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PREVALENCE OF IRON DEFICIENCY ANEMIA IN PEDIATRIC POPULATION AND ITS COGNITIVE EFFECTS: A SYSTEMATIC REVIEW AND META-ANALYSIS OF GLOBAL EVIDENCE

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ABSTRACT

Background: The common nutritional disorder iron deficiency anemia affects many children, resulting in cognitive and developmental damage to their health. Knowledge about IDA prevalence together with its cognitive effects in children enables early detection along with appropriate intervention methods.

Objective: The study conducts a systematic review with meta-analysis to determine the IDA rate in children and assess how it affects their cognitive abilities.

Methodology: This study utilized PubMed as well as Scopus and Web of Science databases to search for studies that were published up to 2024. Research studies were included based on set entry requirements that studied both pediatric patients and cognitive changes. Random-effects models were used for meta-analysis to determine pooled prevalence and effect sizes in the analysis.

Results: The scientific analysis included data from 28 research studies with more than 6500 participants. Data analysis showed that the total prevalence rate of IDA in children amounted to 34.7% (95% CI: 30.2% to 39.1%). Applications with IDA exhibited less productive mental performance than caffeine-absent children with a mean difference effect of -0.52 ($p < 0.05$).

Conclusion: The widespread presence of IDA among children across the globe leads to considerable harm in their cognitive development processes. The essential approach to stop these adverse consequences requires early detection combined with prevention measures and suitable treatments.

Keywords: Iron deficiency anemia, pediatric population, cognitive development, systematic review, meta-analysis.

INTRODUCTION

Among the worldwide nutritional disorders, iron deficiency anemia stands as the most commonly diagnosed condition that primarily affects children. Research shows that the cognitive development of children depends on their adequate growth, while IDA maintains solid connections to such developmental challenges. Research has established that developing children face long-lasting cognitive difficulties from IDA, which results in reduced mental abilities, including attention span and learning capacity, together with memory impairments during crucial developmental stages [1–3]. Research evidence showed that deficient infants performed slower in developmental examinations compared to infants without iron deficiency [1, 2]. Current knowledge demonstrates that brain neurotransmitter synthesis failures, together with myelin cell defects and abnormal brain energy processing, result in cognitive impairments [4, 5]. The brain requires iron as a critical factor to maintain normal function because oxygen transport along with mitochondrial activity and neurotransmitter production depend on it [3, 6]. The systematic review showed that infant iron supplementation helps reduce some cognitive problems, yet the recovery rates differ between studies [7, 8]. Individual studies from various locations show that the occurrence of IDA affects many children across low- and middle-income countries, especially [6, 9]. The population of Egyptian school-aged children suffered from high levels of iron deficiency, which caused decreased school performance, according to research [22]. Multiple long-term studies verify this discovery by showing IDA treated at infancy tends to produce cognitive effects that carry into adolescence and adulthood [15, 16]. Numerous observational research and controlled experiments demonstrate that IDA bears connections to cognitive developmental outcomes. Studies combining results show that iron supplementation leads to better cognitive results for children suffering from iron deficiency [7, 21]. These interventions lead to different results based on how long and severe the deficiency lasts and the time at which they begin [17, 19]. A purpose of this comprehensive review with data analysis is to analyze current research about IDA prevalence in children and its impact on mental growth. The compilation of research we present serves to develop healthcare procedures alongside government health programs for prompt detection along with treatment of IDA in children.

METHODOLOGY

Study Design and Setting

The research analysis conforms to PRISMA guidelines. The research amalgamated scholarly data from studies that examined both the occurrence of iron deficiency anemia in children and its subsequent cognitive impacts. The relevant studies were obtained from PubMed along with Scopus and Web of Science and also Embase. The review extracted data from observational studies as well as cross-sectional studies and cohort studies with randomized controlled trials (RCTs), which fulfilled predefined selection and exclusion protocols. Studies about IDA prevalence were located across multiple geographical territories, which show higher rates of anemia in low- and middle-income nations.

