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Original Research Article

Study On Iron Deficiency Anemia and Cognitive Performance in School Children

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Abstract:

Background: Iron deficiency anaemia (IDA) remains one of the most prevalent nutritional disorders affecting school-aged children and is known to adversely impact cognitive development.

Aim and Objective: This study assesses the prevalence of IDA among school children aged 6–14 years and evaluates its association with various cognitive domains

Methods: A school-based cross-sectional analytical study was conducted among 420 children selected through multistage random sampling. Socio-demographic details, anthropometric measurements, and haematological parameters (Hb, serum ferritin, serum iron, TIBC, transferrin saturation) were collected. Cognitive performance was assessed using Binet–Kamat IQ Test, Digit Span, Coding Test, and Color Trails Test. Data were analysed using SPSS v25. Independent t-tests, Pearson's correlation, and multiple linear regression were applied.

Results: Anaemia was present in 41.9% of participants, with 29.5% classified as having IDA. Children with IDA demonstrated significantly lower cognitive scores across all domains compared to non-anaemic peers ($p < 0.001$). Mean IQ scores (96.4 vs. 87.1), Digit Span scores (10.2 vs. 7.8), and Coding Test scores (68.5 vs. 59.4) were markedly reduced in the IDA group. Haemoglobin and ferritin showed significant positive correlations with IQ and attention measures ($r = 0.31–0.45$, $p < 0.001$). Multiple regression confirmed haemoglobin, ferritin, and socioeconomic status as independent predictors of cognitive performance.

Conclusion: IDA is highly prevalent among school-aged children and is strongly associated with impaired cognition. Improving iron status may significantly enhance academic and neurocognitive outcomes. Early screening and targeted interventions within school health programs are urgently required.

Keywords: Iron Deficiency Anaemia, Cognitive Performance, School Children, Haemoglobin, Ferritin, IQ, Digit Span, Executive Function.

Introduction

Iron deficiency anaemia (IDA) is the most widespread micronutrient deficiency globally and a major cause of morbidity in children. The World Health Organization estimates that nearly 40% of children under 15 years are anaemic, with iron deficiency contributing to about half of these cases [1,2]. Global burden studies show that anaemia significantly contributes to impaired growth, infections, poor school performance, and long-term neurodevelopmental deficits [3,4].

India bears one of the highest burdens of childhood anaemia worldwide. National surveys report that almost two-thirds of Indian children are anaemic, largely due to inadequate dietary intake, infections, and socio-economic factors [5-8]. Studies across rural and urban regions consistently show that iron deficiency is the predominant cause of anaemia in school-aged children, with prevalence rates often exceeding 40–60% [9–11]. This period of life is critical because it overlaps with rapid cognitive development and formal education.

Iron plays an essential role in brain maturation. It is required for neurotransmitter synthesis, myelination, hippocampal development, and energy metabolism in neurons [12,13]. Deficiency during key growth phases may adversely affect synaptic development and neural connectivity, potentially leading to long-standing cognitive impairments [13,14]. Evidence from neuropsychological studies shows that children with iron deficiency or IDA commonly have deficits in attention, memory, executive functions, language development, school achievement, and psychomotor speed [12,14,15].

Observational studies consistently show poorer cognitive test scores and academic performance in iron-deficient children compared with iron-sufficient peers. Indian studies have reported that school-going children with IDA have significantly lower IQ, reduced attention and memory scores, and poorer scholastic performance [16–18]. International research similarly shows that adolescents with low haemoglobin or ferritin levels demonstrate poorer performance in multiple cognitive domains [19,20].

Intervention studies further support a direct link between iron deficiency and cognitive deficits. Randomized controlled trials have shown that iron supplementation improves attention, memory, learning ability, and overall cognitive performance, particularly in iron-deficient school-age children [21–23]. A recent meta-analysis confirms that iron therapy significantly improves intelligence and attention in school-age populations [24].

Despite substantial evidence, limited studies have specifically assessed the cognitive effects of IDA among primary and middle-school children in India—an age group where cognitive skills directly influence academic outcomes. Variations in cognitive testing methods and confounding factors such as nutrition and socio-economic status underscore the need for context-specific research.

Therefore, the present study aims to determine the prevalence of iron deficiency anaemia among school children and assess its association with cognitive performance using standardized, age-appropriate tools. Understanding this relationship in the Indian context is essential for guiding school health programmes, nutritional interventions, and educational policies aimed at improving both health and learning outcomes.

