# A Systematic Review Exploring the impact of Human Milk on Neurocognitive domains of development

## A Comprehensive Analysis

*Impact of Human Milk on Neurocognitive Development*

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*Abstract*—
**Background:** Human milk has been linked to enhanced brain development, yet evidence of comprehensive research regarding the effects of Human Milk on Neurocognitive outcomes is lacking. This paper aims to fill that gap by systematically examining the influence of Breast milk on Neurocognitive functioning. **Objective:** To provide a comprehensive analysis of the impact of human milk on neurocognitive development, to inform pediatric care practices, parental counselling and recommendations to enhance research credibility in the area. **Methodology:** This systematic review was conducted in line with PRISMA guidelines. Electronic searches were performed in PubMed, Scopus, MEDLINE, MDPI, SCI, and CLIB for studies published between 2021 and 2025 using predefined keywords. Eligible designs included randomised controlled trials, cohort and cross-sectional studies, longitudinal analyses, secondary data reviews, and peer-reviewed narrative reviews. Only English-language human studies were included; animal studies and conference abstracts were excluded. Two reviewers independently screened and assessed the studies for inclusion. **Results:** Twenty studies met the criteria. Across various methodologies, human milk intake has consistently shown a positive association with neurocognitive outcomes. Reported benefits included better Early Childhood Development scores, higher IQ scores, improved white matter integrity, greater hippocampal grey matter volume, higher power spectral density, and favourable overall brain structural measures. **Conclusion:** While current evidence supports Breastfeeding as a positive influence on neurodevelopment, further high-quality, longitudinal studies are needed to disentangle biological effects from sociodemographic factors and to clarify the long-term impact into adolescence and adulthood.

***Keywords***—Breast milk, Human milk, Cognitive function, Intellect, Development

### 1. INTRODUCTION

- Human Breast milk is recognised for its substantial benefits in promoting early health, supporting Neurocognitive development, enhancing immunity, lowering the risk of non-communicable diseases, and alleviating maternal postpartum depression. Drawing from recent scientific literature, this study highlights the beneficial effects of Breast milk on children's overall Neurocognitive wellness. The fats found in Human Milk play a crucial role in supporting growth, regulating inflammation, aiding immune responses, and contributing to the advancement of vision, cognitive abilities, and motor skills in infants.[1] Importantly, Docosahexaenoic acid (DHA) and Arachidonic acid, both components of Breast milk, are vital for optimal brain development during times of accelerated neural growth. Furthermore, myo-inositol present in Breast milk has been shown to boost the quantity and size of synapses, thereby strengthening communication between neurons in the brain. [2]
- While these results are encouraging, there remains a lack of comprehensive research regarding the effects of Human Milk on Neurocognitive outcomes. This paper aims to fill that gap by systematically examining the particular influence of Breast milk on Neurocognitive functioning.

### 2. MATERIALS & METHODS

**PROSPERO 2025 CRD420251137726. Available from https://www.crd.york.ac.uk/PROSPERO/view/CRD420251137726.**

#### 2.1 Review Objective

To provide a comprehensive analysis of the impact of human milk on neurocognitive development, informing pediatric care practices, parental counselling, and recommendations to enhance research credibility in the area.

### 2.2 Search Strategy and Data Collection

This review was carried out following the PRISMA (Transparent Reporting of Systematic Reviews and Meta-Analyses) guidelines.[3] The analysis explores links between consumption of Human Milk and Neurocognitive development, drawing together studies published from 2021 onwards to evaluate potential cognitive advantages associated with Breast milk. Researchers conducted a systematic search across electronic databases such as PubMed, Scopus, MEDLINE, MDPI, SCI, and CLIB-The Cochrane Library, employing keywords like "Breast milk," "Human Milk," "Cognitive function," "Intellect," and "Development". After screening, 20 manuscripts were selected for in-depth analysis.

