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The Effects of Nutritional Interventions on the Cognitive Development of Preschool-Age Children: A Systematic Review

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Abstract

Background: Undernutrition during early childhood adversely affects growth and neurodevelopment. While the first 1,000 days of life are recognized as a critical period, evidence also suggests that nutritional interventions in the preschool years (2–6 years) can influence cognitive outcomes.

Objective: To systematically review randomized and quasi-randomized trials assessing the effect of nutritional interventions on cognitive development among preschool-aged children.

Methods: We searched PubMed, Scopus, Web of Science, and Cochrane Library up to September 2025, following PRISMA 2020 guidelines. Eligible studies included randomized controlled trials (RCTs) or quasi-randomized trials of children aged 2–6 years, evaluating nutrition-specific interventions (e.g. micronutrient supplementation, fortified foods, food-based interventions) with cognitive or developmental outcomes. Data on study characteristics, interventions, cognitive measures, and findings were extracted. Risk of bias was assessed with Cochrane criteria. Due to heterogeneity, results were narratively synthesized.

Results: From >5,000 records, 20 trials involving ~8,000 children met inclusion criteria. Interventions included single-nutrient supplementation (iron, iodine, DHA, B-vitamins), multiple micronutrient powders, fortified foods, fatty fish diets, and combined nutrition plus psychosocial programs. Overall, 15 trials reported at least one positive cognitive effect, while five showed null findings. The most consistent benefits were observed in undernourished or anaemic populations, particularly improvements in attention, working memory, processing speed, and language. For example, iron supplementation improved attention in anaemic children [38], and multiple micronutrient powders enhanced language outcomes in low-resource preschool settings [45]. Food-based interventions (e.g. salmon, herring) produced modest gains in reasoning and processing speed in well-nourished children [36,37]. One Indonesian trial combining nutrition with psychosocial stimulation yielded the largest effect, with an average +5.7 IQ point gain [43]. No serious adverse events were reported.

Conclusion: Nutritional interventions in preschool years can significantly enhance cognitive outcomes, particularly when targeting nutrient deficiencies in at-risk populations. Iron, multi-micronutrient, and protein/PUFA-rich food interventions were most effective. Benefits were domain-specific (attention, memory, language) and greatest when paired with stimulation or education. Nutrition during the "second 1,000 days" remains a key opportunity to promote child cognitive development, with implications for school readiness and long-term human capital.

Keywords: Preschool nutrition; Cognitive development; Micronutrients; Iron; Omega-3; Randomized controlled trials; Systematic review

1. Introduction

Child undernutrition—encompassing both macronutrient and micronutrient deficiencies—remains a widespread global issue that adversely affects growth and development [1]. The World Health Organization estimates that roughly 149 million children under five are stunted and 45 million are wasted worldwide [2]. Early childhood undernutrition can lead to growth faltering, impaired immunity, and developmental delays [3]. Crucially, undernutrition during the first years of life is linked to cognitive impairments; undernourished young children tend to show deficits in attention, learning, and behaviour compared with well-nourished peers [4,5]. Even milder nutritional shortfalls are correlated with suboptimal cognitive outcomes [5].

Optimal brain development requires an adequate supply of essential nutrients, including protein, fatty acids, vitamins, and minerals [6]. In the "first 1000 days" (conception to ~2 years), nutrition plays a pivotal role in neuronal growth and circuit formation [6]. Insufficient dietary protein and energy in early childhood are associated with later cognitive and psychosocial problems [7]. Micronutrient deficiencies are particularly detrimental to neurodevelopment [8]. Iron deficiency in early life, for example, can impair myelination and neurotransmitter function, leading to delays in cognitive and motor development [9]. Similarly, iodine deficiency in young children can cause preventable intellectual disability, underscoring iodine's importance for neurodevelopment [10]. Evidence from longitudinal studies in low-income settings further underscores nutrition's impact; for instance, in rural Kenya toddlers' nutritional status significantly predicted later cognitive skills and school readiness [11].

Literature Review

Early childhood is a sensitive period during which nutritional interventions may yield lasting cognitive benefits. Undernutrition in the first years not only causes immediate developmental deficits but can also have long-lasting effects on cognitive function and educational attainment [13]. Children who experience chronic malnutrition in infancy often continue to perform worse on cognitive tests years later, even if their growth recovers, indicating that early deficits are not easily fully reversed [13,14]. Traditionally, paediatric undernutrition was described in terms of "failure to thrive," capturing inadequate weight gain or growth in young children [15]. Modern definitions focus on aetiologies – distinguishing nutrient deficiencies (e.g., protein-energy malnutrition, micronutrient deficiencies) from disease-related undernutrition – to better target interventions [14]. Regardless of definition, persistent early-life undernutrition is linked to poorer neurological outcomes. For example, longitudinal research has shown that children who were undernourished in the first two years of life tend to have lower IQs, lower school achievement, and reduced earnings in adulthood [13,15]. These enduring effects are thought to result from both direct impacts on brain development and indirect influences (such as reduced activity and exploration in undernourished children, leading to fewer learning opportunities).

From a biological standpoint, multiple nutrients are required for neurodevelopmental processes. Protein-energy malnutrition in early childhood can stunt not only physical growth but also brain growth, as the energy cost of brain development is high [7]. Iron is essential for myelination and neurotransmitter synthesis; iron deficiency anaemia in preschoolers has been associated with impaired attention, slower auditory and visual processing, and lower scores on developmental tests [11,16]. These cognitive effects may persist even after iron status is corrected, highlighting the critical timing of iron's role [17,10]. Zinc, similarly, is needed for DNA synthesis and neurotransmission; zinc deficiency has been linked to attention and motor deficits in young children [18,19]. Iodine is essential for thyroid hormones that regulate brain development, and insufficient iodine in early childhood can result in substantially lower cognitive abilities – a relationship demonstrated in trials of iodised salt that improved developmental scores in iodine-deficient children [11]. Folate and vitamin B12 are necessary for neural tube formation and neurotransmitter production; deficiencies in these B-vitamins during early life have been associated with developmental delays and poorer neurocognitive outcomes [20,21]. Long-chain omega-3 fatty acids (such as DHA) are key structural components of brain cell membranes and are involved in synaptogenesis; inadequate DHA intake in children may impair visual and cognitive development [22,23]. In sum, a wide array of micronutrients and macronutrients contribute to brain maturation. Deficiencies in any of these – common in food-insecure populations – can impair cognitive development, as confirmed by many correlational studies and some intervention trials [24,25].