Materials and Method

A school-based cross-sectional analytical study was conducted among government and private school children in the selected urban/rural field practice area in Department of paediatrics in collaboration with Department of Community Medicine, Chalmeda Anand Rao Institute of Medical Sciences, Karimnagar. The study was carried out over a period of 12 months.

The study population included school children aged 6–14 years enrolled in classes 1–8. Schools were selected using simple random sampling from the list of all schools in the field practice area.

Inclusion Criteria

- Children aged 6–14 years.
- Children present on the day of data collection.
- Children whose parents/guardians provided written informed consent.
- Children who assented to participate.

Exclusion Criteria

- Children with known chronic illnesses (e.g., thalassemia, sickle cell disease, chronic kidney disease).
- Children currently on iron supplementation or hematinic therapy.
- Children with acute febrile illness at the time of study.
- Children with known neurological disorders or learning disabilities.

Sample Size Estimation: Sample size was calculated using the formula for prevalence studies:

$$n = \frac{4PQ}{ME^2}$$

Assuming a prevalence of iron deficiency anaemia among school children as 50% from previous studies, 5% absolute error, and 95% confidence level, the minimum sample size required was 384. Considering a 10% non-response rate, the final sample size was fixed at 420 students.

A multistage sampling method was adopted:

1. From all schools in the study area, schools were selected using simple random sampling.
2. From each selected school, classes were chosen by simple random sampling.
3. Eligible students were selected using systematic random sampling from class attendance registers.

Method

1. **Socio-Demographic Questionnaire**

A pre-tested, semi-structured questionnaire was used to obtain:

- Age, gender, class
- Socio-economic status (as per Modified BG Prasad scale)
- Dietary habits (24-hour recall & frequency of iron-rich foods)
- History of worm infestation, menstrual history (for girls above 10 years)

2. **Anthropometric Measurements**

Standardised procedures were used:

- **Height:** Measured to nearest 0.1 cm using stadiometer
- **Weight:** Measured to nearest 0.1 kg using digital weighing scale
- **BMI:** Calculated using WHO growth charts for age and sex

3. **Hematological Assessments**

Venous blood samples (2–3 mL) were collected by trained phlebotomists under aseptic precautions.

The following investigations were performed:

- **Hemoglobin (Hb):** Cyanmethemoglobin/automated analyser
- **Serum Ferritin:** Chemiluminescence immunoassay
- **Serum Iron and TIBC:** Automated analyser; Transferrin Saturation calculated
- **CRP (optional):** To rule out false elevation of ferritin due to infection

Diagnostic Criteria

- **Anaemia:** Hb < 11.5 g/dL (6–11 years) / < 12 g/dL (12–14 years) – WHO criteria
- **Iron Deficiency Anaemia (IDA):**
  - Low Hb **AND**
  - Serum ferritin < 15 µg/L (with normal CRP) **OR**
  - Transferrin saturation < 16%

4. **Cognitive Performance Assessment**

Standardized, validated cognitive tests were used appropriate for the child's age:

- **Binet–Kamat Test (BKT)** for Intelligence Quotient
- **Digit Span Test** for attention & working memory
- **Coding Test** for processing speed
- **Color Trails Test** for executive function
- **School performance** (recent exam marks) obtained with school permission

All tests were administered by trained psychologists/teachers in a quiet classroom environment.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using SPSS version 25.0 (IBM Corp., Armonk, NY). Descriptive statistics such as mean, standard deviation (SD), frequencies, and percentages were used to summarize socio-demographic characteristics, haematological parameters, and cognitive test scores. Comparison of cognitive performance between anaemic and non-anaemic groups, as well as across different levels of iron status, was carried out using the Independent t-test or one-way ANOVA for continuous variables, while the Chi-square test was applied for categorical variables. The correlation between haemoglobin, serum ferritin levels, and various cognitive domain scores was assessed using Pearson's correlation coefficient. Further, multiple linear regression analysis was performed to identify independent predictors of cognitive performance after adjusting for potential confounders. A p-value of less than 0.05 was considered statistically significant.

