South Africa (44.4%) and India (53.4%), but higher compared to developed countries like the United States (6.1%), Germany (15.1%), and Japan (16.7%). Social and economic development in China has brought about a decrease in the prevalence of anemia in recent years [5]; however, there are regional differences among the population. Survey results indicate that the prevalence of anemia among children is higher in Western China and in the female population [6]. The prevalence of anemia in children decreases with age before puberty and increases during puberty [5]. School-going age is a key period of physical and mental development for children and an important period for acquiring new knowledge. Anemia may cause irreversible impairment of learning ability in children. As estimated by the World Health

Organization, iron deficiency anemia is the primary cause of loss of disability-adjusted life years among 10–14-year-old children [7].

However, childhood anemia, which is common, has not received enough attention in China, particularly in rural areas. With the recent slowdown in China's economic development and the particularly challenging job market for young people, exacerbated by the COVID-19 pandemic, the pressure on education and the rapid devaluation of educational qualifications has extended to primary schools and even kindergartens. This has intensified parents' focus on students' academic performance and investments in education. The main objective of this research is to draw more attention from parents to the potential health issue of childhood anemia in China through examining its relationship with academic performance. It also aims to provide an explanation and possible solutions for children with poor academic performance due to anemia. By addressing the issue of childhood anemia and its impact on academic performance, we strive to support effective interventions and strategies that can improve both the health and educational outcomes of affected children. In the long run, it is also beneficial for the accumulation of human resources and the promotion of sustainable socioeconomic development.

There is a long history of academic performance research among children, but only a limited number of studies have been devoted to investigating the relationship between anemia and academic performance. Based on the literature published in the past, although there were differing results regarding the relationship between anemia and academic performance, more studies tended to lean towards an association between the two, especially in recent research. For instance, a recent study systematically reviewed the relationship between iron status, anemia, iron interventions, cognition, and academic performance in adolescents aged 10–19 years [8]. This review included 50 relevant publications that were published prior to 2020, consisting of 26 cross-sectional observational studies and 24 iron intervention studies. It indicated that in certain contexts, iron status and anemia were related to academic performance, and iron supplementation during adolescence might improve academic performance and attention. However, the review found that the quality rating of all cross-sectional studies was poor, and almost all supplementation trials showed a bias towards medium to high risk. Additionally, it was also found that there was no evidence of a relationship between iron status or anemia and attention, intelligence, or memory among adolescents. On the other hand, a different conclusion was reached in a more recent meta-analysis [9]. Based on 13 randomized controlled experiments, this study found that iron supplementation significantly improved intelligence, attention, and memory in children aged 6–12 years, though no relationship was observed between iron supplementation and academic performance. Given the higher prevalence of anemia in middle- and low-income countries, researchers conducted a meta-analysis focusing on these settings [10]. Based on 9 studies from 5 countries, this analysis demonstrated that increasing iron supplementation dosage could improve intelligence test scores, but had no effect on attention, short-term memory, long-term memory, or academic performance. Moreover, there were two large-scale observational studies, one cross-sectional and one longitudinal, which supported an association between anemia and academic performance in adolescents [11, 12].

Regarding studies conducted in China on the relationship between anemia and academic performance, the literature was relatively scarce. A survey conducted in the 1980s involved 478 middle school students aged 13–15 in Shanghai, and it did not find a relationship between iron deficiency anemia and IQ or academic performance [13]. However, recent studies have shown positive associations. One study included 2,646 students aged 7–14 in Taiyuan, and the results showed a positive correlation between academic performance and hemoglobin levels [14]. Another study conducted in Gansu province in Western China included 45,549 students from grades 1–5. Using instrumental variable estimation, the study found a significant negative impact of iron deficiency on children's academic performance [15]. Furthermore, a study conducted in Henan province, located in central China, surveyed 493 fourth-grade students and found that anemic students were more likely to have poor scores on standard math exams [16]. The few studies published to date regarding anemia and academic performance in children in China have been limited by (1) relatively small sample sizes [13, 16] that were concentrated in specific regions of China [13–16]. This resulted in low statistical power, and the results could not be extrapolated to the general children population throughout China; (2) some surveys using an age range for children that was too wide, with relatively small sample sizes for certain ranges. This provided insufficient data to explain the relationship between anemia and academic performance among children of specific ages [16]; and (3) some studies focusing on the relationship between anemia and academic performance or cognition, without exploring the mechanism or mediation analysis between them [13–16]. Exploring the relationship between anemia status and academic performance would provide valuable insight.

This study involved four mediating variables, namely cognition, BMI, sleep duration, and CESD score. Currently, there was no literature reporting the mediating effects of these variables on the relationship between anemia and academic performance. The notion of mediating variables was more commonly utilized in the fields of sociology or psychology, while epidemiological research predominantly focused on establishing the connection between anemia and academic performance, with little exploration of potential mechanisms. However, based on existing published literature, these four variables had the potential to play significant roles in the relationship between anemia and academic performance. In short, firstly, there had been numerous reports, especially recently, both domestically and internationally, on the relationship between anemia and cognition [17–19]. Moreover, there was a general consensus that iron supplementation improved cognitive levels [9, 10]. Furthermore, many studies investigating the relationship

between anemia and academic performance also simultaneously discussed cognitive levels [9, 10], and the association between cognition and academic performance was evident. Therefore, cognition level was the first mediating variable to be considered. Secondly, there was evidence from meta-analyses demonstrating the relationship between childhood obesity and dual burden of micronutrient deficiency, as well as the relationship between obesity and anemia [20]. Similarly, meta-analyses had also shown a negative correlation between BMI and academic performance [21]. Therefore, BMI might have exerted a mediating effect. Thirdly, as primary school students, sleep duration played a crucial role as a measure of their health behaviors. Previous population studies indicated a relationship between anemia and sleep duration in adults [22, 23], and studies on children found an association between sleep and academic performance [24]. This suggested that sleep duration might have had a mediating effect on the association between anemia and academic performance. Lastly, among the main symptoms caused by anemia were fatigue, lethargy, and depression [25]. The relationship between depression and academic performance had been reported in cross-sectional studies [26], and it had been found that this association could persist long term [27]. Therefore, depression might have also acted as a mediating variable. In light of this, the hypotheses to be tested in this study were as follows: (1) Anemia was negatively correlated with academic performance. (2) Anemia was negatively correlated with cognitive levels, and cognition mediated the relationship between anemia and academic performance. (3) Anemia was positively correlated with BMI, and BMI mediated the relationship between anemia and academic performance. (4) Anemia was positively correlated with sleep duration, and sleep duration mediated the relationship between anemia and academic performance. (5) Anemia was positively correlated with depression, and depression mediated the relationship between anemia and academic performance (see Figure 1).

