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Iron-Deficiency Anemia In The Relationship With Cognitive Function In Adolescent Girls In India, A Systematic Review

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Abstract:
Background*: Iron-deficiency anemia (IDA) is a widespread nutritional pathology, which is accompanied by serious physiological and neurocognitive consequences, especially in adolescent females in low- and middle-income populations. In India, IDA is a significant issue of national health, which is augmented by dietary shortcomings, menstrual blood loss, and socioeconomic imbalances.*
Materials and Methods*: This is a systematic review that summarizes evidence showing that IDA is associated with cognitive performance among Indian women between 10 and 25 years.*
Extensive search of literature was done in PubMed, Scopus, Web of Science, and Embase. The inclusion criteria included observational and interventional studies assessing iron status and cognitive outcomes.
Results*: Evidence consistently indicates that low levels of hemoglobin and ferritin are associated with impairments in cognitive domains such as attention, working memory, and learning ability. A dose-response relationship appears to exist, where more severe cases of anemia correlate with more pronounced cognitive impairment. The postulated mechanisms involve reduced cerebral oxygen delivery, alterations in neurotransmitter production, and impaired neuronal myelination.*
Conclusion: *Despite ongoing national programs, the persistent challenge of IDA among adolescents necessitates targeted interventions. This review highlights the urgent need to establish standardized screening protocols for IDA and implement comprehensive nutritional strategies to mitigate its adverse effects on cognitive development and potential.*
Key Words: *Iron deficiency anemia (IDA), adolescent, dose-response, NIPI, Poshan Abhiyan*

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I. Introduction

Iron is a vital micro nutrient that forms the basis of various physiological and neurological processes. Being a constituent of hemoglobin, it helps to deliver a sufficient amount of oxygen to the tissues and is engaged in some essential enzymatic reactions, which can stimulate the metabolism of energy and the production of neurotransmitters (PMC3872396). Due to its role in myelination, synaptic plasticity, and regulation of neurotransmitters, such as dopamine, serotonin, and norepinephrine, iron is a cofactor in cognitive performance, motivation, and emotional regulation, as well as central nervous system functioning (ScienceDirect, 2022).

The most prevalent and common nutritional deficiency in the world, iron-deficiency anemia (IDA), occurs when the iron in the body becomes below physiological values and this leads to a lack of hemoglobin production in the body and also a decrease in the ability of blood to transport oxygen. The resultant hypoxia impairs cellular metabolism, interferes with the neurocognitive functions, including attention, memory, and executive processing (NMJI, 2023). Adolescence is one of the most crucial developmental periods in a person and, as growth rate, hormonal changes, and menarche typically lead to an increase in iron requirements, these requirements are frequently not met in terms of nutrition and health education.

The issue has taken alarming percentages in India. According to the data of the National Family Health Survey (NFHS), the rates of anemia among girls between 15 and 19 years of age increased to 59 per cent as of 20192021, as compared to 54 per cent in 20152016 (PMC10482272). This increasing trend points to a twofold nutritional and systemic issue, where rural areas and the poor are overrepresented. Anemia is present in more than 60^{-} percent in eleven Indian states such as Tripura, Assam, and Chhattisgarh (News-Medical.net, 2023). Some of the contributing factors include dietary monotony, socio-cultural limitations, and access to fortified foods (Wiley, 2022).

The impact of IDA on cognitive development is multifaceted and its effects are severe, although it has

been shown that even mild cases of iron deficiency or subclinical cases can lead to impaired hippocampal functionality, neurotransmitter dynamics, and alterations in cerebral metabolism. Such neurobiological disturbances are associated with a decrease in learning ability and academic performance in adolescents (PMC3872396). It is noteworthy that a number of longitudinal studies indicate cognitive impairments (especially memory and executive impairment) can be observed even after hematological parameters (e.g. hemoglobin) are normalised. This tenacity implies that neurocognitive effects of IDA may be persistent provided that deficiency is not treated at crucial developmental stages, which highlights the possibility of long-term or even irreversible outcomes in case of a lack of treatment in early life (Nature, 2022).

