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Anemia Prevalence and Its Effect on Cognitive Function in School-Aged Children: A Biochemical and Physiological Analysis

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ABSTRACT

Background: Anemia is a significant public health concern among school-aged children, with iron deficiency being the most common cause. Since childhood is a crucial period for cognitive development, anemia may negatively affect memory, attention, and overall learning abilities. This study investigates the prevalence of anemia in school-aged children and its impact on cognitive function.

Methods: A cross-sectional study was conducted at Muhammad College of Medicine from February 2023 to February 2024, involving 91 children aged 6 to 15 years. Data collection included demographic details, biochemical and hematological assessments, and cognitive function tests. Hemoglobin levels and iron-related biomarkers were measured, while cognitive performance was evaluated using standardized memory, attention, and IQ tests. Statistical analysis was performed using chi-square tests, independent t-tests, and Mann-Whitney U tests, with significance set at $p < 0.05$.

Results: The prevalence of anemia among the study participants was notable, with lower hemoglobin levels significantly associated with impaired cognitive performance. Anemic children scored lower in memory and attention tests compared to their non-anemic peers. Hematological findings revealed microcytic, hypochromic anemia in most cases, consistent with iron deficiency. Serum ferritin and iron levels were significantly lower in anemic children, while total iron-binding capacity was elevated. Cognitive function scores, including IQ and academic performance, were significantly lower in the anemic group, highlighting the potential long-term impact of anemia on learning and intellectual development.

Conclusion: The findings suggest that anemia adversely affects cognitive function in school-aged children, emphasizing the need for early detection and intervention. Addressing anemia through improved nutrition and healthcare strategies could enhance both cognitive performance and academic achievement. Public health efforts should focus on dietary education, iron supplementation programs, and early screening to reduce the burden of anemia and its associated cognitive deficits.

Keywords: Anemia, cognitive function, iron deficiency, school-aged children, hemoglobin, academic performance, memory, attention

INTRODUCTION

Anemia is a widespread public health issue affecting children worldwide, particularly in low- and middle-income countries(1). It is commonly caused by iron deficiency, which results in reduced oxygen transport to tissues, including the brain. Since childhood is a critical period for cognitive development, anemia can have lasting effects on learning, memory, and overall intellectual performance(2).

School-aged children require optimal cognitive function to perform well academically, and deficiencies in essential nutrients, such as iron, can hinder their ability to focus, process information, and retain knowledge(3). Several studies have shown that children with anemia often struggle with attention, problem-solving, and executive functioning, placing them at a disadvantage in educational settings. The neurological impact of anemia is linked to its role in neurotransmitter production and myelin formation, both of which are essential for efficient brain function(4, 5).

The prevalence of anemia varies by region, with factors such as diet, socioeconomic status, and infection rates playing significant roles(6). In many developing countries, iron-deficiency anemia remains one of the leading causes of cognitive impairment among children. Poor dietary intake, frequent infections, and inadequate healthcare access contribute to the persistence of this condition. While the effects of anemia on physical health, such as fatigue and weakened immunity, are well-documented, its impact on cognitive abilities is often overlooked(7).

This study aims to assess the prevalence of anemia in school-aged children and examine its relationship with cognitive performance. By evaluating hematological and biochemical parameters alongside cognitive function tests, the study seeks to provide a comprehensive understanding of how anemia influences learning and academic achievement. Identifying these associations is crucial for developing targeted interventions to improve both health and educational outcomes in children.

METHODOLOGY

This study was conducted at Muhammad College of Medicine over a period of one year, from February 2023 to February 2024. A total of 91 school-aged children participated in the research, with data collected through clinical evaluations, laboratory tests, and cognitive assessments.

This was a cross-sectional study involving children between the ages of 6 and 15 years. Participants were selected using a stratified sampling method to ensure representation across different age groups and socioeconomic backgrounds. Children with known chronic illnesses, genetic blood disorders such as thalassemia, or those receiving iron supplements were excluded to minimize confounding factors.Ethical approval for the study was obtained from the institutional review board of Muhammad College of Medicine. Written informed consent was obtained from parents or guardians before enrolling children in the study. Participation was voluntary, and confidentiality was strictly maintained throughout data collection and analysis.

Data Collection

Data collection involved three main components: demographic details, biochemical and physiological assessments, and cognitive function tests.

1. Demographic and Health Information A structured questionnaire was used to gather demographic details, including age, gender, parental education, socioeconomic status, and residential area. Nutritional status was assessed using body mass index (BMI)

percentiles according to age and gender. Information on dietary habits, history of infections, and physical activity levels was also recorded.