This study used the baseline data of primary school students who completed the China Education Panel Survey in 2018 to analyze the relationship between anemia and academic performance and further explored the mediation effect of health-related factors. The goal was to provide scientific evidence for the relationship between anemia and academic performance and the possible factors mediating this association.

2. Materials and Methods

2.1. Survey Introduction. This study was based on primary school student cohort data from the China Education Panel Survey. The fieldwork of the cohort was conducted by the National Survey Research Center at the Renmin University of China from September 2018 to June 2019. The survey's main goal was to elucidate the effects of family, school, community, and social structure on educational attainment, as well as educational influence on a child's life course. A probability proportional to the size sampling method in four stages was used to sample students. The baseline survey sample covered all fourth-grade students in 160 primary schools located across 40 counties within 20 provinces throughout China. A paper-based, self-administered survey with instruction from a supervisor was conducted for all respondents; respondents included students, their fathers or mothers, head teachers, main teachers, and school masters. The student questionnaire included information on demographics, physical and mental health status, life experience, parents' involvement, Hukou and immigration, learning at school, after-school activities, parents' educational expectations, relationships with teachers and classmates, social behavior, and family members' information. The survey tested students' cognition and collected the results of the previous mid-term and final examinations. The physical parameters measured included height, weight, visual acuity, and hemoglobin levels. All physical measurements were performed by medical staff trained by the Chinese Center for Disease Control and Prevention.

Student assent and parental consent were obtained before conducting the survey. Informed consent was provided and the strict confidentiality of information was guaranteed. The study was approved ethically by the Biomedical Ethics Review Board of the Chinese Center for Disease Control and Prevention and conducted in accordance with the Declaration of Helsinki and its later amendments.

2.2. Study Variables

(1) The dependent variables were the final examination results from the previous semester for the subjects Chinese, Mathematics, and English; the average score of all the three subjects was calculated. To adjust for different test contents in different schools, the standardized scores for each student were calculated by school and the standardized scores were normalized back in the final data analysis.

(2) The main independent variable was anemia. The existence of anemia was determined by measuring hemoglobin levels in blood samples taken from the fingerstick blood test, adjusted by local altitude [28]. The hemoglobin test was performed using the Hemocue Hb 301 analyzer (origin: Sweden, manufacturer: HemoCue AB). The test result was written on a form in the field and entered into a database after the survey fieldwork. Students identified as having anemia were classified into the anemia group, and those without anemia were classified into the nonanemia group.

(3) The main study covariates were the socioeconomic characteristics of student's age, sex (male/female), Hukou type (rural/urban), only child (yes/no), parents' educational expectations (senior high school or lower/bachelor/master or higher/do not care), self-assessed family economic status (very difficult/relatively difficult/middle income/relatively wealthy/very wealthy), the highest educational attainment of parents (primary school or lower/junior high school/senior high school/college or higher), and number of books in the family (<10/10–49/50–149/≥150).

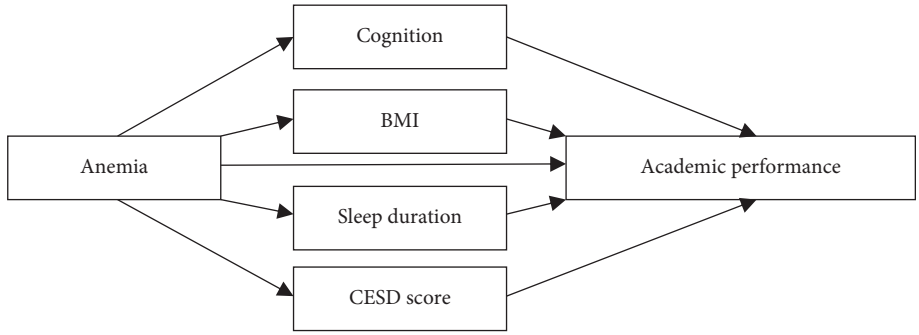

Figure 1: Hypothetical model diagram of the study.

(4) Secondary covariates included learning pressure, relationships with other students, and relationships with teachers. Learning pressure contained difficulty levels of learning Chinese, Mathematics, and English. The difficulty level for each subject was categorized into four types: very difficult (3 points), slightly difficult (2 points), not too difficult (1 point), and not difficult at all (0 points). The total score for learning pressure was calculated by adding the difficulty scores of all three subjects. The question posed to elucidate the nature of their relationships with other students was whether the student was kind to me or not, and the five options were totally unfit, not quite fit, not sure, relatively fit, and totally fit. The measurement of teacher-student relationships used 16 questions [29]: 6 regarding satisfaction, 6 regarding assistance, and 4 regarding conflict. All the questions had five options: totally unfit (0 points), not quite fit (1 point), not sure (2 points), relatively fit (3 points), and totally fit (4 points). The total score was the sum of the 16 questions' score, in which the conflict score was reversed as totally unfit (4 points), not quite fit (3 point), not sure (2 points), relatively fit (1 points), and totally fit (0 points): the higher the average score, the better the relationship.

(5) Mediation variables were health-related, including body mass index (BMI; kg/m^2), sleep duration (hours), degree of depression, and the results of cognition tests. BMI was calculated based on height (m) and weight (kg) measurements. Sleep duration was defined as the usual amount of time spent sleeping at night. Degree of depression was measured using a short version of Center for Epidemiologic Studies Depression Scale that included five questions regarding physical symptoms, five regarding depression, and three regarding positive emotions [30]. All questions had four options: none (0 points), a little (1 point), some (2 points), and quite a lot (3 points). The total score was the sum of the 13 questions, in which the scores for the questions regarding positive emotions was reversed as none (3 points), a little (2 point), some (1 points), and quite a lot (0 points): a higher score indicates a more severe state of depression. The cognition test—characterized by international comparability and national standardization [31]—focused on logical thinking and problem-solving capacity. Graphic reasoning was tested with 30 questions that had to be answered within 25 minutes. Ten questions relating to an expanded graph had to be answered within 15 minutes. According to the number of correct responses, the score ranged from 0 to 80, with higher values indicating better cognition.

2.3. Statistical Analysis. For descriptive analyses, continuous variables were expressed as means and standard deviations. The *t*-test, analysis of variance, or nonparametric test was used to compare students with anemia and students without anemia. Categorized variables were expressed as percent (%) and the Chi-square test was administered to compare between the two groups.

Ordinary least squares (OLS) regression was used to analyze the relationship between anemia and academic performance, and multivariate analysis was adjusted by sex, age, Hukou type, only child or not, family socioeconomic status, the highest educational attainment of parents, number of books in the family, parents' educational expectations, learning pressure, student-student relationships, and teacher-student relationships. The fixed effect of school was considered in the regression analysis to control for the school effect after the academic performance was standardized. Analyses stratified by sex and age grouping were likewise performed in the multivariable OLS regression analyses.