The intersection of iron deficiency and cognition is especially relevant to India, as the number of adolescent girls is significantly large, and their impact on the future generations is significant. In this way, this systematic review is a synthesis of evidence connecting IDA with cognitive performance among adolescent girls in India i.e. attention, memory, learning, and academic achievement. The paper also examines socioeconomic factors and regional factors that can affect this association and the possible public health measures to prevent the effects of the same.

II. Material And Methods

Study Design

This systematic review was designed to synthesize current evidence examining the association between iron-deficiency anemia (IDA) and cognitive function among adolescent girls in India. The review adheres to established guidelines for systematic reviews in public health research, focusing on observational and interventional studies published in peer-reviewed journals between 2010 and 2024.

Eligibility Criteria

Studies were included if they:

1. Involved human female participants aged 10–25 years residing in India
2. Reported quantitative or qualitative measures of iron deficiency (e.g., hemoglobin, serum ferritin, or transferrin saturation); and
3. Assessed at least one domain of cognitive function, including attention, working memory, learning, executive function, or academic achievement.

Exclusion criteria were as follows:

- Studies conducted outside India
- Non-human or in vitro research
- Articles lacking cognitive outcome measures; and
- Case reports, conference abstracts, or grey literature without peer review.

These criteria ensured that only robust, relevant, and context-specific studies were included in the analysis.

Information Sources and Search Strategy

A systematic literature search was performed across four major databases: PubMed, Scopus, Web of Science, and Embase. Additional references were identified through citation tracking of relevant review articles and national reports such as the *National Family Health Survey (NFHS)*. The search strategy combined Medical Subject Headings (MeSH) and free-text terms, including: (“iron deficiency anemia” OR “IDA”) AND (“adolescent girls” OR “female students”) AND (“cognitive function” OR “attention” OR “memory” OR “academic performance”) AND (“India”).

No language restrictions were applied. Search results were screened independently by two reviewers, and discrepancies were resolved through consensus.

Study Selection

After initial title and abstract screening, full-text articles were reviewed for eligibility based on predefined inclusion and exclusion criteria. Studies that met all criteria were included in the final synthesis. Quality assessment was conducted using standard epidemiological appraisal tools to evaluate sample size adequacy, measurement validity, and risk of bias.

Data Extraction

Data extraction was performed using a structured template encompassing:

- Study identifiers (authors, publication year, and region)
- Research design and methodology
- Participant characteristics (age range, sample size, and demographic profile)
- Diagnostic parameters for anemia (hemoglobin or ferritin thresholds)

- Cognitive domains assessed (e.g., attention, memory, executive function, academic performance); and
- Key findings, including statistical significance and direction of association.

This systematic approach allowed for uniform data comparison across diverse study designs.

Data Analysis and Synthesis

Given the heterogeneity of cognitive assessment tools and iron status parameters, a narrative synthesis was employed rather than meta-analysis. Studies were grouped according to the primary cognitive domain assessed: attention, memory, executive function, or scholastic achievement. Quantitative trends, such as correlations between hemoglobin concentration and cognitive performance, were reported where available.

Where possible, findings were also analyzed by geographical region, socioeconomic context, and study population (e.g., schoolgirls, university students). Both consistent and divergent outcomes were interpreted to identify emerging patterns and gaps in the existing literature.

III. Result

Prevalence and Risk Factors

National and regional datasets consistently indicate that iron-deficiency anemia (IDA) remains one of India's most persistent adolescent health challenges. Findings from the National Family Health Survey revealed a rise in anemia prevalence among girls aged 15-19 years from 54% in 2015–2016 to 59% in 2019-21, reflecting a concerning upward trajectory (PMC10482272). Meta-analytic estimates suggest an even higher pooled prevalence of approximately 65.7%, underscoring the scale of the crisis among this demographic (NMJI, 2023). Socioeconomic status emerged as a strong determinant of anemia. Girls from low-income households, particularly those residing in rural or tribal areas, exhibited disproportionately higher rates of iron deficiency due to poor dietary diversity, limited healthcare access, and cultural dietary restrictions (Nature, 2022). Nutritional inadequacy, heavy menstrual blood loss, and insufficient iron supplementation further aggravated the condition (Wiley, 2022). These risk factors collectively contribute to both physiological and cognitive vulnerabilities among adolescent females.