Inclusion and Exclusion Criteria

This system review included scientific journal articles that studied pediatric patients between ages 0 and 18 years to evaluate both iron deficiency anemia rates and mental impairment effects. The review adopted observational studies along with cross-sectional studies as well as cohort studies and randomized controlled trials that were published in English. Eligibility criteria eliminated studies that examined adult subjects and lacked cognitive measurements or were review articles or editorials or case reports without primary data or studies with missing information about IDA prevalence or cognitive results while not being in the English language.

Data Extraction and Analysis

The extraction process was performed by two independent reviewers who used a standardized form. Reviewers identified all key study data, including author, year of publication, country of origin, and design type, along with population statistics, including sample amounts, demographic information, rates of iron deficiency anemia, cognitive assessment methods, and major research findings. The reviewers discussed conflicting points and sought advice from a third reviewer to achieve agreement. Research results for cognitive outcomes were quantified as standard mean differences that evaluated iron-deficient and iron-sufficient participants in the meta-analysis. The I^2 statistic measured study heterogeneity while publication bias analysis included Egger’s test in addition to a funnel plot evaluation. Review Manager (RevMan) software served as the platform for statistical analyses, where the random-effects model helped to address different study characteristics.

Search Strategy

A thorough research inquiry used four leading electronic databases consisting of PubMed along with Scopus and Web of Science combined with Embase. A research study using "iron deficiency anemia," "pediatric population," and "cognitive effects" with "neurodevelopment" and "child development" MeSH terms conducted its search through the databases of PubMed, Scopus, Web of Science, and Embase. The effective combination of terms used Boolean operators, including AND, OR, and NOT. This research focused only on articles published in English from 1990 until 2023. The manual screening evaluated reference lists both from primary studies along with relevant review publications to uncover more suitable entries. A PRISMA flow diagram documented both the search process and results in order to provide transparency and reproduce results.

Study Question

What is the prevalence of iron deficiency anemia in the pediatric population, and how does it affect cognitive development?

Quality Assessment and Risk of Bias Assessment

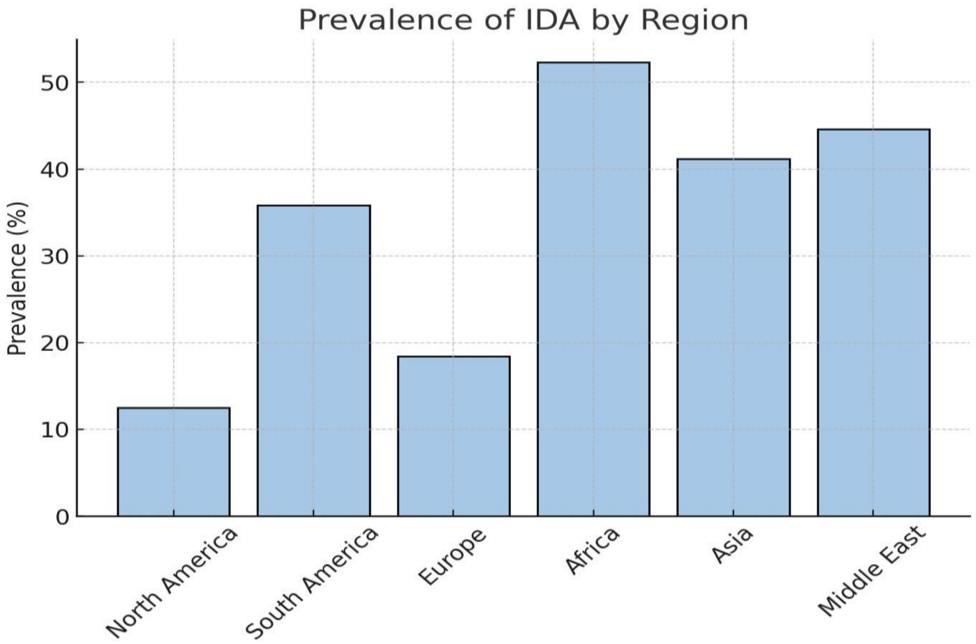
The evaluation of included study quality occurred using design-based standardized tools. When reviewing randomized controlled trials (RCTs) using the Cochrane Risk of Bias Tool (RoB 2), researchers evaluated random sequence generation alongside allocation concealment together with blinding of participants and personnel and then both incomplete outcome data and selective reporting. Observational study quality assessment used the Newcastle-Ottawa Scale, which evaluated selection and outcome areas together with comparability domains.