Mediation analysis was used to explore the possible health-related factors mediating the association between anemia and academic performance [32]. The mediators included the cognition score, BMI, sleep duration, and degree of depression. Briefly, there were several steps for the mediation analysis. Firstly, the previous statistical relationship analysis (model 3) between each test score and anemia was the basis for further mediation exploration. Secondly, models 13 were constructed based on model 3 by adding four mediators, respectively. The mediation effect was examined using "sgmediation" code in Stata. The bootstrap method was used to calculate the confidence intervals of the associated products of the mediation analyses. Finally, the direct and indirect effect sizes were calculated. When examining the mediating effects in the analysis, sex, age, Hukou type, only child or not, self-assessed economic

status, the highest educational attainment of parents, number of books in the family, parents' educational expectations, learning pressure scores, relationships with other students, teacher-student relationship scores, and school fixed effect were controlled.

All statistical analyses were performed using Stata statistical software (version 16.0, College Station, TX, USA).

3. Results

3.1. Social Demographic and Health-Related Characteristics. The study involved a total of 36,826 respondents, but 18,543 students did not participate in the hemoglobin measurement. After excluding 588 students who were not 10 or 11 years old, a total of 17,695 fourth-grade students were ultimately used for this study (see Figure 2). Table 1 presents the social demographic and health-related characteristics of the study population. The prevalence of anemia was 6.52%, with no difference in prevalence between males and females ($P > 0.05$). Anemia was more prevalent among rural Hukou children. Higher family economic status, larger number of books in the family, and higher parents' educational expectations were associated with a lower prevalence of anemia in children, as were better student-student or teacher-student relationships. High learning pressure was associated with a high prevalence of anemia. Children with upper quantile cognition scores or body mass indices had the lowest prevalence of anemia. Longer sleep duration and higher CESD score were associated with a higher prevalence of anemia (all $P < 0.05$).

3.2. Test Score Distribution. The average test scores of the three subjects was 54.34 ± 0.18 and 51.04 ± 0.71 in the nonanemia and anemia groups, respectively, as shown in Table 2. On average, children in the nonanemia group had higher average scores than those in the anemia group within categories of sex, age, Hukou type, only child. As shown in Figure 3, there was a left-skewed distribution with the nonanemia group having a higher proportion of higher scores than the anemia group.

The test scores for Chinese, Mathematics, and English, were higher for children in the nonanemia group than for children in the anemia group by subtotal, sex, age, Hukou type, and only child (see Figure 4 and Table 2); the distribution was almost similar to the average test score of the three subjects (see Figures S1–S3 in the supplementary material).

3.3. Multivariate Analysis. As shown in Table 3, univariate and multivariate OLS regression analysis found that anemia status was negatively associated with the average test score of the three subjects after they were adjusted by sex, age, Hukou type, only child or not, self-assessed economic status, the highest educational attainment of parents, number of books in the family, parents' educational expectations, learning pressure scores, relationships with other students, and teacher-student relationship scores. This negative association was also found with each of the three subjects.

Univariate and multivariate OLS regression analyses were conducted on the association between anemia status and academic performance according to sex and age grouping. Anemia status was associated with a decrease of average, Chinese and Mathematics test score in female students within multivariate OLS regression analyses ($P < 0.01$), but not in male students. After stratifying by age group, the association between anemia status and average, mathematics and English test score remained in the subpopulations aged 11 years ($P < 0.05$), but lack of association was found in students aged 10 years.

3.4. Mediation Analysis. Models 13–16 shown in Table 4 used the average test score as the dependent variable and added the independent variables of cognition score, BMI, sleep duration, and CESD score to explore the direct effect of anemia and the indirect effect of the four independent variables. The results showed that anemia had a direct effect on the average test score ($P < 0.05$), and it affected the average test score indirectly by decreasing the cognition score ($P < 0.05$); the indirect effect accounted for 19.9% of the total effect. No indirect effect on the average test score was found for BMI, sleep duration, and CESD score. In addition, the mediation models were conducted for test scores of Chinese, Mathematics, and English respectively, and the results were almost similar to the average test score of the three subjects (see Tables S1–S3 in the supplementary material).

4. Discussion

This study utilized a large-scale nationally representative dataset to analyze the prevalence of anemia among fourth-grade primary school students in China in 2018. It revealed the current situation of anemia among fourth-grade students in China and reported differences in anemia prevalence among different socioeconomic statuses. Additionally, this study provided empirical evidence from a large population survey for the hypothesis that anemia affects academic performance, which has not only direct but also indirect effects through cognition score. This study not only provides fundamental data for researching the prevalence of anemia among children in China but also offers valuable insights into the factors influencing children's academic performance. It serves as a valuable reference for future policy-making related to the prevention and control of anemia among children.

This study showed that the prevalence of anemia is 6.52% in Chinese Grade 4 students, which is similar to the results of other current national surveys on the prevalence of anemia in China. The China Nutrition and Health Surveillance data showed that the prevalence of anemia was 4.01% and 3.25% in children aged 10 and 11 years, respectively [33]. Data from the Chinese National Survey on Student Constitution and Health revealed that the prevalence of anemia in children aged 9 and 12 years was 6.8% and 9.6%, respectively [34]. The reasons for the different results may be associated with different survey sampling and methods for testing for anemia, as well as diagnostic criteria. In addition, surveys

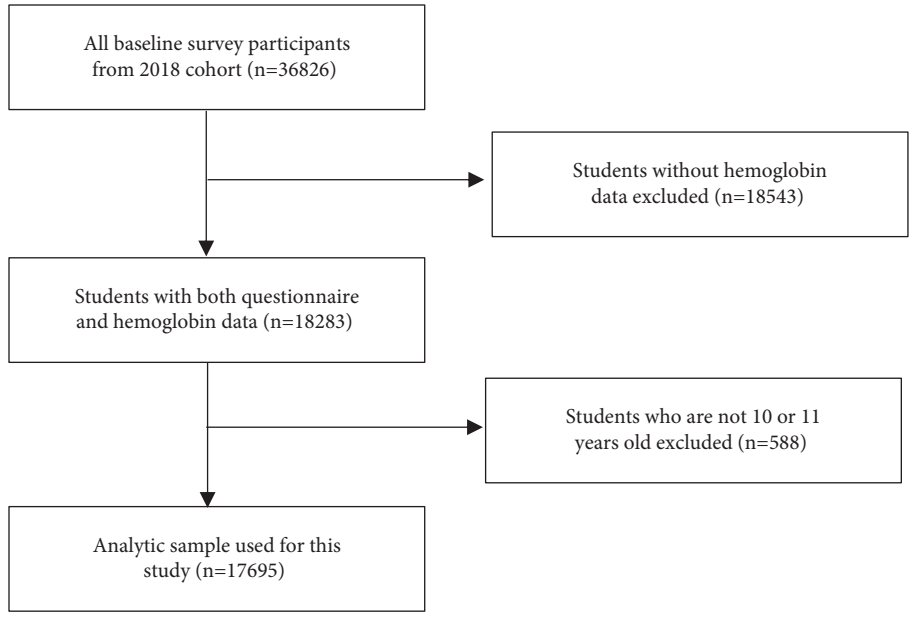

Figure 2: Sample selection process diagram for analysis in this study (China, 2018).

conducted in the poorer or western regions of China reported a higher prevalence of anemia than other regions. A 2019 nutritional improvement program survey for compulsory education for students in rural areas showed that the prevalence of anemia was 8.3% among 11 to 13-year-old children [35]. The prevalence of anemia among girls was higher than that among boys. According to data from the 2015–2017 China Nutrition and Health Surveillance, the prevalence of anemia was 8.5% among girls aged 10–17 years old [36].