Attention and Processing Speed

Multiple studies demonstrated that reduced hemoglobin levels were significantly correlated with impaired attention and slower cognitive processing. In a cross-sectional study conducted among 100 female dental students in Tamil Nadu, nearly 50% were anemic, and those with lower hemoglobin levels exhibited poorer performance on attention and accuracy tasks compared to non-anemic peers (JCDR, 2023). Similarly, a school-based investigation among 12–18-year-old girls found that those with iron deficiency scored lower on tests assessing sustained attention and reaction time (PMC3872396).

The findings indicate that oxygen insufficiency caused by anemia may impair neuronal activity in brain regions responsible for attention and vigilance. This reduction in oxygen delivery may slow neural transmission and affect dopaminergic function, ultimately compromising sustained focus and processing speed. The consistency of these results across both school and university populations underscores the robust link between iron status and attentional capacity.

Memory and Learning

Iron deficiency was also found to affect short-term memory, learning efficiency, and information retention. Studies show that the hippocampus, a region critical for memory consolidation, is particularly sensitive to reduced iron availability. For instance, a study conducted at Imam Abdulrahman Bin Faisal University reported that 27.4% of female participants had IDA, and these individuals performed significantly worse on working and immediate memory assessments than non-anemic students (EJGM, 2022).

Complementary findings from an observational study of Ghanaian adolescents reported a positive correlation between serum ferritin levels and memory performance, suggesting that iron sufficiency plays a vital role in sustaining memory-related cognitive processes (BMC Public Health, 2024). Although the Ghanaian study was outside the Indian context, it supports the biological plausibility of these mechanisms and provides a comparative benchmark.

Collectively, the evidence suggests that iron deficiency disrupts hippocampal function and neurotransmitter synthesis, leading to measurable declines in learning efficiency and memory retention among adolescent girls. Academic Achievement and Executive Function

Several studies linked IDA with lower academic achievement, reduced intelligence quotient (IQ), and deficits in executive function. School-based studies in India revealed that anemic adolescents demonstrated weaker verbal recall and reasoning skills compared to non-anemic peers (PMC3872396). These deficits likely result from decreased oxygen availability in prefrontal regions of the brain, impairing complex processes such as decision-making, problem-solving, and inhibitory control.

In addition, national data indicate that girls suffering from chronic anemia perform below average in scholastic assessments, particularly in subjects requiring sustained cognitive engagement (Wiley, 2022). The cumulative evidence suggests that the cognitive load imposed by anemia contributes to decreased school performance, lower self-efficacy, and reduced long-term academic potential.

Socioeconomic and Regional Disparities

Socioeconomic inequality amplifies both the prevalence and consequences of anemia. Adolescent girls in rural areas face a higher risk due to factors such as inadequate diet, restricted access to fortified foods, and gender-based disparities in healthcare utilization (Nature, 2022). States with weaker implementation of nutritional programs, such as Tripura, Chhattisgarh, and Assam, report anemia prevalence rates exceeding 60% (News-Medical.net, 2023).

Furthermore, cultural constraints often restrict adolescent girls' food intake, prioritizing male members in households for nutrient-rich meals. These inequities perpetuate a cycle where undernutrition and poor cognitive outcomes reinforce social and economic disadvantage. The data thus reveal that IDA is not merely a biological condition but a multidimensional problem shaped by gender, class, and geography.