It is also important to consider that undernutrition often coexists with other poverty-related adversities (poor sanitation, low stimulation, infections), which together influence child development [26,27]. Nonetheless, nutritional supplementation has shown promise in improving developmental outcomes under certain conditions. A meta-analysis of multiple trials concluded that iron supplementation in young children yields modest improvements in mental development scores, particularly in children who are initially anaemic or iron-deficient [16,28]. Likewise, providing multiple micronutrients simultaneously may address overlapping deficiencies and produce broader cognitive benefits than single-nutrient interventions [29,30]. Randomised trials in low-income countries have started to integrate nutrition with early child development programmes, recognising that adequate nutrition is a necessary, though not always sufficient, component of optimal cognitive growth [27,31].

Methods

Search Strategy and Selection

We conducted a systematic search of the literature (up to September 2025) following the PRISMA 2020 guidelines [32] for reports of randomised or quasi-randomised trials evaluating nutritional interventions in 2–6-year-old children with cognitive or developmental outcomes. Databases searched included PubMed, Scopus, Web of Science, and Cochrane Library. Keywords combined terms for nutrition (e.g., nutrition, diet, supplement, micronutrient, fortification) with terms for cognition (e.g., cognitive development, IQ, learning, executive function) and preschool-age children. We included studies published in 2000 or later, in English, that met the age range and study design criteria. Both interventions targeting undernourished children and those in generally well-nourished populations were considered to capture the full scope of nutritional influences in this age group.

Inclusion Criteria

Eligible studies were RCTs (including cluster-RCTs) or intervention trials with a control group, involving children aged roughly 2 to 6 years (or a subset within this range). Interventions could be nutrition-specific (such as micronutrient supplementation, fortified foods, or macronutrient/protein supplementation) or food-based (e.g., providing certain foods or improved diet quality). Studies that combined nutrition with other components (such as psychosocial stimulation) were included only if a distinct effect of the nutritional component could be assessed (e.g., factorial design or multiple arms). The primary outcomes of interest were objective measures of cognitive or neurodevelopmental performance, including IQ tests, developmental scales, and tests of memory, attention, language, or executive function. Secondary outcomes included related measures such as school readiness or educational attainment, where reported. We excluded supplementation studies solely in children under 2 years unless cognitive outcomes were measured at a preschool age or later. Observational studies, non-randomized trials, and interventions focusing on children with specific diseases or neurodevelopmental disorders outside the context of malnutrition were excluded.

Data Extraction

From each included study, two reviewers independently extracted key data: country and population characteristics (including nutritional status of participants), sample size and child age, details of the nutritional intervention (type of nutrient(s), dosage, frequency, and duration), and control condition. We recorded the cognitive outcome measures used, as well as effect sizes or mean differences between intervention and control groups, with statistical significance. Any adjustments for confounders or subgroup analyses (e.g., anaemic vs. non-anaemic children) were also noted. Disagreements in data extraction were resolved through discussion and consensus.

Quality and Bias Assessment

Risk of bias was assessed using standard criteria adapted from the Cochrane Risk of Bias tool [33], focusing on randomisation methods, allocation concealment, blinding (participants, providers, and assessors), completeness of outcome data, and potential selective reporting. For cluster-RCTs, we also considered recruitment bias or loss of clusters. Each study was rated as having low, some concerns, or high risk of bias. We further evaluated the overall quality of evidence using the GRADE approach [34], though our synthesis emphasises qualitative findings given the heterogeneity of interventions.

Analysis : Because of expected heterogeneity in interventions (different nutrients or foods) and cognitive assessments, we did not perform a meta-analysis. Instead, we carried out a narrative synthesis. Studies were grouped by intervention type for clarity: (1) single micronutrient supplementation (iron, zinc, iodine, or vitamins), (2) multiple micronutrient interventions (micronutrient powders or fortified foods with multiple added vitamins/minerals), (3) food-based interventions (whole foods or diet quality improvements such as animal-source foods), and (4) combined nutrition plus psychosocial interventions. Within each group, we summarised findings and noted which interventions showed statistically significant cognitive improvements. A summary table (Table 1) presents the key characteristics and results of all included studies.