The current study found that the average test score of children without anemia was higher than that of children with anemia, and each individual subject had similar results (all $P < 0.05$). Anemia was negatively associated with average test score adjusted by sex, age, Hukou type, only child, self-assessed family economic status, highest educational attainment of parents, number of books in the family, parents' educational expectations, learning pressure scores, and good relationships with other students. On average, the average test score of children with anemia was 1.96 points lower than that of children without anemia. A negative association between anemia and test scores was also found individually for the subjects Chinese, Mathematics, and English. These results indicated we detected total effects of anemia status on academic performance. These total effects were found only in female or subpopulation aged 11 years, which meant anemia status may mainly affect the girls and children in puberty. Our findings were similar to those of other studies in China and abroad [15, 16, 37] and provided new evidence for the relationship between anemia and academic performance.

According to current studies, the negative impact of anemia on academic performance may be associated with brain dysfunction. Anemia can decrease the oxygen saturation of blood in the brain [38] and cause silent infarcts [39] as well as cognitive dysfunction, which manifests as pallor, listlessness, behavioral disturbances, impaired performance in some cognitive tasks, et cetera [40]. All these syndromes affect academic performance in children. It is worth mentioning that the current study mainly focused on children aged 10 and 11 years, but the age at which onset of anemia occurred was difficult to determine. Onset of iron deficiency anemia at a young age increases the possibility of mental retardation in later life [41].

To explore the mechanism underlying the relationship between anemia and academic performance, this study analyzed the mediating effects of cognition, BMI, sleep duration, and CESD score. After mediation analysis, anemia was shown to affect academic performance directly ($P < 0.05$) and, by decreasing the cognition score, indirectly ($P < 0.05$). The indirect effect was 19.9%. The results provide statistical support for the causal chain of anemia-cognition dysfunction-decreasing academic performance. This result was similar to other studies in China and abroad [42–44]; however, additional high quality research to confirm it is required.

The study had several advantages: (1) it was the first nationwide study to explore the association between anemia and academic performance in China. Except for age, the study population had a high level of heterogeneity and thus the results are generalizable to the entire Chinese population. The heterogeneity also provided the study with stronger evidence with higher statistical power; (2) it was based on a survey that focused on Grade 4 students, which narrowed the age range of the study population. This narrow range was valuable in removing any interference that age may have imposed on the results, thus benefitting the exploration of the association between anemia and academic performance; and (3) it first explored the mediating effect of cognition on the relationship between anemia and academic performance based on nationwide survey data. Although the results were still statistically significant, this provided a possible explanation for the relationship between anemia and academic performance.

Table 1: Social demographic and health-related characteristics of the enrolled participants (China, 2018).

Variable	Group	Total (%) $N = 17,695$	Nonanemia group (%) $N = 16,541$	Anemia group (%) $N = 1,154$	$\chi^2/Z/t$	P
Age	10 years	49.21	93.22	6.78	1.8111	0.178
	11 years	50.79	93.72	6.28		
Sex	Male	52.51	93.59	6.41	0.3661	0.545
	Female	47.49	93.36	6.64		
Hukou type	Urban region	41.74	94.96	5.04	45.8633	<0.001
	Rural region	58.26	92.41	7.59		
Only child	Yes	25.70	95.05	4.95	25.4540	<0.001
	No	74.30	92.90	7.10		
Self-assessed family economic status	Very difficult	5.36	87.64	12.36	145.7494	<0.001
	Relatively difficult	18.56	89.99	10.01		
	Middle income	71.19	94.67	5.33		
	Relatively or very wealthy	4.89	95.09	4.91		
Highest educational qualification of parents	Primary school or lower	10.73	90.62	9.38	79.3485	<0.001
	Junior high school	34.16	92.13	7.87		
	Senior high school	25.50	93.93	6.07		
	College or higher	29.61	95.56	4.44		
Number of books in the family	<10	15.64	90.11	9.89	79.8581	<0.001
	10–49	42.98	93.67	6.33		
	50–149	27.04	94.58	5.42		
	≥150	14.33	95.99	4.01		
Parents' educational expectations	Senior high school or lower	13.13	91.53	8.47	42.7579	<0.001
	College or bachelor degree	38.02	93.02	6.98		
	Master or higher	44.63	94.72	5.28		
	Do not care	4.23	91.51	6.49		
Learning pressure score	0-1 point	27.89	94.20	5.80	12.1576	0.007
	2-3 points-	34.75	93.57	6.43		
	4-5 points-	23.55	93.26	6.74		
	6 points-	13.81	92.10	7.90		
Good relationships with other students	Totally unfit	7.09	91.72	8.28	14.0838	0.007
	Not quite fit	11.22	92.94	7.06		
	Not sure	11.25	93.01	6.99		
	Relatively fit	24.77	93.21	6.79		
	Totally fit	45.66	94.13	5.87		
Teacher-student relationship score[a]	0-	25.51	91.84	8.16	27.2594	<0.001
	Q1-	26.71	93.11	6.89		
	Q2-	23.24	94.33	5.67		
	Q3-	24.54	94.40	5.60		

Table 1: Continued.

Variable	Group	Total (%) $N = 17,695$	Nonanemia group (%) $N = 16,541$	Anemia group (%) $N = 1,154$	$\chi^2/Z/t$	P
Cognition test score[b]	0-	26.15	93.28	6.72	9.2535	0.026
	Q1-	25.94	92.79	7.21		
	Q2-	23.42	93.56	6.44		
	Q3-	24.48	94.34	5.66		
Body mass index[c]	0-	25.00	93.47	6.53	10.6419	0.014
	Q1-	25.00	92.97	7.03		
	Q2-	25.01	93.04	6.96		
	Q3-	24.99	94.49	5.51		
Sleep duration (hours)	<8.0	8.41	94.37	5.63	16.4881	0.001
	8.0–8.9	23.45	94.32	5.68		
	9.0–9.9	41.98	93.53	6.47		
	10.0-	26.15	92.31	7.69		
CESD score[d]	0-	21.95	95.13	4.87	30.4298	<0.001
	Q1-	28.86	93.55	6.45		
	Q2-	24.14	93.13	6.87		
	Q3-	25.06	92.04	7.96		

[a,b,c,d]Q1 represents the first quantile; Q2 represents the second quantile; Q3 represents the third quantile.