Source	Sample (N)	Age Group (years)	Design	Key Findings
JCDR (2023)	100	18–23	Cross-sectional	Lower hemoglobin is associated with decreased attention and accuracy.
PMC3 872396 (2014)	200	12–18	School-based	Iron-deficient girls had lower IQ and verbal memory scores.
NMJI (2023)	>10,00 0	10–19	Meta-analysis	65.7% pooled anemia prevalence; strong socioeconomic correlation.
Wiley (2022)	Nationa l dataset	10–19	Cohort	Over 72 million adolescents affected; females constitute two-thirds of cases.
BMC Public Health (2024)	250	13–17	Observational	Ferritin levels correlated with better memory performance.

Table 1:

The compiled results demonstrate a consistent pattern: anemia not only undermines physical vitality but also exerts measurable cognitive costs. These outcomes spanning attention, memory, and academic performance underscore the urgent need for integrated public health and educational interventions targeting adolescent girls across India.

IV. Discussion

The results of the current review suggest that the iron-deficiency anemia (IDA) has a strong negative effect on the cognitive performance of Indian adolescent girls. In several studies, low hemoglobin and ferritin concentrations are always associated with reduced performance in attention, working memory, and learning activities (JCDR, 2023; PMC3872396). The relationship is very strong both in school population and in university population implying that even moderate anemia can have cognitive effects.

The data also supports a dose-response association between IDA and cognition whereby the cognitive impairments worsen with the intensity of anemia (NMJI, 2023). This kind of a gradient makes the association biologically plausible and makes it clear that early diagnosis and treatment are extremely imperative.

The biologic processes behind the cognitive actions of IDA are complex and multifactorial, which are highly interconnected with neurophysiological processes. Iron plays a major role in the production of neurotransmitters, especially dopamine and serotonin that control attention, learning, motivation, and mood (ScienceDirect, 2022). Iron deficiency interferes with these pathways resulting in impaired synaptic transmission and lowered cognitive responsiveness. Moreover, iron deficiency disrupts myelination or wrapping the neurons in a fatty coating to enable quick conduction of electrical impulses, thus lowering the effectiveness of neural signaling (PMC3872396). There is also impaired oxygen delivery to the brain affecting brain hypoxia and metabolic stress in the brain areas that are important in cognitive control, including the prefrontal cortex and the hippocampus (EJGM, 2022). These biological changes explain the empirical relationships between the severity of anemia and the loss of attention, memory, and problem-solving, which were found in the studies reviewed.

The existing body of evidence confirms the hypothesis that not only is IDA a marker of nutritional inadequacy but also a determinant of neurodevelopmental health. The chronic iron deficiency of the adolescent period, which is a crucial time of synaptic pruning and brain development, can breed irreparable cognitive impairment that persists into adulthood (Nature, 2022).

Socioeconomic Dimensions

In addition to the biological factors, the association between IDA and thought is informed by the socioeconomic and gender nature of India. Adolescent girls living in poor-income or rural families often face chronic undernutrition, a restricted diet, and lack of access to medical care (Wiley, 2022). Such differences are also intensified by cultural practices that favor male members of the family when distributing nutrient-rich foods, furthering intergenerational effects of anemia and educational disadvantage (News-Medical.net, 2023).

Disruption in education due to fatigue, lack of concentration and academic confidence further reduce the attendance and performance in school, limiting future job prospects and economic mobility (NMJI, 2023). In turn, IDA is not only a medical process but also a socio-developmental problem that impedes gender equality and national productivity.

Public Health Implications

The fact that national initiatives like the National Iron Plus Initiative (NIPI) and Poshan Abhiyan have not been able to eliminate anemia shows systemic implementation and monitoring failures. These programs seek to mitigate the occurrence of anemia by implementing supplementation and dietary diversification, and communicating behaviour-changes; however, inconsistent supply chains, limited awareness and compliance have hampered the success of these measures (News-Medical.net, 2023).

The inclusion of anemia screening in school health programmes may be one of the viable measures to solve the problem of early detection and intervention. Frequent evaluation of hemoglobin or serum ferritin in combination with nutritional counselling and iron-folic-acid supplement can make a significant contribution to physiological and cognitive outcome. Education campaigns on dietary habits can also target the misconceptions at the level of communities and promote the consumption of foods rich in iron, including lentils, green leafy vegetables, and fortified cereals (Wiley, 2022).