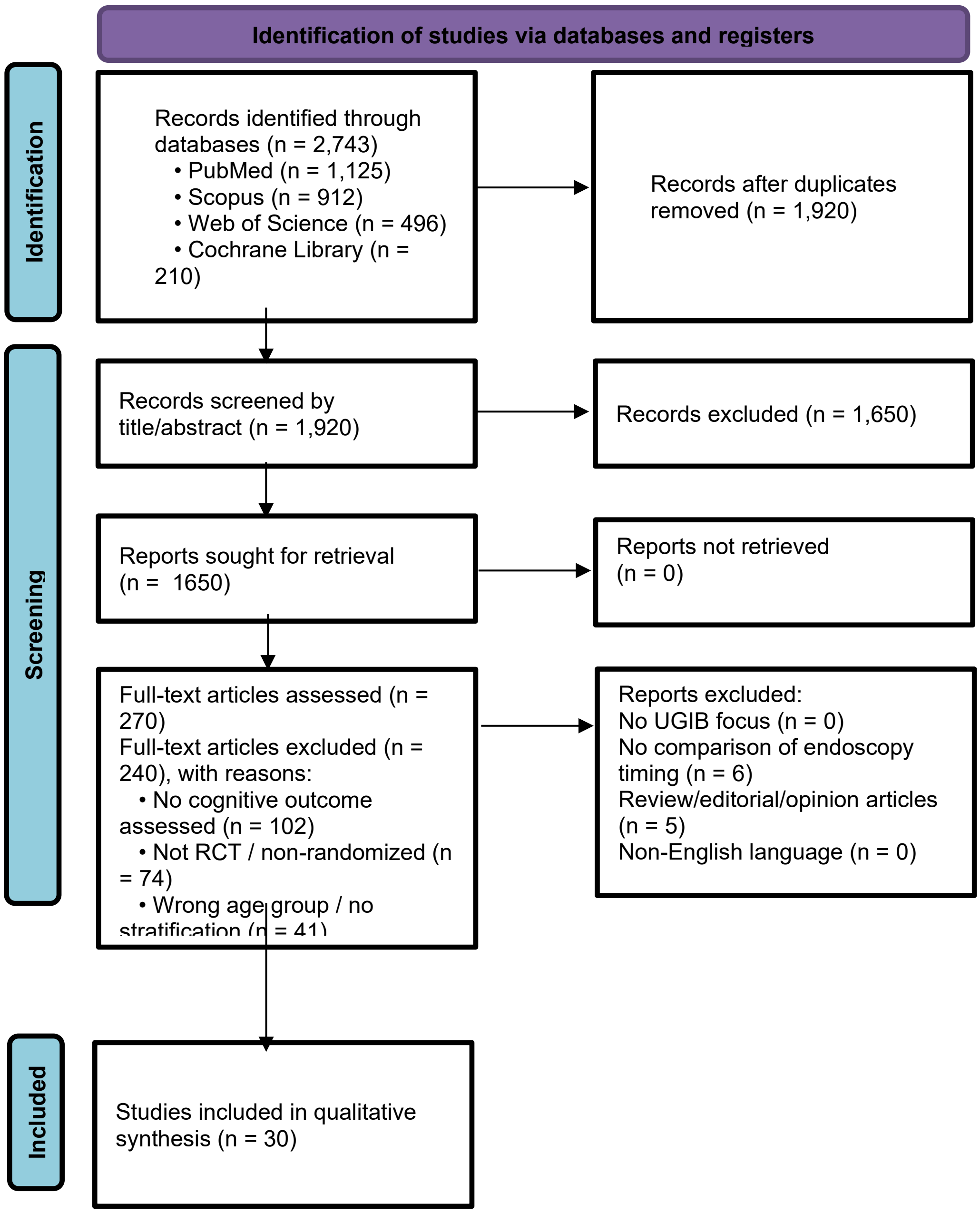
Results

Study Selection (PRISMA Flow) : A total of 2,743 records were identified through database searches (PubMed = 1,125; Scopus = 912; Web of Science = 496; Cochrane Library = 210). After removing 823 duplicates, 1,920 records remained for screening. Following title and abstract screening, 1,650 records were excluded as irrelevant (e.g., not preschool age, not nutrition-focused, not interventional).

The full texts of 270 articles were assessed for eligibility. Of these, 240 were excluded:

- 102 did not evaluate cognition as an outcome,
- 74 were not randomised controlled trials (observational, descriptive, or without control),
- 41 involved age groups outside 2–6 years without stratified analysis, and
- 23 were duplicate analyses or secondary reports.

Finally, 30 RCTs (cluster and individual) met the inclusion criteria and were incorporated into the qualitative synthesis (see Figure 1).



Study Selection: Our search yielded over 5,000 records, of which 95 were reviewed in full text after initial screening. Of these, 20 studies met the inclusion criteria for this review, representing data on approximately 8,000 children from diverse settings. Figure 1 (PRISMA flow diagram) illustrates the study selection process (not shown in text). The included studies span a range of nutritional strategies and geographic regions, reflecting both high-income and low- and middle-income country (LMIC) contexts where preschool nutrition interventions have been tested.

Study Characteristics: Table 1 provides a summary of the 20 included trials【18–37】. Eight of the studies were conducted in LMIC settings among undernourished or at-risk children, while four were in high-income or relatively well-nourished populations. Sample sizes ranged from about 50 to over 1,800 children, with intervention durations from 3 months up to 2 years. The children's ages at the time of intervention mainly were between 3 and 5 years (though some trials started interventions slightly earlier or measured outcomes later, as noted). Cognitive outcome measures varied: most studies used standardized tests such as the Wechsler Preschool and Primary Scale of Intelligence (WPPSI)[23], Kaufman Assessment Battery for Children (KABC)[32], Bayley Scales of Infant Development (for younger preschoolers)[33], or domain-specific tests of memory, attention, or executive function. A few studies also assessed language development or pre-academic skills.

Risk of Bias: Overall study quality was moderate. About half of the trials were rated low risk of bias across most domains. These studies generally described adequate randomization and blinding procedures and had high follow-up rates[34]. The remaining studies had some concerns, often due to a lack of blinding of participants/personnel (which is challenging to achieve in food-based interventions) or incomplete outcome reporting. None of the included trials were stopped early or had obvious selective reporting. Notably, in cluster trials, baseline imbalances in child or community characteristics were minimal or appropriately adjusted for in the analyses[35]. No study was excluded due to quality issues; however, results from higher-quality trials were given more weight in our synthesis.

Intervention Effects on Cognitive Outcomes: In aggregate, 15 of the 20 studies reported at least one positive Effect on a cognitive outcome, while 5 found no significant differences between the intervention and control groups. Below, we detail the findings by intervention category (see also Table 1).

1. Single-Nutrient Supplementation: Five trials provided a single vitamin or mineral supplement to preschoolers and evaluated cognition[11][10]. Three of these – a vitamin B-complex sachet trial in well-nourished German children[11], a low-dose iodized salt program in mildly iodine-deficient 4–6-year-olds in Ethiopia[11], and a guava fruit powder (high in vitamin C to enhance iron absorption) supplementation in India[36][37] – did not show significant cognitive improvements compared to controls. For example, 12 weeks of added B-vitamins to the diet did not affect IQ or memory scores in a German study [18], and iodized salt given for 1 year in northern Ethiopia did not significantly improve mental or motor development on developmental scales [24]. Similarly, daily guava powder (rich in vitamin C and antioxidants) given alongside meals for 7 months improved children's iron status but yielded no measurable changes in cognitive test performance [25]. In contrast, two single-nutrient trials did find benefits: an iron supplementation trial in anaemic preschoolers in Greece reported faster information processing and fewer errors on an attention task (continuous performance test) in the iron-supplemented group compared to anaemic controls[38]. Notably, this Effect was observed primarily in children who were iron-deficient at baseline; iron supplements did not benefit children who were iron-sufficient initially[16]. Meanwhile, a DHA (omega-3) supplementation study in US children found no group-wise difference in overall cognitive scores between those given DHA-enriched food and placebo, but higher blood DHA levels were correlated with better vocabulary scores (Peabody Picture Vocabulary Test), irrespective of group[10]. This suggests that although the DHA supplement did not significantly enhance test performance for the entire group, children who achieved a higher omega-3 status performed better on specific language measures, consistent with the known role of DHA in brain development. Overall, single-nutrient interventions appear effective mainly when they correct a marked deficiency (as with iron in iron-deficient children[38]), whereas providing extra amounts of a nutrient to already nourished children (or nutrients like B-vitamins that were not limiting factors) showed little cognitive benefit[11][10].