Table 2: Comparison of test score distribution between nonanemia and anemia groups by social and demographic characteristics (China, 2018).

Test score	Variable	Group	Nonanemia group, $N = 16{,}541$ mean (SE)	Anemia group, $N = 1{,}154$ mean (SE)	t	P
Average test score	Subtotal	—	54.34 ± 0.18	51.04 ± 0.71	4.7788	<0.001
	Sex	Male	51.29 ± 0.26	48.34 ± 1.01	2.9845	0.003
		Female	57.70 ± 0.25	53.93 ± 0.98	4.0524	<0.001
	Age	10 years	54.69 ± 0.25	51.72 ± 0.98	3.1563	0.002
		11 years	53.98 ± 0.26	50.33 ± 1.04	3.6268	<0.001
	Hukou type	Urban region	55.52 ± 0.26	51.56 ± 1.21	3.4859	<0.001
		Rural region	53.44 ± 0.26	50.81 ± 0.88	3.0020	0.003
	Only child	Yes	56.16 ± 0.33	52.70 ± 1.48	2.4878	0.013
		No	53.84 ± 0.22	50.74 ± 0.81	3.9139	<0.001
Chinese test score	Subtotal	—	54.40 ± 0.20	51.21 ± 0.79	4.0903	<0.001
	Sex	Male	49.58 ± 0.29	46.64 ± 1.10	2.6345	0.008
		Female	59.75 ± 0.27	56.11 ± 1.10	3.5057	<0.001
	Age	10 years	54.64 ± 0.28	51.06 ± 1.08	3.3277	0.001
		11 years	54.17 ± 0.29	51.36 ± 1.15	2.4767	0.013
	Hukou type	Urban region	55.55 ± 0.30	51.79 ± 1.35	2.8520	0.004
		Rural region	53.56 ± 0.27	50.93 ± 0.97	2.6909	0.007
	Only child	Yes	55.93 ± 0.38	53.38 ± 1.72	1.5209	0.128
		No	54.02 ± 0.24	50.84 ± 0.89	3.5957	<0.001
Mathematics test score	Subtotal	—	54.47 ± 0.20	51.62 ± 0.79	3.6638	<0.001
	Sex	Male	53.86 ± 0.28	52.77 ± 1.10	0.9925	0.321
		Female	55.14 ± 0.28	50.40 ± 1.13	4.3137	<0.001
	Age	10 years	54.63 ± 0.28	51.92 ± 1.08	2.5598	0.010
		11 years	54.31 ± 0.28	51.31 ± 1.16	2.6389	0.008
	Hukou type	Urban region	55.16 ± 0.29	51.68 ± 1.32	2.6990	0.007
		Rural region	53.96 ± 0.27	51.59 ± 0.98	2.4070	0.016
	Only child	Yes	56.14 ± 0.36	51.47 ± 1.70	2.8922	0.004
		No	54.00 ± 0.24	51.75 ± 0.89	2.5376	0.011
English test score	Subtotal	—	54.10 ± 0.22	50.54 ± 0.86	4.2314	<0.001
	Sex	Male	50.18 ± 0.32	46.19 ± 1.22	3.3048	0.001
		Female	58.42 ± 0.30	55.22 ± 1.18	2.8315	0.005
	Age	10 years	55.14 ± 0.31	52.48 ± 1.18	2.3026	0.021
		11 years	53.06 ± 0.32	48.50 ± 1.26	3.7230	<0.001
	Hukou type	Urban region	55.90 ± 0.32	51.71 ± 1.42	3.0317	0.002
		Rural region	52.71 ± 0.31	50.01 ± 1.08	2.5265	0.012
	Only child	Yes	56.42 ± 0.40	53.27 ± 1.79	1.8374	0.066
		No	53.42 ± 0.27	49.91 ± 0.98	3.6296	<0.001

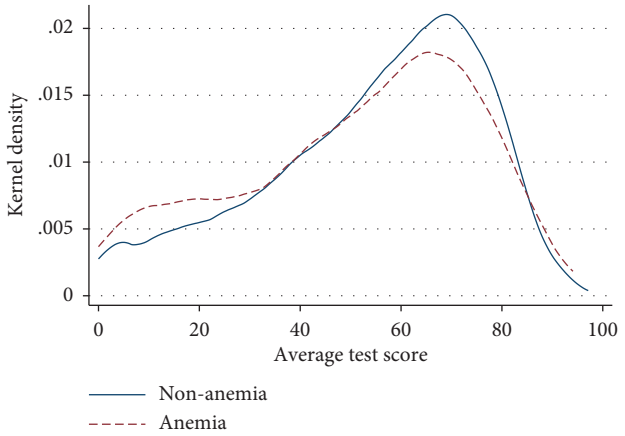

Figure 3: Average test score distribution for the nonanemia and anemia groups (China, 2018).

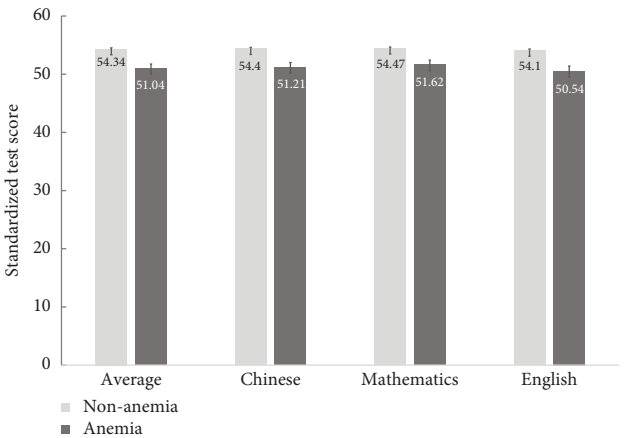

Figure 4: Comparison of the average and individual test score of three subjects between the nonanemia and anemia groups (China, 2018).

Table 3: Univariate and multivariate ordinary least squares (OLS) analysis regarding the association between anemia and academic performance by total, sex and age group (China, 2018).