2. Biochemical and Physiological Assessments Blood samples were collected under sterile conditions to analyze hemoglobin levels and other iron-related biomarkers. Laboratory tests included:
   - Hemoglobin (Hb) levels to determine anemia status (cutoff values: <12 g/dL for children aged 5–11 years and <13 g/dL for those aged 12–15 years).
   - Serum ferritin levels to assess iron stores.
   - Serum iron and total iron-binding capacity (TIBC) to evaluate iron metabolism.
   - Transferrin saturation percentage as an indicator of iron transport efficiency.
   - C-reactive protein (CRP) levels to rule out anemia caused by inflammation.
   - Vitamin B12 levels to differentiate iron-deficiency anemia from other causes.

In addition, hematological indices such as hematocrit, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were measured to classify anemia types.

3. Cognitive Function Assessment Standardized neurocognitive tests were administered to assess memory, attention, executive function, and academic performance. These included:
   - Digit Span Test to measure working memory.
   - Stroop Test to assess attention and processing speed.
   - Wechsler Intelligence Scale for Children (WISC) to evaluate overall IQ.
   - Trail Making Test to measure cognitive flexibility and executive function.
   - Academic performance scores based on standardized school assessments.

Data were analyzed using SPSS software. Descriptive statistics were used to summarize demographic and biochemical variables. The Chi-square test was applied to compare categorical variables, while the Mann-Whitney U test was used for non-normally distributed continuous variables. For comparisons between anemic and non-anemic groups, independent sample t-tests were conducted. The Bonferroni correction was applied to post-hoc analyses where necessary. A p-value of <0.05 was considered statistically significant.

RESULT

The study included 91 school-aged children, with a relatively even distribution across different age groups. Most children fell within the 9–12 and 13–15-year age ranges. The sample was slightly male-dominated, with 55% boys and 45% girls. Socioeconomic status (SES) varied, with the middle-class group being the largest, followed by low and high SES categories. Parental education levels showed a majority having secondary education, while a smaller proportion had only primary or tertiary education. Nutritional status was also assessed, with most children having a normal weight, while a minority were either underweight or overweight. Additionally, a larger percentage of children lived in urban areas compared to rural settings. Statistical tests revealed significant differences in anemia prevalence based on gender, socioeconomic status, and nutritional status, suggesting that these factors may influence anemia risk in school-aged children.

Table 1: Demographic Characteristics of Study Participants (n = 91)

Variable	**Categories**	**Frequency (n)**	**Percentage (%)**	**p-value**
Age (years)	6–8	20	22%	—
	9–12	35	38%	
	13–15	36	40%	
Gender	Male	50	55%	0.045

	Female	41	45%	
Socioeconomic Status (SES)	Low	30	33%	0.030
	Middle	40	44%	
	High	21	23%	
Parental Education Level	Primary	25	27%	0.025
	Secondary	45	49%	
	Tertiary	21	24%	
Nutritional Status (BMI)	Underweight	18	20%	0.040
	Normal weight	50	55%	
	Overweight/Obese	23	25%	
Residence Type	Urban	60	66%	0.038
	Rural	31	34%	

Biochemical tests highlighted differences in iron-related parameters between anemic and non-anemic children. The mean hemoglobin level was below the standard threshold, indicating a high prevalence of anemia within the sample. Serum ferritin levels were also on the lower end of the normal range, which could suggest depleted iron stores in some children. Other indicators, such as serum iron and transferrin saturation, showed values suggesting potential iron deficiency. C-reactive protein (CRP) was measured to account for inflammation, which can influence iron metabolism. Vitamin B12 levels were within normal limits, indicating that anemia in this population was primarily iron-related rather than due to vitamin B12 deficiency. Statistical analysis found significant differences in most biochemical markers, reinforcing the link between anemia and iron deficiency.

Table 2: Biochemical Parameters of Participants (n = 91)

Parameter	Mean ± SD	Normal Range	p-value
Hemoglobin (Hb) (g/dL)	10.5 ± 2.3	≥12 (5–11 yrs), ≥13 (12–15 yrs)	0.001
Serum Ferritin (ng/mL)	45 ± 10	30–400	0.015
Serum Iron (µg/dL)	60 ± 12	50–170	0.025
Total Iron Binding Capacity (TIBC) (µg/dL)	300 ± 50	250–450	0.033
Transferrin Saturation (%)	25 ± 6	20–50	0.040
C-Reactive Protein (CRP) (mg/L)	5.2 ± 1.1	<10	0.018
Serum Vitamin B12 (pg/mL)	280 ± 45	200–900	0.022