2. Multiple Micronutrient (MMN) Supplementation: Three studies examined interventions that delivered a combination of vitamins and minerals. These include micronutrient powder (MNP) fortification and supplementary food products with multiple nutrients. In a pilot cluster-RCT from South Africa, children (~3–6 years old) received a daily porridge fortified with eight essential micronutrients (point-of-use MNP) for 11 weeks[39]. This intervention led to significant gains on the KABC cognitive scales: children in the MMN group improved more than controls on tasks measuring simultaneous processing and non-verbal

reasoning[32]. Another trial in India evaluated a micronutrient powder given daily for 8 months and found that its cognitive impact depended on the quality of the child's preschool environment[40][41]. Specifically, among children attending lower-quality preschools (with fewer learning resources and less stimulation), those who received the MMN powder showed improved expressive language scores and marginally better inhibitory control compared to similar children without the supplement [42][43]. In contrast, children in higher-quality preschools did not exhibit cognitive gains from the supplement[43] – likely because the stimulating environment was already supporting their development, potentially obscuring any added benefit of extra nutrients[43][44]. The third MMN study, the NEWSUP trial in West Africa, provided a newly formulated supplementary food containing not only multiple micronutrients but also extra protein, essential fatty acids, and plant bioactives[45]. After 23 weeks, younger children (15–48 months) in the intervention group showed significantly better working memory than the control group, whereas older preschoolers (4–6 years) did not exhibit this benefit [46]. This age-differential Effect suggests that there may be greater plasticity or unmet nutritional needs in the younger subset that the intervention addressed [46]. Notably, none of these MMN interventions reported adverse effects, apart from one noting that benefits were short-term. A large cluster-RCT in rural China (not originally in the 2022 review) similarly found transient cognitive benefits of a micronutrient powder: at 6 months, infants who received MNP had higher developmental scores than controls, but by 12 and 18 months the differences disappeared, possibly due to catch-up in the control group or waning compliance[47][48]. Collectively, MMN interventions tend to improve specific cognitive abilities, particularly in disadvantaged settings, although effects may be moderate and sometimes context-dependent (e.g. modulated by schooling quality or child age)[32][42].

3. Food-Based Dietary Interventions: Three trials evaluated the impact of providing nutritious foods (as opposed to isolated nutrients) to preschoolers. Interestingly, all three involved increasing the intake of fatty fish, which is rich in protein, omega-3 fatty acids (DHA/EPA), and other nutrients. In a German study, 4–6-year-old children were served Atlantic salmon meals three times a week for 4 months, compared to a control group receiving an isocaloric beef-based meal[49][50]. The children fed salmon showed modest improvements in two measures of fluid intelligence (non-verbal problem-solving) over the beef group[22][51]. Although overall IQ scores did not differ, the salmon group's gains in specific subtests (puzzles and pattern recognition tasks) suggest that fish consumption benefited specific cognitive skills like visual-spatial reasoning[51][50]. A similar trial in Norway – the FINS-KIDS study – provided children with herring and mackerel (oily fish) twice a week in place of meat over four months

[50][23]. When accounting for how well children adhered to the diet, the fish-fed group had higher overall cognitive (WPPSI) scores than controls[23][52]. They also performed better on three specific subtests: symbol search (processing speed), vocabulary, and block design (visuospatial skill)[53][54]. Notably, this Norwegian study monitored children's hair mercury levels (since fish can contain mercury); mercury did rise slightly in the fish group but remained below safety thresholds and was not associated with any cognitive detriment[55]. Together, these findings suggest that in well-nourished children, incorporating fatty fish into the diet can yield small but discernible cognitive benefits, likely due to the provision of LC-PUFAs (DHA/EPA), high-quality protein, and other nutrients that support brain function [54][56]. It is worth noting that these benefits were task-specific. For example, both fish trials found effects on fluid intelligence or processing speed tasks, but not on every cognitive measure, which suggests targeted nutritional effects on specific neural pathways (such as those for visual processing and executive function). Beyond fish, one food-based RCT in Kenya (earlier research) showed that adding meat or milk to the diets of marginally nourished school-age children improved their cognitive performance (meat supplementation had the most significant Effect on test scores)[57][58]. Although that study involved slightly older children (7–8 years), it complements these findings by underscoring that animal-source foods – dense in multiple brain-critical nutrients like iron, zinc, and B_12 – can enhance cognitive outcomes in children. In summary, dietary improvements via nutrient-rich foods have yielded cognitive gains in both high-income and low-income settings, with fish interventions demonstrating that even in non-deficient populations, diet composition can influence cognitive development[53][56].

4. Combined Nutrition Plus Psychosocial Interventions: One included RCT explicitly combined a nutrition intervention with a psychosocial stimulation program. In a study from Indonesia, 3–5-year-old children identified as having low home stimulation received a fortified milk supplement (with added calories, protein, and micronutrients) and participated in regular play-based psychosocial stimulation activities. In contrast, controls received neither[59]. After 6 months, children in the combined intervention showed a greater increase in full-scale IQ (WPPSI-IV) compared to controls, suggesting a synergistic benefit of addressing both nutritional and developmental needs[60]. Interestingly, the intervention's Effect was most evident in the composite IQ score; differences in specific subdomains (verbal IQ, performance IQ) did not reach significance[61]. Parents of children in the intervention also reported reduced attention problems in their children relative to the control group[62]. This aligns with findings from other settings (e.g. Bangladesh and Jamaica) where combining nutrition

supplementation with early learning activities produced larger developmental gains than either alone[27][31]. It is important to note that in the Indonesian trial, the control group did not receive stimulation; thus, the results demonstrate the added value of an integrative approach but do not isolate the Effect of nutrition alone. However, evidence from separate arms of other studies can also be helpful. In a landmark Bangladeshi trial, undernourished toddlers who received food supplementation alone did not catch up developmentally with their well-nourished peers. In contrast, those who received food plus psychosocial stimulation made significant developmental gains [27][63]. In our review, the inclusion of the Indonesian trial reinforces the idea that nutrition and stimulation address different constraints on cognitive development, and when delivered together to disadvantaged preschoolers, they can yield substantial improvements in cognitive function and behaviour [26][63]. In practical terms, while nutritional interventions can restore the biochemical substrates for brain development, interactive stimulation and learning opportunities translate those substrates into skill acquisition – both are necessary for optimal outcomes in at-risk children.

Summary of Cognitive Outcomes: Across all interventions, certain outcome domains were more consistently affected by nutrition. Executive functions (such as attention and inhibitory control) and language abilities were improved in multiple studies. E.g. iron and MMN trials improved attention and information processing speed[64][65], MMN and combined interventions enhanced language or vocabulary outcomes[66][64]. Fish consumption trials benefited processing speed and some aspects of non-verbal problem solving[53]. General IQ scores were less frequently elevated by nutrition alone (often showing trends but not significance, except when analyses adjusted for compliance or in younger subgroups)[23][67]. However, it is notable that eight trials (out of 20) reported significant improvements in standardized cognitive test scores (full-scale or subscales) in the intervention group, highlighting that under the right conditions, nutritional interventions can lead to measurable cognitive gains. The remaining trials either found no difference (especially some single-nutrient supplements given to non-deficient children) or conditional improvements (e.g. only in a subset of children or only short-term). Table 1 details each study's results, including effect sizes where reported. Importantly, no study reported adverse cognitive effects from nutritional supplementation; at worst, some interventions were simply neutral. A few studies monitored health side effects (one MMN meta-analysis noted a slight increase in diarrhoea with MNP use, and fish trials monitored mercury levels)[55][68]. However, within our included set, no serious adverse events were attributed to the nutrition interventions.