Group	Average test score			Chinese test score			Mathematics test score			English test score		
	Model	β (95% CI)	P	Model	β (95% CI)	P	Model	β (95% CI)	P	Model	β (95% CI)	P
Total	Model 1[a]	−3.29 (−4.64, −1.94)	<0.001	Model 4[a]	−3.20 (−4.73, −1.66)	<0.001	Model 7[a]	−2.85 (−4.37, −1.32)	<0.001	Model 10[a]	−3.55 (−5.20, −1.91)	<0.001
	Model 2[b]	−2.22 (−3.57, −0.87)	0.001	Model 5[b]	−2.09 (−3.61, −0.57)	0.007	Model 8[b]	−1.86 (−3.40, −0.31)	0.018	Model 11[b]	−2.38 (−4.03, −0.73)	0.005
	Model 3[c]	−1.96 (−3.37, −0.55)	0.007	Model 6[c]	−1.98 (−3.61, −0.35)	0.017	Model 9[c]	−1.88 (−3.57, −0.18)	0.030	Model 12[c]	−1.92 (−3.72, −0.12)	0.036
Male	Model 1	−2.95 (−4.89, −1.01)	0.003	Model 4	−2.94 (−5.13, −0.75)	0.008	Model 7	−1.09 (−3.24, 1.06)	0.321	Model 10	−3.99 (−6.35, −1.62)	0.001
	Model 2	−1.35 (−3.30, 0.61)	0.177	Model 5	−1.31 (−3.53, 0.90)	0.245	Model 8	0.22 (−1.96, 2.39)	0.846	Model 11	−2.05 (−4.45, 0.35)	0.094
	Model 3	−1.45 (−3.54, 0.64)	0.173	Model 6	−1.41 (−3.84, 1.02)	0.255	Model 9	−0.40 (−2.83, 2.03)	0.746	Model 12	−1.90 (−4.56, 0.75)	0.160
Female	Model 1	−3.77 (−5.60, −1.95)	<0.001	Model 4	−3.64 (−5.68, −1.60)	<0.001	Model 7	−4.74 (−6.90, −2.59)	<0.001	Model 10	−3.20 (−5.42, −0.98)	0.005
	Model 2	−3.18 (−5.02, −1.33)	0.001	Model 5	−2.98 (−5.04, −0.92)	0.005	Model 8	−4.05 (−6.23, −1.87)	<0.001	Model 11	−2.80 (−5.04, −0.55)	0.015
	Model 3	−2.58 (−4.49, −0.68)	0.008	Model 6	−2.96 (−5.14, −0.77)	0.008	Model 9	−3.31 (−5.69, −0.93)	0.006	Model 12	−2.03 (−4.45, 0.39)	0.100
10 years	Model 1	−2.97 (−4.82, −1.13)	0.002	Model 4	−3.58 (−5.68, −1.47)	0.001	Model 7	−2.72 (−4.80, −0.64)	0.010	Model 10	−2.65 (−4.91, −0.39)	0.021
	Model 2	−1.32 (−3.16, 0.53)	0.162	Model 5	−1.87 (−3.96, 0.22)	0.079	Model 8	−1.30 (−3.41, 0.81)	0.228	Model 11	−0.85 (−3.12, 1.42)	0.461
	Model 3	−0.89 (−2.85, 1.06)	0.371	Model 6	−1.77 (−4.04, 0.49)	0.125	Model 9	−0.89 (−3.24, 1.46)	0.460	Model 12	−0.02 (−2.52, 2.48)	0.985
11 years	Model 1	−3.65 (−5.62, −1.68)	<0.001	Model 4	−2.81 (−5.04, −0.59)	0.013	Model 7	−3.00 (−5.23, −0.77)	0.008	Model 10	−4.56 (−6.95, −2.16)	<0.001
	Model 2	−3.06 (−5.02, −1.09)	0.002	Model 5	−2.25 (−4.45, −0.04)	0.046	Model 8	−2.35 (−4.60, −0.10)	0.040	Model 11	−3.86 (−6.26, −1.46)	0.002
	Model 3	−2.84 (−4.90, −0.79)	0.007	Model 6	−1.98 (−4.34, 0.39)	0.102	Model 9	−2.96 (−5.42, −0.49)	0.019	Model 12	−3.45 (−6.06, −0.84)	0.010

[a]Model 1, 4, 7, 10: univariate analysis. [b]Model 2, 5, 8, 11: adjusted for sex, age, Hukou type, only child, and self-assessed economic status. [c]Model 3, 6, 9, 12: adjusted for additional variables (highest educational qualification of parents, number of books in the family, parents' educational expectations, learning pressure score, good relationships with other students, and teacher-student relationship score) and school-level fix effects.

Table 4: Mediation effect analysis of factors mediating the association between anemia and average test score (China, 2018).

Variable	Mediation analysis			
	Model 13	Model 14	Model 15	Model 16
Anemia	−1.57 (−2.93, −0.22)[a]	−1.92 (−3.33, −0.50)[a]	−2.00 (−3.43, −0.58)[b]	−2.17 (−3.59, −0.75)[b]
Cognition	0.50 (0.46, 0.53)[c]	—	—	—
Body mass index (kg/m^2)	—	−0.16 (−0.28, −0.05)[b]	—	—
Sleep duration	—	—	−0.67 (−1.00, −0.34)[c]	—
CESD score	—	—	—	−0.52 (−0.58, −0.46)[c]
	Mediation effect estimation			
Total effect	−1.96 (−3.35, −0.28)	−1.90 (−3.25, −0.35)	−2.02 (−3.56, −0.50)	−2.20 (−3.61, −0.54)
Indirect effect	−0.39 (−0.78, −0.00)	0.02 (−0.01, 0.08)	−0.01 (−0.08, 0.03)	−0.02 (−0.25, 0.24)
Percent of indirect effect	19.9%	1.0%	0.5%	0.9%

Models 13–16 were based on the dependent variable of average test score, adjusted for factors such as sex, age, Hukou type, only child, self-assessed economic status, highest educational qualification of parents, number of books in the family, parents' educational expectations, learning pressure score, good relationships with other students, teacher-student relationship score, and fixed effects at the school level. This table only reported the coefficients of the variables related to anemia and mediation. [a]$P < 0.05$; [b]$P < 0.01$; [c]$P < 0.001$.

The study's limitations are that (1) the sample population was Grade 4 students of 10 to 11 years old, so the findings can only be representative of children in this age group and cannot be extrapolated to other age groups; (2) the analysis used baseline data from the China Education Panel Survey for primary school students, so the association between anemia and academic performance shows a cross-sectional relationship, not a causal effect. More data from a follow-up survey are needed to provide stronger evidence for this relationship; and (3) it only explored health-related mediation factors such as cognition score, BMI, sleeping duration, and CESD score. Other factors might have been missed that also could have mediated the relationship between anemia and academic performance.

5. Conclusions

This study analyzed the data of primary school students who participated in the China Education Panel Survey. The findings showed that the prevalence of anemia in children aged 10 and 11 years was 6.52%, and the prevalence was different among students with different characteristics. This indicates that anemia is a very important health issue among Grade 4 students in China, even in heterogeneous populations. Analyses showed that, in the study population, anemia was associated with academic performance, and that it affects academic performance both directly and indirectly. More nutrition-related interventions are needed to reduce the prevalence of anemia among children to ensure a healthy population base and guarantee human capital accumulation in China [45].