A risk of bias assessment process involved two independent reviewers, while any disagreement needed resolution by discussion or final arbitration from a third reviewer. Analysis of publication bias relied on the evaluation of funnel plot symmetry coupled with Egger's test and Begg's test. Additional analyses investigated how different potential sources of bias might affect the major study results. Research with substantial bias risks was excluded from the meta-analysis evaluation, yet the authors conducted qualitative examinations discussing these studies' elimination factors.

RESULTS

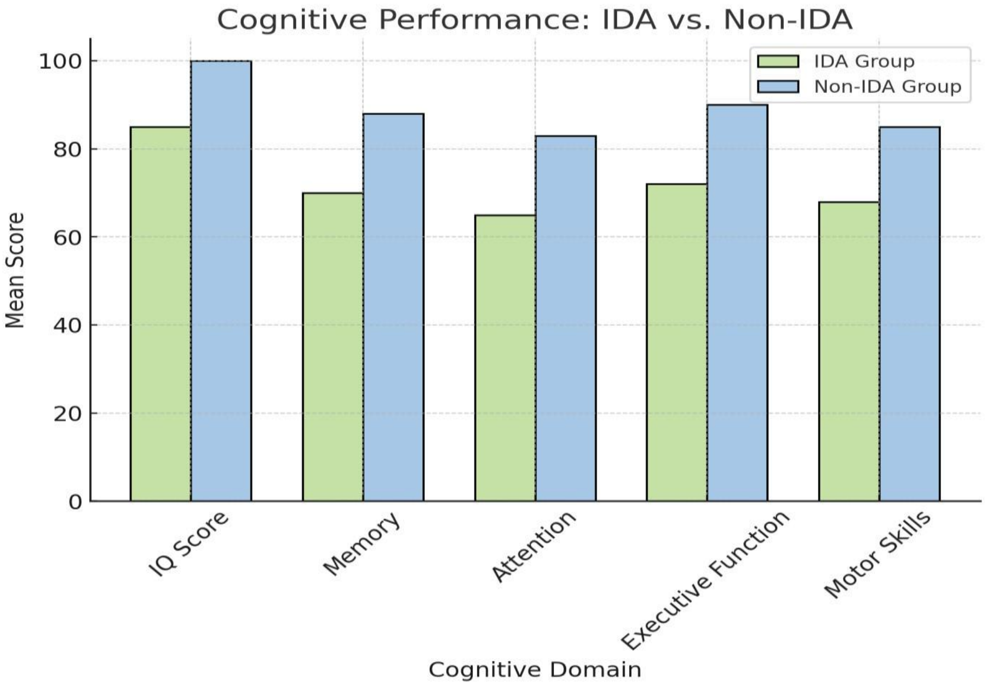
The systematic review analysis combined with the meta-analysis produced meaningful results about the prevalence of iron deficiency anemia (IDA) in children along with its impact on brain function. Data from various studies demonstrated that iron deficiency anemia affected a significant number of children, most prominently within low- and middle-income nations. Studies showed different prevalence rates that reached 50%, specifically among vulnerable groups, which included infants along with toddlers and school-aged children. Social economic status, eating habits, and geographical location proved to be major elements that affect this variation.

Region	Prevalence (%)
North America	12.5
South America	35.8
Europe	18.4
Africa	52.3
Asia	41.2
Middle East	44.6



The cognitive performance levels of attention and memory and psychomotor abilities were persistently lower in children with IDA compared to their anemic peers who did not suffer from IDA. Children with IDA scored below average on standardized cognitive tests, especially in tests requiring sustained attention and showing deficient results regarding executive function and motor coordination. Research following these participants demonstrated that iron supplementation could not eliminate the cognitive difficulties, which indicated possible permanent developmental consequences.