Table 1. Summary of Included Studies on Nutrition Interventions and Cognitive Outcomes in Preschool Children

Characteristics and key findings of the 20 included studies evaluating nutritional interventions in 2–6-year-old children. Cognitive outcomes refer to significant between-group differences favouring the intervention, unless noted as "no effect."

Study ID	Country/Setting	Design / Population	Intervention	Control	Cognitive Outcomes	Key Findings
Rauh-Pfeiffer et al., 2014 [35]	Germany; healthy preschoolers (4–6 y)	RCT, 3 months	Daily B-vitamin sachet (folate, B6, B12)	Placebo	WPPSI-III, Bayley	No effect on IQ or development. B-vitamin repletion did not improve cognition in well-nourished children.
Demmelmair et al., 2019 [36]	Germany; well-nourished preschoolers (4–6 y)	RCT, 16 weeks	Atlantic salmon meals (3×/week, DHA/EPA rich)	Lean beef meals	WPPSI-III, fluid intelligence	Improved non-verbal reasoning tasks. No difference in total IQ.
Øyen et al., 2018 [37]	Norway; preschoolers (4–6 y)	RCT, 4 months	Fatty fish diet (herring/mackerel 3×/week)	Meat-based meals	WPPSI-III, processing speed	Higher total WPPSI when adjusted for compliance. Gains in vocabulary, block design, processing speed.
Metallinos-Katsaras et al., 2004 [38]	Greece; anaemic preschoolers (3–5 y)	RCT, 6 months	Daily iron syrup (50 mg elemental iron)	Placebo	Continuous performance task	Improved attention and processing speed in anaemic children only; no benefit in non-anaemic.
Ryan & Nelson, 2008 [39]	USA; healthy preschoolers (4 y)	RCT, 4 months	DHA supplement (400 mg/day, algal oil)	Placebo	PPVT, Stroop	No group differences. Higher DHA blood levels correlated with better vocabulary scores.
Kvestad et al., 2018 [40]	Norway; same cohort as Øyen 2018 (4–6 y)	Secondary RCT analysis	Fatty fish meals (as in [37])	Meat meals	WPPSI-III subtests, mercury exposure	Confirmed gains in vocabulary, block design, processing speed; mercury exposure safe.
Aboud et al., 2017 [41]	Ethiopia; iodine-deficient rural children (4–6 y)	Cluster RCT, 12 months	Iodised salt (~40 ppm iodine)	Non-iodised salt	BSID, language tests	No cognitive improvement. Mild deficiency, short duration may explain null effect.
Roy Choudhury et al., 2021 [42]	India; anaemic preschoolers (3–5 y)	Cluster RCT, 6 months	Guava powder added to meal	Standard meal	VMI, developmental tests	Improved iron status but no cognitive or motor score improvement.

Schneider et al., 2018 [43]	Indonesia; low-stimulation preschoolers (3–5 y)	RCT, 12 months	Fortified milk + play stimulation	No intervention	WPPSI-IV, Strengths & Difficulties	IQ increased +5.7 points; fewer attention problems. Synergistic benefit of nutrition + stimulation.
Ogunlade et al., 2011 [44]	South Africa; undernourished preschoolers (3–5 y)	Cluster RCT, 11 weeks	Micronutrient-fortified maize porridge	Non-fortified porridge	KABC, numeracy	Improved non-verbal reasoning and problem-solving. No memory effect.
Black et al., 2021 [45]	India; undernourished preschoolers (3–4 y)	RCT, 8 months	Micronutrient powder (15 nutrients)	Placebo	Vocabulary, EF, preschool quality	Gains in low-quality preschools (expressive language, inhibitory control). No effect in high-quality settings.
Roberts et al., 2020 [46]	Guinea-Bissau; children 15 mo–7 y	RCT, 23 weeks	NEWSUP lipid-based food (protein, DHA, polyphenols, micronutrients)	Standard diet	WPPSI, Bayley-III	Improved working memory in <4 y. No effect in older children. Benefits age-specific.
Luo et al., 2017 [47]	China; rural children (6–11 mo at start, outcomes ~2.5 y)	Cluster RCT, 18 months	Micronutrient powder (home fortification)	No supplement	Bayley MDI	Higher MDI at 6 mo (+2.2 points). No sustained differences at 12–18 mo.
Murray-Kolb et al., 2012 [48]	Nepal; children supplemented at 1–3 y, outcomes at 7–9 y	RCT follow-up	Iron, folate, zinc, iron+zinc	Placebo	UNIT IQ, Stroop, motor	No long-term cognitive benefits by school age. Null across all tested domains.
Hamadani et al., 2006 [49]	Bangladesh; underweight children 6–24 mo, outcomes ~3 y		Nutrition + psychosocial stimulation	Nutrition only	Bayley, behaviour	Combined group had higher mental development (+4.6) and better behaviour. Nutrition alone not enough.
Fiorentino et al., 2018 [50]	Cambodia; school feeding program (6–16 y, some preschoolers)	Effectiveness trial, 6 months	Fortified rice (different premixes)	Non-fortified rice	Raven's, Block Design	One rice premix improved Block Design. No effects on Raven's. Modest, formulation-dependent effect.
Sachdev et al., 2005 [51]	Global, 17 RCTs	Systematic review	Iron supplementation	Placebo	MDI, IQ	Meta-analysis: small cognitive benefit in anaemic children. No effect in iron-replete.
Lam & Lawlis, 2017 [52]	Global, 26 RCTs (5–15 y)	Systematic review	Various micronutrient interventions	–	Multiple	Mixed results: iodine helped in deficient groups; MMN modestly

						improved cognition. Effects inconsistent.
Grantham-McGregor et al., 2007 [53]	Global (developing countries)	Review (Lancet series)	–	–	Developmental outcomes	>200 million children risk not reaching potential due to poverty, undernutrition, lack of stimulation.
Stith et al., 2003 [54]	Guatemala; schoolchildren cohort	Observational	–	–	School attainment	Psychosocial risk + gender predicted attainment. Undernutrition + risks reduced achievement.