Observation and Results

Table 1: Socio-demographic characteristics of the study participants (n = 420)

Variable	Frequency (n)	Percentage (%)
Age group (years)		
6–9 Years	180	42.8
10–12 Years	145	34.5
13–14 Years	95	22.6
Gender		
Boys	216	51.4
Girls	204	48.6
Diet pattern		
Mixed	222	52.8
Vegetarian	198	47.2
Socio-Economic Status		
Upper	32	7.6
Middle	163	38.8
Lower-middle	99	23.5
Lower	126	30.1
History of worm infestation		
Present	118	28.1
Absent	302	71.9

Table 1 presents the socio-demographic profile of the 420 school children included in the study. The majority of participants belonged to the 6–9-year age group (42.8%), followed by those aged 10–12 years (34.5%), indicating that early school-age children formed the largest subgroup. Gender distribution was nearly equal, with 51.4% boys and 48.6% girls, ensuring balanced representation. More than half of the children (52.8%) consumed a mixed diet, while the remaining followed a vegetarian diet.

Socioeconomic assessment revealed that a substantial proportion of children belonged to the middle (38.8%) and lower (30.1%) socioeconomic classes, reflecting the demographic pattern of the study area. A history of worm infestation was reported in 28.1% of participants, which is relevant given the known association between parasitic infections and anaemia in school-aged children. These findings collectively offer insight into the demographic and environmental factors potentially influencing nutritional and cognitive health in this population.

Table 2: Haematological parameters of the participants

Parameter	Mean ± SD
Haemoglobin (g/dL)	11.2 ± 1.4
Serum Ferritin (µg/L)	19.5 ± 7.8
Serum Iron (µg/dL)	56.3 ± 18.9
TIBC (µg/dL)	355.2 ± 46.1
Transferrin Saturation (%)	15.8 ± 4.2

Table 2 summarises key haematological indicators that help determine iron status among the children. The mean haemoglobin level was 11.2 ± 1.4 g/dL, indicating that a considerable proportion of children likely fell below WHO cut-offs for anaemia. Mean serum ferritin (19.5 ± 7.8 µg/L) and transferrin saturation (15.8 ± 4.2%) suggest depleted iron stores in many participants, consistent with nutritional iron deficiency. A low mean serum iron level (56.3 ± 18.9 µg/dL) combined with elevated TIBC (355.2 ± 46.1 µg/dL) further supports the presence of iron-deficient states. These biomarker distributions align with the high prevalence of iron deficiency observed later in Table 3.

Table 3: Prevalence of Anaemia and Iron Deficiency Anaemia

Category	Frequency (n)	Percentage (%)
Non-anaemic	244	58.1
Anaemic (total)	176	41.9
Iron Deficiency Anaemia (IDA)	124	29.5
Non-iron deficiency anaemia	52	12.4

Table 3 highlights the burden of anaemia in the study population. Out of 420 children, 41.9% were anaemic, demonstrating that anaemia remains a significant public health challenge among school children. Importantly, 29.5% of the total sample had iron deficiency anaemia (IDA), indicating that iron deficiency was responsible for the majority of anaemia cases. The remaining 12.4% had non-iron deficiency anaemia, possibly attributable to other nutritional deficiencies or chronic infections. The high prevalence of IDA underscores the need for targeted nutritional interventions in this age group.

Table 4: Comparison of Cognitive Scores between Non-anaemic and IDA Children

Cognitive Test	(Mean ± SD)		t-test	p-value
	Non-anaemic	IDA		
IQ Score (Binet–Kamat)	96.4 ± 8.7	87.1 ± 7.9	10.42	<0.001
Digit Span	10.2 ± 2.1	7.8 ± 1.9	10.08	<0.001
Coding Test	68.5 ± 9.1	59.4 ± 8.5	9.06	<0.001
Color Trail Test (sec)*	49.8 ± 12.4	58.7 ± 13.1	5.56	<0.01

Table 4 compares multiple domains of cognitive function between non-anaemic children and those with IDA. Across all cognitive tests, non-anaemic children scored significantly higher. IQ scores were substantially better among non-anaemic children (96.4 ± 8.7) compared to IDA children (87.1 ± 7.9, $p < 0.001$), highlighting a strong association between iron status and general intellectual functioning. Similar trends were observed in attention and working memory (Digit Span), processing speed (Coding Test), and executive functioning (Color Trail Test). Notably, IDA children took significantly longer on the Color Trail Test, indicating slower cognitive processing and poorer executive control. The high t-values and highly significant p-values confirm that the differences were statistically robust. Overall, the findings demonstrate that iron deficiency anaemia has a measurable negative impact on multiple dimensions of cognitive performance in school-aged children.