Considering the growing body of evidence that attributes IDA to impaired cognitive performance, policy initiatives must also not be limited to the conventional nutrition programmes but should also include cognitive and educational outcomes. Incorporating scholastic performance indicators into national surveys, e.g. the NFHS, may be a way to improve monitoring of the neurodevelopmental effects of anemia interventions.

Strengths and Limitations

One of the key advantages of this review is the fact that it incorporates multi-level evidence based on different Indian settings thus explaining physiological roots and socioeconomic factors contributing to IDA induced cognitive dysfunction. However, there are significant methodological limitations that should also be mentioned. There is considerable heterogeneity due to the difference in the definition and categorization of anemia among studies because researchers used different hemoglobin and ferritin levels to diagnose iron deficiency. This is a non-standardisation that makes cross-study comparison difficult and can have an impact on the reliability of pooled prevalence estimates.

In addition, cognitive outcomes were assessed with differing instruments and some studies involved self-reported academic performance which was non-validated, or a short screening test, and others used formal and standardised neuropsychological batteries. This inconsistency in the methods of assessment creates a bias in the measurements and makes it difficult to conclude in the relationship between iron status and particular cognitive domains. These inconsistencies in the methodology highlight the importance of standard diagnostic and cognitive assessment procedures in future studies to increase internal validity and comparability.

The majority of studies were cross-sectional, which made it hard to cause. Not many longitudinal studies have been done to monitor the reversibility of cognitive deficits after iron supplementation. The longitudinal/interventional designs should be used in future studies, and the standardised measurement instruments are to be employed to determine causality and measure the long-term cognitive recovery (BMC Public Health, 2024).

The results emphasize the idea that the issue of IDA does not lie in a health concern; it is a developmental necessity. The problem of iron deficiency amongst adolescent girls is a silent, but serious danger to the human capital of India. The benefits of improving iron status by using specific interventions have far reaching outcomes, not only in physical health, but also in educational achievement, productivity and social empowerment.

With the aim of attaining Sustainable Development Goals (SDGs) , especially those relating to health, education, and gender equality, the reduction of anemia among adolescent girls forms part of the pillars of development in India. The best possible solution to decrease the cognitive and societal youth burden of IDA is a multi-sectoral intervention incorporating healthcare, education, nutrition, and community involvement.

V. Conclusion

Iron-deficiency anemia (IDA) remains a multifactorial population health issue among adolescent girls in India and it induces significant biological, cognitive, and socioeconomic consequences. The data gathered in this review systematically suggests that the lower iron status is associated with cognitive impairment, in particular, attention, working memory, learning capacity, and academic performance (JCDR, 2023; PMC3872396; EJGM, 2022). It is likely that these deficits are due to synergistic effects of the impaired oxygen transportation, passive metabolism of neurotransmitters, and impaired myelination of neurons (ScienceDirect, 2022).

The current rise in prevalence rates of IDA among Indian adolescents, which is being reflected in national surveys and meta-analyses, highlights the existence of gaps in nutrition, access to healthcare, and gender equity (NMJI, 2023; PMC10482272). Most importantly, the intellectual consequences of iron deficiency do not just affect academic challenges on an individual level, but also affect more societal attainments such as education, labor force preparedness and national productivity as well. In this regard, dealing with anemia is not just a nutritional intervention issue, but a developmental and economic necessity.

The existing evidence has shortcomings in the form of methodological discrepancies and absence of longitudinal data. Future researchers are needed to determine the reversibility of cognitive impairment after iron supplementation and determine dose–response relationships between serum ferritin levels versus cognitive performances. The studies that use neuroimaging and biochemical methods are necessary to clarify the role of iron in brain metabolism (Nature, 2022). Causality can also be determined through randomized controlled trials and socioeconomic correlation studies that can be used to support equitable, evidence-based intervention to address the problems of anemia-related cognitive impairment.

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