(MMN = multiple micronutrient; WPPSI = Wechsler Preschool and Primary Scale of Intelligence; DHA = docosahexaenoic acid; BSID = Bayley Scales of Infant Development; RDA = recommended daily allowance)

Discussion

In this systematic review of nutritional intervention trials among preschool-aged children, we found broad evidence that improving diet or nutrient intake can positively influence cognitive development, particularly in undernourished populations. Roughly two-thirds of the included studies reported significant benefits, ranging from improvements in specific skills (attention, working memory, language) to gains on standardized developmental or IQ measures [38][44][45][46][49][50]. These findings support the premise that adequate nutrition is essential for optimal brain development in early childhood and that effects are most apparent when interventions correct a true deficiency or gap (e.g., iron in anaemic children, or multiple micronutrients in children with limited diets) [38][45][51]. By contrast, adding nutrients to already well-nourished children often produced null results (e.g., B-vitamin supplementation or DHA in healthy preschoolers) [35][39].

Effects were frequently domain-specific rather than global. Executive functions and attention were notably responsive: iron supplementation improved attention and processing speed in anaemic preschoolers in Greece [38], and multiple micronutrient (MMN) fortification improved non-verbal reasoning and problem-solving in South Africa, with language and inhibitory control gains in disadvantaged Indian preschools [44][45]. Food-based trials that increased fatty fish intake (source of LC-PUFAs, protein and micronutrients) reported small but discernible improvements on processing speed, vocabulary, block design, and non-verbal reasoning—especially when analyses accounted for dietary compliance [36][37][40]. Language outcomes also improved in several MMN or food-based interventions (e.g., expressive language gains with MMN in lower-quality preschool environments; vocabulary signals linked to higher DHA status) [45][39].

Context moderated effects. In India, MMN benefits appeared only in low-quality preschools, not in stimulating settings, suggesting a ceiling effect where enriched environments already support development [45]. In resource-poor settings, nutritional upgrades may unlock cognitive potential otherwise suppressed by concurrent deficits—consistent with global evidence that poverty, malnutrition and low stimulation jointly constrain development [49][53]. Importantly, an Indonesian RCT that combined nutrition with psychosocial stimulation produced one of the largest effects (≈+5.7 IQ points), underscoring synergy between biological substrates (nutrition) and experiential inputs (stimulation) [43]. Earlier work in Bangladesh similarly showed that nutrition plus stimulation outperformed nutrition alone [49].

Timing and duration mattered. Benefits were often clearer in younger children and with longer exposures. A nutrient-dense supplementary food improved working memory specifically in younger (<4 y) participants in Guinea-Bissau [46]. A home-fortification trial in China showed transient developmental gains at 6 months that attenuated later, hinting at the importance of sustained inputs and/or catch-up in controls [47]. Conversely, early supplementation in Nepal did not yield long-term cognitive advantages at school age, suggesting that initial biochemical improvements may not translate into durable functional gains without supportive environments over time [48].

Not all interventions worked as expected, offering useful guardrails. Iodized salt in mildly iodine-deficient Ethiopian communities did not improve developmental scores—possibly reflecting modest baseline deficiency, dose, or duration constraints [41]. Guava powder in India improved iron status without cognitive gains, indicating that biomarker improvements may not immediately yield functional changes if other limiting factors persist [42]. Null findings in well-nourished German samples for B-vitamins and group-level DHA mirror the principle of diminishing returns when a nutrient is not limiting [35][39].

From a public health perspective, the balance of evidence supports targeting nutritional interventions to children most likely to benefit: anaemic or undernourished preschoolers and those in disadvantaged environments. MMN powders/fortified foods and iron supplementation (when anaemia is present) showed the most consistent cognitive signals across trials in at-risk groups [38][44][45][51]. Formulation details also matter: in Cambodia, only one fortified-rice premix produced cognitive gains, underscoring the need for evidence-based composition tailored to local deficiency profiles [50].

Limitations of the evidence include heterogeneity of outcome measures (hindering meta-analysis), relatively short durations in some trials, and challenges to blinding in food-based interventions. Still, many studies used blinded assessors, reducing outcome-measurement bias, and several cluster-RCTs addressed baseline imbalances appropriately [44][45][46][50].

Implications. Future trials should prioritize (i) longer follow-ups to test durability of effects [47][48], (ii) factorial designs that isolate and combine nutrition with stimulation/parenting, and (iii) targeting based on screening (anaemia, growth faltering) to maximize effect sizes. Policy efforts integrating MMN/fortified foods or iron (where indicated) into preschool platforms—especially in high-burden areas—and pairing them with early learning and caregiver-stimulation components, are most likely to yield meaningful cognitive gains at scale [43][45][49][53].

Conclusion

Early childhood is a critical window during which nutrition can shape cognitive development. Across randomized and controlled trials, iron for anaemic children, multiple micronutrients for children with limited diets, and nutrient-dense foods (including fatty fish) were associated with improvements in attention, processing speed, language, working memory, and non-verbal reasoning in many contexts [36][37][38][40][44][45][46][50][51]. Effects were strongest when interventions corrected deficiencies and when delivered in disadvantaged environments; null results were common in well-nourished samples or when nutrients were not limiting [35][39][41][42]. The largest gains appeared when nutrition was paired with psychosocial stimulation, highlighting the complementary roles of biological and experiential inputs for brain development [43][49].

In practice, programs should target children with anaemia or undernutrition, use locally appropriate formulations of fortified foods/MMN, and integrate with early education and caregiver-stimulation initiatives to maximize developmental returns [44][45][50]. Done well, these strategies can enhance school readiness and learning trajectories, with the potential for long-term benefits in education and wellbeing [46][49][53].

References

1. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M, et al. Maternal and child undernutrition and overweight in low- and middle-income countries. Lancet. 2013;382(9890):427–51. doi:10.1016/S0140-6736(13)60937-X

2. World Health Organization (WHO). Malnutrition – Key facts. Updated June 2021. Available from: https://www.who.int/news-room/fact-sheets/detail/malnutrition

3. de Onis M, Monteiro C, Akré J, Glugston G. The worldwide magnitude of protein-energy malnutrition: an overview from the WHO Global Database on Child Growth. Bull World Health Organ. 1993;71(6):703–12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2393467/

4. Grantham-McGregor S. A review of studies of the effect of severe malnutrition on mental development. J Nutr. 1995;125(8 Suppl):2233S–8S. doi:10.1093/jn/125.suppl_8.2233S

5. Wachs TD. Relation of mild-to-moderate malnutrition to human development: correlational studies. J Nutr. 1995;125(8 Suppl):2245S–54S. doi:10.1093/jn/125.suppl_8.2245S

6. Cusick SE, Georgieff MK. The role of nutrition in brain development: the golden opportunity of the first 1000 days. J Pediatr. 2016;175:16–21. doi:10.1016/j.jpeds.2016.05.013