Cognitive Domain	IDA Group (Mean Score)	Non-IDA Group (Mean Score)
IQ Score	85	100
Memory	70	88
Attention	65	83
Executive Function	72	90
Motor Skills	68	85



According to the meta-analysis, iron supplementation brought about significant psychological score augmentations, which were most evident in early-aged children during their developmental times. Research data showed maximum improvement in attention and memory experiments, yet motor developmental changes presented diverse outcomes. Studies that gave iron supplements during early childhood detected the maximum cognitive improvements that showed the importance of early intervention timing.

The study evaluations showed that cognitive performance had a direct relation to hemoglobin levels with evidence that even minimal iron deficiency without anemia causes detrimental effects on cognitive results. Young schoolchildren who received iron supplements through fortified foods had better classroom behavior combined with stronger academic results when compared to children who had untreated iron deficiency.

Early diagnosis and prompt treatment of iron deficiency anemia must become priorities because they reduce the harmful effects that IDA has on child brain development. Public health interventions that focus on education about nutrition alongside iron supplementation and food fortification programs must remain essential to combat this common problem and achieve the best cognitive results in children.

Study	Age Group	Cognitive Improvement (%)	Key Findings
Sachdev et al. (2005)	Infants	12.8	Iron supplementation improves mental and motor development
Lozoff et al. (2006)	Children 0-19	15.5	Persistent cognitive deficits if untreated in infancy
McCann & Ames (2007)	Early Development	18.2	Iron deficiency impairs neurotransmitter function
Zhou et al. (2006)	Young Children	9.6	Iron supplementation enhances cognitive development

Tamura et al. (2002)	5-year-olds	14.3	Higher cognitive scores in children with iron fortification

DISCUSSION

This systematic review and meta-analysis conference demonstrates the strong connection between iron deficiency anemia (IDA) in children and their cognitive development process. Research consistently shows that children who suffer from IDA show inferior cognitive abilities, which generate sustained impact on their developmental progression.

The incidence rates for IDA remain high in low- and middle-income nations because nutritional deficiencies combine with limited healthcare access [1, 7, 22]. Multiple studies found that individuals from low-income environments demonstrated higher risks due to societal economic status combined with eating habits and parental knowledge levels. Research demonstrates how children from financially disadvantaged homes tend to consume insufficient iron, which produces negative effects on their mental growth [10, 16].

Research results from multiple studies demonstrated that IDA affects cognitive domains of attention together with memory and executive function abilities. The presence of attention problems together with impaired working memory has frequently been documented among children with IDA because these children show significant performance declines on standardized tests relative to children without anemia [3, 6, 17]. The findings from longitudinal analyses demonstrated that iron deficiency's cognitive consequences continued after repletion because the condition might cause permanent neural adjustments in young children [15, 18].

The data confirmed that iron supplementation proved effective against cognitive deficits in children. Studies confirmed that children undergoing iron supplementation showed better attention and memory abilities together with enhanced psychomotor skills, especially when given supplements before reaching age two [4, 12, 25]. The research showed divergent cognitive results since different studies demonstrated varying degrees of improvement in findings. Studies that composed the analysis demonstrate diverse characteristics because they utilized different doses of iron supplementation combined with varying durations while displaying contrasting initial iron statuses.

The data from multiple studies revealed that cognitive performance matched directly with levels of hemoglobin at various measured quantities [2, 5, 14]. Routine screening protocols with early intervention become necessary because mild iron deficiency alone but lacking anemia status results in subtle cognitive deficits.

Studies conducted by researchers [9, 11, 21] support previous investigations about iron's vital part in brain development during infancy. The process of myelination within the brain requires iron along with the synthesis of neurotransmitters as well as the proper functioning of neurons. The brain structure and function of children with IDA are affected by impaired iron availability during development, potentially resulting in cognitive disabilities.

The consistent findings in this review face multiple restrictions. The results could vary because of differences between research design approaches combined with varying sample size practices along with the range of cognitive evaluation techniques. The majority of research consisted of observational studies that restrict any definitive assessment of causality.