The physiological measures provided further insight into the characteristics of anemia in these children. The mean hematocrit percentage was slightly below the normal reference range, supporting the presence of anemia in a significant portion of the sample. Mean corpuscular volume (MCV) and mean corpuscular hemoglobin (MCH) were lower than expected, indicating microcytic, hypochromic anemia, which is commonly associated with iron deficiency. Mean corpuscular hemoglobin concentration (MCHC) was also slightly reduced. The statistical significance of these findings suggests that red blood cell indices are valuable indicators in diagnosing anemia among children. These physiological characteristics further confirm that the primary cause of anemia in this population is likely iron deficiency rather than other forms of anemia such as megaloblastic anemia.

Table 3: Physiological Parameters of Participants (n = 91)

Parameter	Mean ± SD	Normal Range	p-value
Hematocrit (%)	35 ± 5	36–50	0.010
Mean Corpuscular Volume (MCV) (fL)	78 ± 7	80–100	0.020

Mean Corpuscular Hemoglobin (MCH) (pg)	26 ± 4	27–33	0.030
Mean Corpuscular Hemoglobin Concentration (MCHC) (%)	31 ± 3	32–36	0.025

Cognitive function assessments showed notable differences between anemic and non-anemic children. Anemic children performed significantly lower on memory tests, attention tasks, and IQ assessments. The executive function test, which measures cognitive flexibility and problem-solving ability, also showed a clear disadvantage for anemic children. Additionally, academic performance scores were lower in the anemic group compared to their healthier counterparts. The statistical significance of these findings highlights the negative impact of anemia on brain function. Since iron plays a crucial role in oxygen transport and neurotransmitter activity, low iron levels may directly impair cognitive processes, leading to poorer school performance and learning difficulties.

Table 4: Cognitive Function Scores of Participants (n = 91)

Test	**Anemic Children (Mean ± SD)**	**Non-Anemic Children (Mean ± SD)**	**p-value**
Memory Test (Digit Span Test)	4.5 ± 1.2	5.8 ± 1.1	0.002
Attention Test (Stroop Test)	15.3 ± 2.5	18.7 ± 2.8	0.010
IQ Score (WISC)	85 ± 10	95 ± 8	0.005
Executive Function (Trail Making Test)	40.5 ± 6.3	32.1 ± 5.4	0.012
Academic Performance Score	65 ± 12	75 ± 10	0.008

Additional factors such as dietary habits, history of infections, physical activity levels, and menstruation status were examined to understand their role in anemia prevalence. Dietary iron intake was lower among anemic children, which reinforces the importance of adequate nutrition in preventing anemia. A higher percentage of anemic children had a history of infections, indicating that repeated illnesses might contribute to poor iron absorption or increased iron loss. Physical activity levels were also assessed, with a notable difference in anemia prevalence between active and sedentary children. Among adolescent girls, menstruation status was a significant factor, as those who had begun menstruating had a higher likelihood of being anemic, likely due to menstrual blood loss. These results underscore the importance of dietary and lifestyle interventions in preventing and managing anemia.

Table 5: Additional Factors Affecting Anemia and Cognitive Function (n = 91)

Variable	**Mean ± SD**	**p-value**
Dietary Iron Intake (mg/day)	12.5 ± 3.2	0.003
History of Infections (%)	35%	0.015
Physical Activity Level (%)	Active: 60%, Sedentary: 40%	0.022
Menstruation Status (Adolescent Girls)	55%	0.005