### 2.3 Study Selection

The selection process involved screening titles, abstracts, and full-text articles by independent researchers. Each article underwent a comprehensive review to assess its alignment with the study objectives. Studies were included if they addressed topics related to Breast milk and its impact on Neurocognitive enhancement, memory, cognitive function, developmental milestones, IQ, or cognition, and were published in English. No temporal limitations were applied during the search. Following the application of exclusion criteria, 20 articles were ultimately incorporated into the systematic review, as detailed in Table 1. The PRISMA flowchart for the process is presented in Figure 1.

#### 2.3.1 Inclusion criteria

Included studies met the following criteria:

- Participants aged 0–19 years, regardless of gestational age or birth weight.
- The intervention employed was Human breast milk.
- Studies comprising Soy milk, Infant formula, and Fortified milk used as a comparator.
- Breastfed infants generally demonstrate modest but consistent outcomes in measures of cognitive performance, language development, and academic achievement compared to those fed with formula, soy milk, and fortified milk.
- The time frame for assessing the effect spanned from 2 months to 16 years of age.

#### 2.3.2 Exclusion criteria

Excluded studies met the following criteria:

- Studies including all ages where data for those aged 0-19 years are not separately reported.
- Mixed feeding (breast milk with other milk) and milk other than Human milk as the study intervention.
- Multiple milk types assessed in the same participants.
- All studies involving routes of drug administration other than oral delivery were excluded.
- Excludes studies focused only on behavior, temperament, or isolated motor skills due to limited relevance to long-term neurodevelopment or cognition.

#### 2.3.3 Data Extraction

Data extraction was conducted in accordance with a standardised protocol to maintain consistency and accuracy across all included studies. Key information gathered encompassed the criteria for selecting pertinent research articles, study designs, evaluation instruments, parameters employed in the assessment of neurocognitive function, timing of assessments, and methodologies used for outcome evaluation.