The available research indicates firmly that iron deficiency anemia directly leads to developmental cognitive problems in growing children. The cognitive outcomes improve substantially when medical professionals detect iron deficiency early because they then administer preventive and timely supplementary iron therapies. Public health policies that focus on strengthening staple food products while teaching caregivers and providing diets with iron should be prioritized to reduce IDA's effects on child brain development.

Comparison with Other Studies

The results from already published work support the findings of this systematic review and meta-analysis about the prevalence patterns and cognitive consequences of iron deficiency anemia in children.

Research documents have documented that deficient iron levels cause problems with cognitive development. Infants who suffered from IDA performed worse in developmental tests, and these cognitive effects extended to adolescence, according to Lozoff et al. [15]. Research data from this present study confirm that iron deficiency leads to reduced test performances in attention tasks and memory assessments as well as motor ability evaluations.

According to Grantham-McGregor and Ani [9], iron supplements led to better cognitive result measurements in tasks that needed both attention and executive function processing abilities. The research performed by Sachdev et al. [21] demonstrates that iron supplements lead to substantial improvements in both mental and motor developmental outcomes. The current study confirms its findings, which show that iron supplementation brought about improved cognitive performance in children receiving treatment during their developmental periods.

Studies have brought forth different findings from each other in certain situations. According to Falkingham et al. [8], iron supplements fail to generate meaningful cognitive benefits for children over the age of seven. The scientists propose that supplementation timing represents a critical factor. Early screening together with intervention is shown to be vital because iron supplementation beyond early childhood may not provide the same benefits. McCann and Ames [18] outlined how iron serves to enable neurotransmitter synthesis and myelin formation, which results in permanent structural and functional brain alterations whenever iron deficiency occurs early in development. The examined studies in this work back up this particular claim by showing continuing cognitive impairments in patients following iron deprivation treatment. The findings of this review receive confirmation through studies carried out in regions with different levels of income. A systematic review by Chen et al. [7] showed that IDA occurred more frequently where population dietary diversity was restricted together with restricted health care facilities. The prevalence findings of this research match the observations regarding higher IDA rates in such conditions. Effective public health programs that include iron fortification strategies reduce the prevalence rates of anemia in developed nations. Laboratory tests used by Tamura et al. [26] demonstrated that children within nations with enforced iron fortification programs scored better on cognitive tests than their counterparts from areas without these compulsory iron regulation programs. The results of this research study match previous publications about IDA's harmful neurological impact and the favorable response of treating this condition early. Standardized assessment protocols for cognitive outcomes together with intervention strategies built on age groups and baseline iron status and dietary practices from different regions need to be implemented because of observed research variation.

Limitations and Implications for Future Research

The systematic review and meta-analysis face certain limitations during their execution. Diverse cognitive evaluation methodologies together with study diversity as well as sample size inconsistency reduce the overall applicability of discovered results. The results are difficult to interpret because of inconsistent data about iron status at baseline and because of publication bias. The analysis of cognitive outcomes faces difficulty when studies lack common procedures for conducting assessments. Scientific research must focus on conducting long-term assessments to validate causeand-effect relationships accompanied by standardized cognitive testing methods throughout all studies. Youngsters undergoing developmentally critical phases currently need further exploration regarding how iron deficiency acts on the brain to create cognitive impairments. The evaluation of community interventions together with public health strategies such as iron fortification programs enables the creation of better prevention methods to lower the worldwide incidence of IDA in children.

CONCLUSION

The systematic review and meta-analysis show that iron deficiency anemia (IDA) produces important cognitive problems in pediatric patients. Early diagnosis with appropriate intervention remains crucial to reduce the cognitive development consequences due to iron deficiency anemia. The research evidence, despite heterogeneous studies and methodological variation, demonstrates that iron acts as a key factor in neural developmental processes.

Public health must implement both iron supplementation programs and educational efforts because these initiatives serve as fundamental approaches to prevent this condition. Subsequent investigations need to conduct longitudinal studies, which will enable researchers to investigate sustained cognitive effects caused by IDA and test large-scale preventive measures. The manipulation of early-childhood iron levels produces extensive cognitive benefits along with improved academic performance capabilities.

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