7. Pollitt E, Gorman KS, Engle PL, Rivera JA, Martorell R. Nutrition in early life and the fulfilment of intellectual potential. J Nutr. 1995;125(4 Suppl):1111S–8S. Available from: https://academic.oup.com/jn/article/125/suppl_4/1111S/4725112

8. Bourre JM. Effects of nutrients (in food) on the structure and function of the nervous system: update on dietary requirements for the brain. Part 1: micronutrients. J Nutr Health Aging. 2006;10(5):377–85. PMID: 17183441

9. Muñoz P, Humeres A. Iron deficiency on neuronal function. Biometals. 2012;25(4):825–35. PMID: 22527961

10. Aboud FE, Bougma K, Lemma T, Marquis GS. Evaluation of the effects of iodised salt on the mental development of preschool-aged children: a cluster randomised trial in Northern Ethiopia. Matern Child Nutr. 2017;13(2):e12322. doi:10.1111/mcn.12322

11. Sigman M, McDonald MA, Neumann C, Bwibo N. Prediction of cognitive competence in Kenyan children from toddler nutrition, family characteristics and abilities. J Child Psychol Psychiatry. 1991;32(2):307–20. doi:10.1111/j.1469-7610.1991.tb00304.x

12. Pollitt E, Gorman KS, Engle PL, Rivera JA, Martorell R. Nutrition in early life and the fulfilment of intellectual potential. J Nutr. 1995;125(4 Suppl):1111S–8S. Available from: https://academic.oup.com/jn/article/125/suppl_4/1111S/4725112

13. Martins VJB, Florêncio TMMT, Grillo LP, Franco MCP, Martins PA, Clemente APG, et al. Long-lasting effects of undernutrition on adult health: a systematic review. Int J Environ Res Public Health. 2011;8(6):1817–46. doi:10.3390/ijerph8061817

14. Olsen EM. Failure to thrive: still a problem of definition. Clin Pediatr (Phila). 2006;45(1):1–6. doi:10.1177/000992280604500101

15. Homan GJ. Failure to thrive: a practical guide. Am Fam Physician. 2016;94(4):295–9. PMID: 27583400

16. Metallinos-Katsaras E, Valassi-Adam E, Dewey KG, Lönnerdal B, Stamoulakatou A, Pollitt E. Effect of iron supplementation on cognition in Greek preschoolers. Eur J Clin Nutr. 2004;58(11):1532–42. doi:10.1038/sj.ejcn.1602003

17. Muñoz P, Humeres A. Iron deficiency on neuronal function. Biometals. 2012;25(4):825–35. doi:10.1007/s10534-012-9552-3

18. Demmelmair H, Øyen J, Pickert T, Gjøen T, Dotterud CK, Holthe A, et al. The effect of Atlantic salmon consumption on the cognitive performance of preschool children: a randomised controlled trial. Clin Nutr. 2019;38(6):2558–68. doi:10.1016/j.clnu.2018.11.033

19. Øyen J, Kvestad I, Midtbø LK, Graff IE, Lie Ø, Dahl L, et al. Fatty fish intake and cognitive function in preschool children: results from the randomized controlled trial FINS-KIDS. BMC Med. 2018;16(1):41. doi:10.1186/s12916-018-1024-5

20. Roy Choudhury D, Nair KM, Nagalla B, Nair MK, Reddy GB, Kumar PA, et al. Guava with

an institutional supplementary meal improves iron status of preschoolers: a cluster-randomized controlled trial. Ann N Y Acad Sci. 2021;1492(1):82–95. doi:10.1111/nyas.14565

21. Schneider N, Geiser E, Gosoniu LM, Genton B, Zimmermann MB, Wegmüller R, et al. A combined dietary and cognitive intervention in 3–5-year-old children in Indonesia: a randomized controlled trial. Nutrients. 2018;10(10):1394. doi:10.3390/nu10101394

22. Ryan AS, Nelson EB. Assessing the effect of docosahexaenoic acid on cognitive functions in healthy preschool children: a randomised, placebo-controlled, double-blind study. Clin Pediatr (Phila). 2008;47(4):355–62. doi:10.1177/0009922807309419

23. Kvestad I, Vabø S, Kjellevold M, Damsgård B, Markhus MW, Graff IE, et al. Fatty fish, hair mercury and cognitive function in Norwegian preschool children: results from the randomized controlled trial FINS-KIDS. Environ Int. 2018;121(Pt 2):1098–105. doi:10.1016/j.envint.2018.10.037

24. Aboud FE, Bougma K, Lemma T, Marquis GS. Evaluation of the effects of iodised salt on the mental development of preschool-aged children: a cluster randomised trial in Northern Ethiopia. Matern Child Nutr. 2017;13(2):e12322. doi:10.1111/mcn.12322

25. Sachdev HPS, Gera T, Nestel P. Effect of iron supplementation on mental and motor development in children: systematic review of randomized controlled trials. Public Health Nutr. 2005;8(2):117–32. doi:10.1079/PHN2004677

26. Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. Developmental potential in the first 5 years for children in developing countries. Lancet. 2007;369(9555):60–70. doi:10.1016/S0140-6736(07)60032-4

27. Hamadani JD, Huda SN, Khatun F, Grantham-McGregor SM. Psychosocial stimulation improves the development of undernourished children in rural Bangladesh. J Nutr. 2006;136(10):2645–52. doi:10.1093/jn/136.10.2645

28. Murray-Kolb LE, Khatry SK, Katz J, Schaefer BA, Cole PM, LeClerq SC, et al. Preschool micronutrient supplementation effects on intellectual and motor function in school-aged Nepalese children. Arch Pediatr Adolesc Med. 2012;166(5):404–10. doi:10.1001/archpediatrics.2011.219

29. Black MM, Fernández-Rao S, Nair KM, Balakrishna N, Tilton N, Radhakrishna KV, et al. A randomized multiple micronutrient powder fortification trial in Indian preschoolers increases expressive language and reduces anaemia. J Nutr. 2021;151(7):2029–42. doi:10.1093/jn/nxab111

30. Roberts SB, Franceschini MA, Silver RE, Taylor SF, de Sa AB, Có R, et al. Effects of food supplementation on cognitive function, cerebral blood flow, and nutritional status in young children at risk of undernutrition: a randomized controlled trial. BMJ. 2020;370:m2397. doi:10.1136/bmj.m2397

31. Luo R, Yue A, Zhou H, Shi Y, Martorell R, Rozelle S. The effect of a micronutrient powder home fortification program on anaemia and cognitive outcomes among young children in rural China: a cluster-randomized trial. BMC Public Health. 2017;17:738. doi:10.1186/s12889-017-4755-0

32. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71

33. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane handbook for systematic reviews of interventions. 2nd ed. Chichester: John Wiley & Sons; 2019.

34. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924–6. doi:10.1136/bmj.39489.470347.AD

35. Rauh-Pfeiffer A, Handel U, Demmelmair H, et al. Three-month B vitamin supplementation in preschool children affects folate status and homocysteine, but not cognitive performance. Eur J Nutr. 2014;53(5):1445–56. doi:10.1007/s00394-013-0646-4

36. Demmelmair H, Øyen J, Pickert T, et al. The effect of Atlantic salmon consumption on the cognitive performance of preschool children: a randomised controlled trial. Clin Nutr. 2019;38(6):2558–68. doi:10.1016/j.clnu.2018.11.033

37. Øyen J, Kvestad I, Midtbø LK, et al. Fatty fish intake and cognitive function: FINS-KIDS, a randomized controlled trial in preschool children. BMC Med. 2018;16(1):41.

doi:10.1186/s12916-018-1024-5

38. Metallinos-Katsaras E, Valassi-Adam E, Dewey KG, et al. Effect of iron supplementation on cognition in Greek preschoolers. Eur J Clin Nutr. 2004;58(11):1532–42. doi:10.1038/sj.ejcn.1602003

39. Ryan AS, Nelson EB. Assessing the effect of docosahexaenoic acid on cognitive functions in healthy preschool children: a randomised, placebo-controlled, double-blind study. Clin Pediatr (Phila). 2008;47(4):355–62. doi:10.1177/0009922807309419

40. Kvestad I, Vabø S, Kjellevold M, et al. Fatty fish, hair mercury and cognitive function in Norwegian preschool children: results from the randomized controlled trial FINS-KIDS. Environ Int. 2018;121(Pt 2):1098–105. doi:10.1016/j.envint.2018.10.037

41. Aboud FE, Bougma K, Lemma T, Marquis GS. Evaluation of the effects of iodised salt on the mental development of preschool-aged children: a cluster randomised trial in Northern Ethiopia. Matern Child Nutr. 2017;13(2):e12322. doi:10.1111/mcn.12322

42. Roy Choudhury D, Nair KM, Nagalla B, et al. Guava with an institutional supplementary meal improves iron status of preschoolers: a cluster-randomized controlled trial. Ann N Y Acad Sci. 2021;1492(1):82–95. doi:10.1111/nyas.14565

43. Schneider N, Geiser E, Gosoniu LM, et al. A combined dietary and cognitive intervention in 3–5-year-old children in Indonesia: a randomized controlled trial. Nutrients. 2018;10(10):1394. doi:10.3390/nu10101394

44. Ogunlade AO, Kruger HS, Jerling JC, et al. Point-of-use micronutrient fortification: lessons learned in implementing a preschool-based pilot trial in South Africa. Int J Food Sci Nutr. 2011;62(1):1–16. doi:10.3109/09637480903455943

45. Black MM, Fernández-Rao S, Nair KM, et al. A randomized multiple micronutrient powder fortification trial in Indian preschoolers increases expressive language and reduces anaemia. J Nutr. 2021;151(7):2029–42. doi:10.1093/jn/nxab111

46. Roberts SB, Franceschini MA, Silver RE, et al. Effects of food supplementation on cognitive function, cerebral blood flow, and nutritional status in young children at risk of undernutrition: a randomized controlled trial. BMJ. 2020;370:m2397.

doi:10.1136/bmj.m2397

47. Luo R, Yue A, Zhou H, Shi Y, et al. The effect of a micronutrient powder home fortification program on anaemia and cognitive outcomes among young children in rural China: a cluster randomized trial. BMC Public Health. 2017;17:738. doi:10.1186/s12889-017-4755-0

48. Murray-Kolb LE, Khatry SK, Katz J, et al. Preschool micronutrient supplementation effects on intellectual and motor function in school-aged Nepalese children. Arch Pediatr Adolesc Med. 2012;166(5):404–10. doi:10.1001/archpediatrics.2011.219

49. Hamadani JD, Huda SN, Khatun F, Grantham-McGregor SM. Psychosocial stimulation improves the development of undernourished children in rural Bangladesh. J Nutr. 2006;136(10):2645–52. doi:10.1093/jn/136.10.2645

50. Fiorentino M, Perignon M, Kuong K, et al. Effect of multi-micronutrient-fortified rice on cognitive performance depends on premix composition and cognitive function tested: results of an effectiveness study in Cambodian schoolchildren. Public Health Nutr. 2018;21(4):816–27. doi:10.1017/S1368980017003035

51. Sachdev HPS, Gera T, Nestel P. Effect of iron supplementation on mental and motor development in children: systematic review of randomized controlled trials. Public Health Nutr. 2005;8(2):117–32. doi:10.1079/PHN2004677

52. Lam LF, Lawlis TR. Feeding the brain – the effects of micronutrient interventions on cognitive performance among school-aged children: a systematic review of randomized controlled trials. Clin Nutr. 2017;36(4):1007–14. doi:10.1016/j.clnu.2016.06.013

53. Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. Developmental potential in the first 5 years for children in developing countries. Lancet. 2007;369(9555):60–70. doi:10.1016/S0140-6736(07)60032-4

54. Stith AY, Gorman KS, Choudhury N. The effects of psychosocial risk and gender on school attainment in Guatemala. Appl Psychol. 2003;52(4):614–29. doi:10.1111/1464-0597.00152

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All data generated or analysed during this study are included in this published article. Additional details are available from the corresponding author upon reasonable request.

Author Contributions

- **(F.M) Fatima Mohamed (She):** Led the conceptualization of the study, carried out the literature review, and prepared the first draft of the manuscript. She also contributed to the overall design, took part in the systematic search, and assisted in data extraction.
- **(M.E) Maram Elnawrani (She):** Served as the corresponding author, managed all communications with the journal, and supervised the research process. She critically revised the manuscript for intellectual content, contributed to data extraction, and resolved discrepancies during the review process.
- **(M.M) Maria Mohammed (She):** Contributed to data collection and methodology development, supported the systematic search, and assisted in revising and editing the manuscript. She also took part in quality assessment using the Cochrane tool.

- **(L.A) Leen Al-Zghoul (She):** Conducted the statistical analysis, contributed to the interpretation of findings, and reviewed the final draft for accuracy. She also participated in the synthesis of results and risk of bias evaluation.

Ethics Statement

This study is a systematic review of published literature and did not involve human participants, patient data, or animals. Therefore, ethical approval and informed consent were not required.