Data Availability

The datasets analyzed during the current study are not publicly available due to them containing information that could compromise the privacy of the participant but are available from the corresponding author on reasonable request.

Additional Points

What Is Known About This Topic? (i) Although children anemia was one of the public health problems faced by China, it did not receive enough attention in the country. (ii) China lacked research on the relationship between childhood anemia and academic performance, especially large-scale empirical analysis based on nationally representative data. (iii) The mechanisms of childhood anemia and academic performance in China were unclear, and there were almost no relevant published studies on this topic. *What This Paper Adds*? (i) The prevalence of anemia was 6.52% among Grade 4 students in China. (ii) In China, Grade 4 students without anemia exhibited higher academic performance than students with anemia. (iii) Anemia directly impacted the academic performance of Grade 4 students in China, as well as indirectly through lower cognitive levels.

Disclosure

The manuscript has been made available as a preprint, which can be accessed via the following link: https://www.researchsquare.com/article/rs-2410445/v1 [46]. The funder had no role in the design, conduct, or reporting of this work.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

The formal data analysis, oversight of the study methodology, and first drafting was completed by Yisong Hu. Weidong Wang was the first corresponding author who contributed to the entirety of the investigation, supervision, and review. Yanxin Mao was responsible for the data collection and field work organization.

Acknowledgments

The authors gratefully acknowledge all participants in this study. This work was supported by a grant for building world-class universities (disciplines) at the Renmin University of China and research funds of Renmin University of China (Grand number: 18XNF001). In addition, this study was supported by the fundamental research funds for the

Central Universities and the research funds of Renmin University of China. Program name: China Education Panel Survey.

Supplementary Materials

Supplementary Figures S1–S3 show the distribution of test scores in Chinese, Mathematics, and English for both the nonanemia and anemia groups. Supplementary Table S1–S3 provided an analysis of the mediating factors that affect the relationship between anemia and the test scores in Chinese, Mathematics, and English, respectively. (*Supplementary Materials*)

References

[1] J. Sun, H. Wu, M. Zhao, C. G. Magnussen, and B. Xi, "Prevalence and changes of anemia among young children and women in 47 low- and middle-income countries, 2000-2018," *EClinicalMedicine*, vol. 41, Article ID 101136, 2021.

[2] L. N. Yin, W. Zhao, H. Q. Hu et al., "Prevalence and trends of anemia among pregnant women in eight provinces of China from 2016 to 2020," *Zhonghua Yufang Yixue Zazhi*, vol. 57, no. 5, pp. 736–740, 2023.

[3] World Health Organization, "Prevalence of anaemia in children aged 6–59 months (%)," 2019, https://www.who.int/data/gho/data/indicators/indicator-details/GHO/prevalence-of-anaemia-in-children-under-5-years-(-).

[4] World Health Organization, "Anaemia in women and children," 2019, https://www.who.int/data/gho/data/themes/topics/anaemia_in_women_and_children.

[5] Y. Song, H. J. Wang, B. Dong, Z. Wang, J. Ma, and A. Agardh, "National trends in hemoglobin concentration and prevalence of anemia among Chinese school-aged children, 1995-2010," *The Journal of Pediatrics*, vol. 183, pp. 164–169.e2, 2017.

[6] Z. Zhu, C. R. Sudfeld, Y. Cheng et al., "Anemia and associated factors among adolescent girls and boys at 10-14 years in rural western China," *BMC Public Health*, vol. 21, no. 1, p. 218, 2021.

[7] World Health Organization, "Global accelerated action for the health of adolescents (AA-HA!)-Guidance to support country implementation 2017," 2017, https://www.who.int/publications/i/item/9789241512343.

[8] K. L. I. Samson, J. A. J. Fischer, and M. L. Roche, "Iron status, anemia, and iron interventions and their associations with cognitive and academic performance in adolescents: a systematic review," *Nutrients*, vol. 14, no. 1, p. 224, 2022.

[9] B. T. Gutema, M. B. Sorrie, N. D. Megersa et al., "Effects of iron supplementation on cognitive development in school-age children: systematic review and meta-analysis," *PLoS One*, vol. 18, no. 6, Article ID e0287703, 2023.

[10] Z. Chen, H. Yang, D. Wang et al., "Effect of oral iron supplementation on cognitive function among children and adolescents in low- and middle-income countries: a systematic review and meta-analysis," *Nutrients*, vol. 14, no. 24, p. 5332, 2022.

[11] A. Mosiño, K. P. Villagómez-Estrada, and A. Prieto-Patrón, "Association between school performance and anemia in adolescents in Mexico," *International Journal of Environmental Research and Public Health*, vol. 17, no. 5, p. 1466, 2020.

[12] P. H. Nguyen, M. Walia, A. Pant, P. Menon, and S. Scott, "Changes in anemia and anthropometry during adolescence predict learning outcomes: findings from a 3-year longitudinal study in India," *The American Journal of Clinical Nutrition*, vol. 115, no. 6, pp. 1549–1558, 2022.

[13] M. Q. Cai and W. Y. Yan, "Study on iron nutritional status in adolescence," *Biomedical and Environmental Sciences: Biomedical and Environmental Sciences*, vol. 3, no. 1, pp. 113–119, 1990.

[14] Z. G. Liu and Y. Y. Wang, "A study on the relationship between children anemia and learning ability," *Academic journal of Shanxi Medical University*, vol. 32, no. 1, pp. 22-23, 2001.

[15] Y. Li, "Iron deficiency and its impact on academic achievement," *China Agricultural Economic Review*, vol. 1, no. 3, pp. 245–259, 2009.

[16] L. Li, L. Huang, Y. Shi, R. Luo, M. Yang, and S. Rozelle, "Anemia and student's educational performance in rural central China: prevalence, correlates and impacts," *China Economic Review*, vol. 51, pp. 283–293, 2018.

[17] B. Larsen, E. B. Baller, A. A. Boucher et al., "Development of iron status measures during youth: associations with sex, neighborhood socioeconomic status, cognitive performance, and brain structure," *The American Journal of Clinical Nutrition*, vol. 118, no. 1, pp. 121–131, 2023.

[18] A. Bahrami, Z. Khorasanchi, M. Tayefi et al., "Anemia is associated with cognitive impairment in adolescent girls: a cross-sectional survey," *Applied Neuropsychology: Child*, vol. 9, no. 2, pp. 165–171, 2020.

[19] X. Ji, N. Cui, and J. Liu, "Neurocognitive function is associated with serum iron status in early adolescents," *Biological Research For Nursing*, vol. 19, no. 3, pp. 269–277, 2017.