Table 5: Correlation Analysis

Correlation	r-value	p-value
Hb vs IQ score	0.45	<0.001
Hb vs Digit Span	0.38	<0.001
Ferritin vs IQ score	0.31	<0.001

Table 5 presents the correlation between haematological indicators (Hb and ferritin) and cognitive test scores. There was a moderate positive correlation between haemoglobin and IQ (r = 0.45, p < 0.001), suggesting that higher haemoglobin levels are associated with better intellectual performance. Similar positive correlations were observed between haemoglobin and Digit Span scores (r = 0.38), reinforcing the relationship between iron status and working memory. Serum ferritin also showed a significant positive correlation with IQ (r = 0.31), indicating that adequate iron stores contribute positively to cognitive development. The consistent pattern of significant positive correlations across multiple cognitive domains supports the biological link between iron sufficiency and improved neurocognitive outcomes.

Table 6: Correlation Analysis

Predictor Variable	Regression Coefficient (β)	Standard Error (SE)	t-value	p-value
Haemoglobin (g/dL)	0.34	0.05	6.8	<0.001
Serum Ferritin (µg/L)	0.22	0.07	3.12	0.003
Socioeconomic Status	0.18	0.06	2.89	0.01
Age (years)	0.07	0.04	1.65	0.099
Gender (Male = 1)	–0.03	0.05	–0.59	0.554
Diet Pattern (Vegetarian = 1)	–0.06	0.04	–1.34	0.182
History of Worm Infestation	–0.09	0.05	–1.81	0.071

Table 6 summarises the results of the multiple linear regression model assessing independent predictors of cognitive performance. After adjusting for potential confounders (age, gender, diet, socioeconomic status, and worm infestation), haemoglobin (β = 0.34, p < 0.001) and serum ferritin (β = 0.22, p = 0.003) remained significant predictors, indicating that iron status directly influences cognitive outcomes even when other factors are controlled. Socioeconomic status was also a significant predictor (β = 0.18, p = 0.01), highlighting the role of environmental and family-level factors in cognitive development. Other variables such as age, gender, diet, and worm infestation did not show statistically significant associations in the adjusted model. These results confirm that both biological (iron status) and social determinants significantly shape cognitive performance in school children.

Discussion

The present school-based study demonstrates a high burden of anaemia among children aged 6–14 years, with 41.9% being anaemic and nearly one-third (29.5%) having iron deficiency anaemia (IDA). Children with IDA had significantly lower IQ, attention/working memory and processing speed scores compared with non-anaemic peers, and haemoglobin as well as ferritin showed positive correlations with cognitive performance. In multivariable analysis, haemoglobin, ferritin and socioeconomic status emerged as independent predictors of cognitive scores, even after adjustment for age, gender, diet and worm infestation. These findings reinforce the central role of iron status in determining cognitive outcomes in Indian school children and are broadly consistent with national and regional evidence.

Our anaemia prevalence of 41.9% in 6–14-year-olds, with 29.5% having IDA, indicates a moderate public health problem in this age group and is in line with the broader Indian context, where NFHS-5 reports anaemia in 67.1% of children aged 6–59 months and high levels among adolescents as well [5,6]. Recent Indian studies among school-aged children show comparable though variable burdens: Ashok et al. reported that nearly half of school-aged children had IDA in a contemporary Indian cohort [23], while Baheti et al. found anaemia prevalence of 36.6% among primary school children in Washim district, Maharashtra [24]. In another western Maharashtra paediatric population, Jadhav et al. observed substantial IDA across age groups in children, underscoring that iron deficiency remains the dominant cause of anaemia in many regions [25]. Taken together, our prevalence estimates fall within the range reported by these Indian studies, suggesting that the study population is representative of the wider problem of IDA among Indian school children.

The most striking finding of our study is the consistent and sizeable cognitive disadvantage among children with IDA across multiple domains—IQ, attention (Digit Span), processing speed (Coding) and executive function (Color Trail

Test). These results are in strong agreement with Indian observational data. More et al., in a village school in rural central India, showed that iron-deficient adolescent girls (both anaemic and non-anaemic) had significantly lower IQ, mathematics scores and poorer performance on tests of attention, mental balance, verbal learning and recognition compared with non-iron-deficient girls [14]. Similarly, Naseem et al. in rural Hyderabad reported that children aged 5–10 years with iron deficiency had significantly poorer scores in memory, attention and intelligence tests compared with iron-replete children, and that these deficits improved after iron supplementation [15].