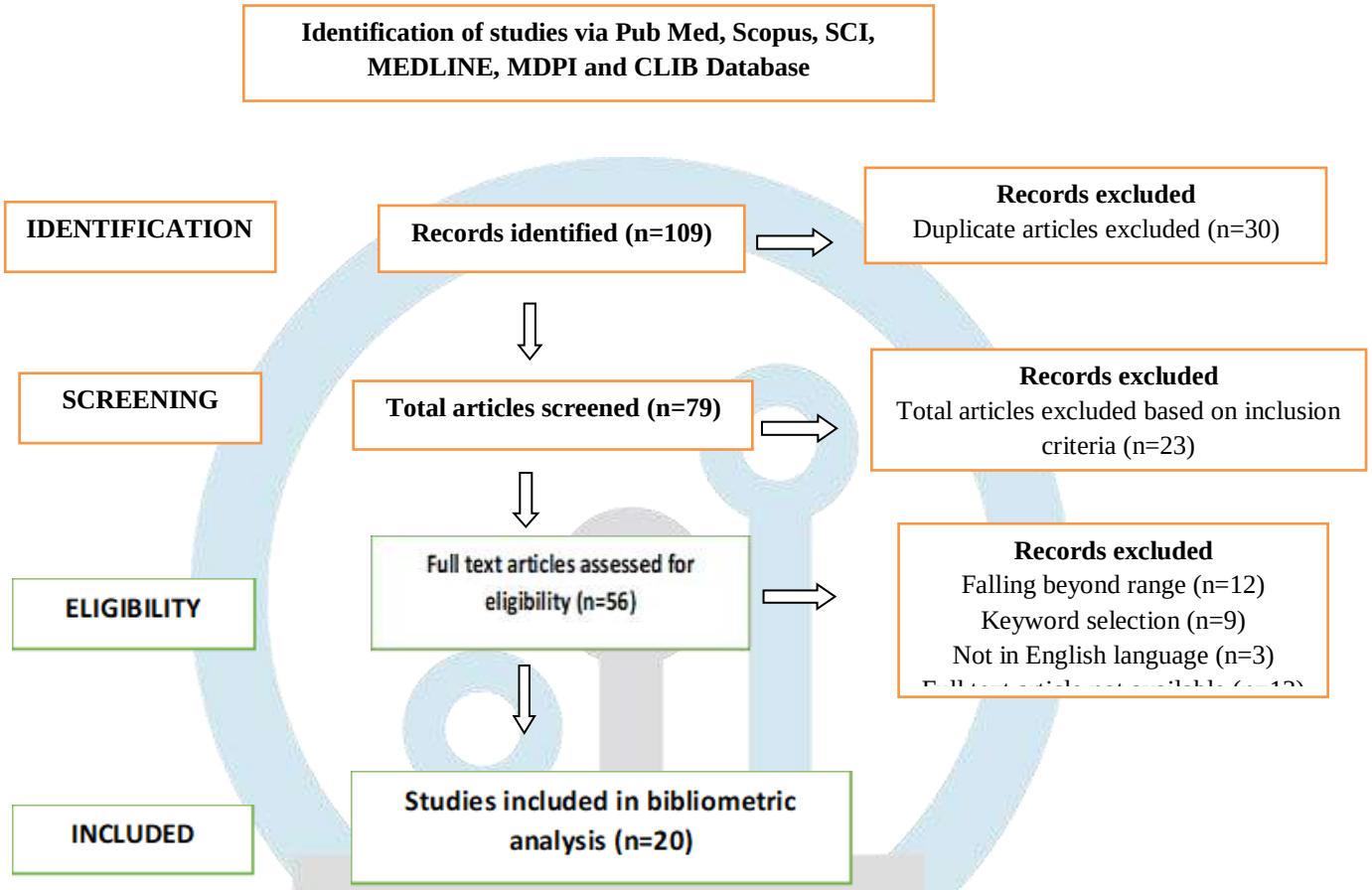


**Figure 1: PRISMA flow diagram of the literature screening process**

## 3. DISCUSSION

A total of 109 records were retrieved through searches of the PubMed, Scopus, MEDLINE, CLIB, MDPI and SCI databases. Following duplicate removal, 79 articles remained for further screening. The titles and abstracts of these 79 records were examined to assess relevance to the research topic. During this initial evaluation, 23 records were excluded because they did not meet the predefined inclusion criteria related to Neurocognitive function. The full texts of the remaining 56 articles were then assessed for eligibility. Of these, 36 records were excluded for the following reasons: 12 had publication dates outside the target range, 9 lacked the required keywords, 3 were not published in English, and 12 had unavailable full texts. Ultimately, 20 studies satisfied all eligibility criteria and were included in the analysis.

**Table 1: Studies selected for the Systematic review**

| Sr. no | Title | Sample size | Study design | Inclusion criteria | Assessment Point (age in years) | Result | Reference |
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| 1 | Association between breastfeeding during infancy and white matter microstructure in early childhood | n=85 | Observational Cohort Study | Full-term birth (>37 weeks' gestation), Birthweight >2500 grams, Living in the Calgary area Ability to speak English as a primary language | At 2.34 & at 6.97 years of age | Infants who are exclusively breastfed demonstrate enhanced development of global and regional white matter microstructure compared to those receiving infant formula. | Kar et al, 2021, Canada[4] |
| 2 | Breastfeeding, Physical | not mentio | Observational | Data from the ongoing Prospective Western Region | At 3 years of age | There was a 0.4-SD mprovement in overall child | Wallenborn et al, |