[20] L. Zhao, X. Zhang, Y. Shen, X. Fang, Y. Wang, and F. Wang, "Obesity and iron deficiency: a quantitative meta-analysis," *Obesity Reviews*, vol. 16, no. 12, pp. 1081–1093, 2015.

[21] J. He, X. Chen, X. Fan, Z. Cai, and F. Huang, "Is there a relationship between body mass index and academic achievement? A meta-analysis," *Public Health*, vol. 167, pp. 111–124, 2019.

[22] X. Liu, Q. Song, W. Hu et al., "Night sleep duration and risk of incident Anemia in a Chinese population: a prospective cohort study," *Scientific Reports*, vol. 8, no. 1, p. 3975, 2018.

[23] M.-Y. Chun, J.-H. Kim, and J.-S. Kang, "Relationship between self-reported sleep duration and risk of anemia: data from the korea national health and nutrition examination survey 2016–2017," *International Journal of Environmental Research and Public Health*, vol. 18, no. 9, p. 4721, 2021.

[24] L. A. Musshafen, R. S. Tyrone, A. Abdelaziz et al., "Associations between sleep and academic performance in US adolescents: a systematic review and meta-analysis," *Sleep Medicine*, vol. 83, pp. 71–82, 2021.

[25] V. Chattu, B. Aeri, and P. Khanna, "Nutritional aspects of depression in adolescents-a systematic review," *International Journal of Preventive Medicine*, vol. 10, no. 1, p. 42, 2019.

[26] A. G. Zarate-Ortiz, H. Verhoef, A. Melse-Boonstra et al., "Depressive symptoms among Mexican adolescent girls in relation to iron status, anaemia, body weight and pubertal status: results from a latent class analysis," *Public Health Nutrition*, vol. 26, no. 2, pp. 408–415, 2023.

[27] A. Wickersham, H. V. Sugg, S. Epstein, R. Stewart, T. Ford, and J. Downs, "Systematic review and meta-analysis: the association between child and adolescent depression and later educational attainment," *Journal of the American Academy of Child and Adolescent Psychiatry*, vol. 60, no. 1, pp. 105–118, 2021.

[28] World health organization, "Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity

2011," 2011, https://iris.who.int/bitstream/handle/10665/85839/WHO_NMH_NHD_MNM_11.1_eng.pdf?sequence=22&isAllowed=y.

[29] R. P. Ang, S. L. Ong, and X. Li, "Student version of the teacher-student relationship inventory (S-tsri): development, validation and invariance," *Frontiers in Psychology*, vol. 11, p. 1724, 2020.

[30] B. Zhang and J. Li, "Reliability and validity of a short version of Center for Epidemiologic Studies Depression Scale in national adult population," *Chinese Mental Health Journal*, vol. 25, pp. 506–511, 2011.

[31] J. Raven, "The Raven's progressive matrices: change and stability over culture and time," *Cognitive Psychology*, vol. 41, no. 1, pp. 1–48, 2000.

[32] Z. Wen and B. Ye, "Analyses of mediating effects: the development of methods and models," *Advances in Psychological Science*, vol. 22, no. 5, pp. 731–745, 2014.

[33] S. Li, X. Cheng, L. Zhao, and H. Ren, "Anemia of school-age children in primary schools in southern China should Be paid more attention despite the significant improvement at national level: based on Chinese nutrition and health surveillance data (2016-2017)," *Nutrients*, vol. 13, no. 11, p. 3705, 2021.

[34] Z. Yang, Y. Li, P. Hu, J. Ma, and Y. Song, "Prevalence of anemia and its associated factors among Chinese 9-12-and 14-year-old children: results from 2014 Chinese national survey on students constitution and health," *International Journal of Environmental Research and Public Health*, vol. 17, no. 5, p. 1474, 2020.

[35] P. P. Xu, Q. Zhang, T. T. Yang et al., "Anemia prevalence and its influencing factors among students involved in the nutrition improvement program for rural compulsory education students in 2019," *Zhonghua Liuxingbingxue Zazhi*, vol. 43, no. 4, pp. 496–502, 2022.

[36] S. Li, L. Zhao, D. Yu, and H. Ren, "Attention should be paid to adolescent girl anemia in China: based on China Nutrition and Health Surveillance (2015-2017)," *Nutrients*, vol. 14, no. 12, p. 2449, 2022.

[37] A. Sen and S. J. Kanani, "Deleterious functional impact of anemia on young adolescent school girls," *Indian Pediatrics*, vol. 43, no. 3, pp. 219–226, 2006.

[38] A. M. Hogan, I. M. Pit-ten Cate, F. Vargha-Khadem, M. Prengler, and F. J. Kirkham, "Physiological correlates of intellectual function in children with sickle cell disease: hypoxaemia, hyperaemia and brain infarction," *Developmental Science*, vol. 9, no. 4, pp. 379–387, 2006.

[39] J. L. Kwiatkowski, R. A. Zimmerman, A. N. Pollock et al., "Silent infarcts in young children with sickle cell disease," *British Journal of Haematology*, vol. 146, no. 3, pp. 300–305, 2009.

[40] S. Gropper, J. Smith, and T. Carr, *Advanced Nutrition and Human Metabolism*, Cengage, Boston, MA, USA, 7th edition, 2018.

[41] E. K. Hurtado, A. H. Claussen, and K. G. Scott, "Early childhood anemia and mild or moderate mental retardation," *The American Journal of Clinical Nutrition*, vol. 69, no. 1, pp. 115–119, 1999.

[42] L. Yang, J. M. Liu, R. W. Ye, S. Hong, J. Zheng, and A. Ren, "Correlation on hemoglobin concentration and the development of cognition among pre-school children," *Zhonghua Liuxingbingxue Zazhi*, vol. 31, no. 4, pp. 389–393, 2010.

[43] I. Jáuregui-Lobera, "Iron deficiency and cognitive functions," *Neuropsychiatric Disease and Treatment*, vol. 10, pp. 2087–2095, 2014.

[44] A. A. Mantey, R. A. Annan, H. E. Lutterodt, and P. Twumasi, "Iron status predicts cognitive test performance of primary school children from Kumasi, Ghana," *PLoS One*, vol. 16, no. 5, Article ID e0251335, 2021.

[45] L. Wang, J. Huo, Y. Wei, Y. Tang, J. Sun, and J. Huang, "Yingyangbao reduced anemia among infants and young children aged 6-23 Months when delivered through a large-scale nutrition improvement program for children in poor areas in China from 2015 to 2020," *Nutrients*, vol. 15, no. 11, p. 2634, 2023.

[46] Y. Hu and W. Wang, "Relationship between anemia and learning performance in Chinese primary school students: evidence from a large national survey," 2023, https://www.researchsquare.com/article/rs-2410445/v1.