Our findings also parallel those of Thalanjeri et al., who observed that school children with IDA had significantly lower Raven's Progressive Matrices scores, indicating impaired non-verbal intelligence; the authors concluded that IDA leads to measurable cognitive impairment that is potentially preventable by timely intervention [26]. These converging lines of evidence from different Indian settings support the view that iron deficiency is not merely a haematological abnormality but is strongly linked to impairments in higher mental functions critical for academic achievement.

We observed moderate positive correlations between haemoglobin and IQ as well as Digit Span scores (r = 0.45 and 0.38, respectively), and a significant correlation between serum ferritin and IQ (r = 0.31), suggesting a dose–response relationship between iron status and cognitive performance. Similar patterns have been described in Indian and international literature. More et al. reported that serum ferritin levels were positively associated with IQ and several cognitive subtests among adolescent girls, even after adjusting for haemoglobin [14]. Naseem et al. also showed significant improvement in cognitive scores accompanying improvements in haemoglobin after iron therapy in younger children [15].

Intervention data further support these associations. Seshadri and Gopaldas, in a seminal Indian study, demonstrated that iron supplementation in preschool and school-aged children improved test scores for attention, memory and concentration, particularly among initially anaemic or iron-deficient children [21]. More recently, Scott et al. conducted a 6-month randomized controlled trial in Indian school-going adolescents and found that consumption of iron-biofortified pearl millet improved iron status and led to significant gains in tasks of attention and memory compared with control millet [16]. These findings, together with our correlation and regression results, strengthen the biological plausibility that better iron status contributes to better cognitive function in school-aged children.

In our regression model, haemoglobin and serum ferritin remained significant independent predictors of composite cognitive scores after controlling for age, gender, diet, worm infestation and socioeconomic status; socioeconomic status itself also showed an independent positive association. This suggests that both biological (iron status) and social determinants shape cognitive performance. Earlier Indian work supports this dual influence. Gopaldas et al. showed that prophylactic iron supplementation for underprivileged school boys improved selected cognitive test scores, highlighting that biological correction of iron status can partially offset disadvantages related to poverty [27]. Sen and Kanani, in Vadodara, demonstrated that daily or twice-weekly iron–folic acid supplementation improved cognitive abilities in schoolgirls, with greater gains among those with higher haemoglobin improvement and better compliance, again underscoring the direct effect of iron status on cognition while operating within socio-economic constraints [28].

Our finding that gender and diet pattern were not significant in the adjusted model is similar to some Indian studies where, once iron status is accounted for, gender differences in cognition diminish [14,15]. However, this does not exclude the possibility that gendered dietary practices and differential access to nutrition contribute to the development of anaemia in the first place, an issue highlighted in national data and anaemia-control guidelines [5,6,23].

The cognitive disadvantage we observed among children with IDA is important in light of interventional evidence that such deficits are at least partly reversible. Besides the Indian studies already mentioned [15,21,27,28], a systematic review and meta-analysis has shown that iron supplementation improves cognitive development and performance in school-age children, particularly in those who are anaemic or iron-deficient at baseline [22]. Our cross-sectional findings thus provide local justification for strengthening existing programmes such as the National Iron Plus Initiative and Anaemia Mukt Bharat, which provide weekly iron–folic acid supplementation and deworming for school-age children [6,23]. Early detection and treatment of IDA through school health programmes could yield dual benefits—improved health and enhanced educational outcomes.

Conclusion

The present study demonstrates that iron deficiency anaemia is highly prevalent among school-aged children and is strongly associated with poorer cognitive performance across multiple domains, including intelligence, attention, memory, processing speed and executive function. Children with IDA consistently scored lower than non-anaemic peers, and haemoglobin as well as serum ferritin levels showed significant positive correlations with cognitive scores. Even after adjusting for socioeconomic and demographic factors, iron status remained an independent predictor of cognitive outcomes. These findings highlight the crucial role of adequate iron nutrition in supporting optimal cognitive development and underscore the need for early screening, dietary improvement, iron supplementation and school-based health programmes to reduce the burden of IDA and enhance academic performance among children.

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