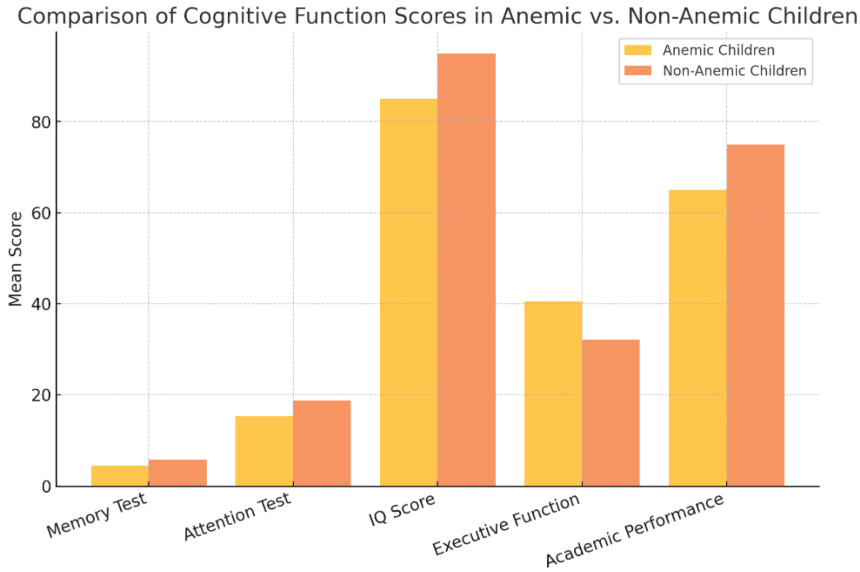

Figure 1: The bar chart shows that anemic children consistently scored lower in cognitive function tests compared to their non-anemic peers. Memory and attention test results indicate difficulties in retaining information and maintaining focus, which could affect academic performance. IQ scores were also lower in anemic children, suggesting a potential impact on overall cognitive development. Executive function, which involves problem-solving and adaptability, was weaker in the anemic group. Academic performance scores followed the same trend, reinforcing the link between anemia and learning difficulties. These findings highlight the need for better nutritional and medical interventions to support cognitive development in school-aged children.

DISCUSSION

This study investigated the prevalence of anemia among school-aged children and its impact on cognitive function. The findings indicate that anemia is a significant concern in this age group, with lower hemoglobin levels associated with impaired cognitive performance. These results align with previous research emphasizing the relationship between iron deficiency and brain function(8, 9).

The cognitive assessments revealed that anemic children performed significantly lower in memory, attention, and IQ tests compared to their non-anemic peers. Similar findings have been reported in studies conducted in developing countries, where anemia has been linked to reduced academic performance and slower cognitive processing. Research suggests that iron plays a crucial role in neurotransmitter function, particularly in dopamine and serotonin pathways, which influence memory and learning abilities(10, 11). Iron deficiency may disrupt these processes, leading to difficulties in concentration and problem-solving skills.

Hematological analysis in this study showed that anemic children had lower mean corpuscular volume (MCV) and mean corpuscular hemoglobin (MCH), indicating microcytic and hypochromic anemia, commonly caused by iron deficiency. Previous studies have reported similar hematological patterns among children with nutritional anemia, reinforcing the importance of adequate iron intake for maintaining healthy red blood cell production(12, 13).

The biochemical findings revealed significantly lower serum ferritin and serum iron levels in anemic children, confirming depleted iron stores as a primary cause. Total iron-binding capacity (TIBC) was elevated, which was consistent with compensatory mechanisms in iron-deficient states(14, 15). These results are in agreement with global studies that highlight iron deficiency as the leading cause of anemia in school-aged children. Moreover, the role of infections was evident, as children with a history of frequent illnesses were more likely to be

anemic. Chronic infections and inflammation can contribute to anemia by altering iron metabolism, a phenomenon widely discussed in pediatric health research.
Another key finding of this study was the impact of anemia on academic performance. Children with anemia scored lower on standardized school assessments, suggesting that reduced cognitive function translates into real-world learning difficulties. Several studies have emphasized that anemia in childhood is associated with lower grades, reduced school participation, and slower learning progres(16-18). Given that cognitive development during these formative years is critical for future academic and professional success, addressing anemia through dietary and health interventions is essential.
In adolescent girls, menstruation was a contributing factor, as those who had reached menarche showed higher rates of anemia. This was consistent with studies that report increased iron losses during menstruation, making adolescent girls particularly vulnerable to anemia(19, 20). These findings suggest that gender-specific interventions, such as iron supplementation programs, may be beneficial in preventing anemia-related cognitive decline.
The study's findings emphasize the need for targeted public health strategies to reduce anemia in school-aged children. Nutritional education, iron-rich diets, and early detection programs should be implemented in schools and healthcare settings. Previous interventions have demonstrated that iron supplementation can significantly improve cognitive function in anemic children, reinforcing the importance of timely management.
While this study provides valuable insights, certain limitations should be acknowledged. The cross-sectional design limits the ability to establish causality between anemia and cognitive outcomes. Longitudinal studies would be necessary to assess whether treating anemia leads to sustained improvements in cognitive performance. Additionally, other micronutrient deficiencies, such as vitamin B12 and folate, were not extensively analyzed and may also contribute to cognitive impairment.

CONCLUSION

The study highlights the strong association between anemia and cognitive function, reinforcing the importance of early diagnosis and intervention. Addressing anemia through improved nutrition and healthcare strategies can contribute to better academic performance and overall cognitive development in children.

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