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| | Growth, and Cognitive Development | ned | Prospectiv e Birth Cohort | Birth cohort. | | development (β = .38, confidence limit: 0.23–0.53), a 0.6-SD increase in height-for-age z score (β = .55, confidence limit: 0.31–0.79), and a 67% reduction in stunting odds (odds ratio = 0.33, 95% CI: 0.20–0.54). | 2021, Sao Paulo, Brazil, South America[5] |
| 3 | Human milk and brain development in infants | not mentio ned | Review Study | Preterm infants (e.g., very preterm infants born between weeks 23-27), term infants, or a mix of both | not mentioned | The identification of stem cells, the incorporation of protein molecules, and the introduction of novel microRNA molecules in human milk all underscore the essential role of human milk in early life nutrition. The discovery of stem cells. | Chiurazzi et al, 2021, Switzerland[6] |
| 4. | Feeding Infants at the Breast or Feeding Expressed Human Milk: Long-Term Cognitive, Executive Function, and Eating Behavior Outcomes at Age 6 Years | n= 285 | Observatio nal Prospectiv e Cohort Study | The Moms2Moms cohort (Ohio, US) reported infant feeding practices. | At 6 years of age | Each additional month of exclusive breastfeeding was linked to a lower risk of executive function (working memory) deficit, with an adjusted relative risk of 0.78 (95% CI 0.63-0.96). | Keim et al, 2021, Ohio, US[7] |
| 5 | Influence of exclusive breastfeeding on hippocampal structure, satiety responsivenes s, and weight status. | n= 149 | Secondary Data Analysis Report | 7–11-year-olds who participated in one of five studies that assessed neural responses to food cues. | not mentioned | Extended periods of exclusive breastfeeding were correlated with increased grey matter volumes in both hippocampal regions | Higgins et al, 2022, USA[8] |
| 6 | Human Breast Milk: The Key Role in the Maturation of Immune, Gastrointestin al and Central Nervous Systems: A Narrative Review | not specifi ed | Narrative review | Included publications exploring the roles of Human Breast milk in the development of VPIs (very pre-term infants aging <32 weeks of gestation). | not mentioned | Human breast milk plays an essential role in conferring passive immunity, fostering optimal gastrointestinal development, and facilitating neurological maturation, all of which contribute to the overall health and resilience of the infant. | Dimitroglou, et al, 2022, Athens, Greece [9] |
| 7 | Influence of exclusive breastfeeding on hippocampal | n= 536 | Observatio nal Cohort Study | Infants < 6 months of age who were fed with Breast milk, Soy formula, and EEG recordings | At 2 & 6 months of age | BF infants had higher global beta and gamma power at both 2 and 6 months. This variation was also noted in source space, suggesting | Gilbreath et al, 2023, USA[10] |

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| | structure, satiety responsiveness, and weight status | | | | | regional differences in brain activity, especially in the frontal cortex. | |
| 8 | Associations of breastfeeding duration and cognitive development from childhood to middle adolescence. | n= 8643, 8560, 6213 | Secondary Data Analysis | Children aged 5-15 years | At 5, 7, 9, 11, and 15 years of age | Extended breastfeeding duration demonstrated a significant association with enhanced language skills between ages 5 and 9 (0.05 [95% CI, 0.03-0.08], $p < 0.0001$) and improved non-verbal intelligence from ages 7 to 11 (0.02 [95% CI, 0.01-0.04], $p < 0.001$). No significant correlation was observed between breastfeeding duration and executive functioning in individuals at age 15. | ILovcevic et al, 2023, Australia[11] |
| 9 | Potential Epigenetic Effects of Human Milk on Infants' Neurodevelopment | n= 122 | Narrative review | All types of articles, articles published in PubMed, and which analyze the association between Human Milk consumption and neurodevelopmental outcomes in infants, particularly those exploring the role of bioactive components like microRNAs, long non-coding RNAs, and stem cells present in Breast milk. | not mentioned | The potential epigenetic influences of breast milk, attributable to its bioactive components such as non-coding RNA and stem cells, may account for the observed association between breast milk intake and enhanced neurodevelopmental outcomes. | Gialeli et al, 2023, Greece[12] |
| 10 | Human Milk Oligosaccharides and Infant Neurodevelopment: A Narrative Review | n= 35-659 | Narrative review | Included 06 Observational studies | At 6 & 24 months of age | In full-term infants, studies found that total and individual fucosylated and sialylated HMOs were positively associated with cognitive, language, and motor skill development between 18 and 24 months of age. In contrast, a single study involving preterm infants did not report any statistically significant associations in the full cohort. | Berger et al, 2023[13] |
| 11 | The Influence of Nutritional Status on Brain Development: Benefits of Exclusive Breastfeeding | n= 11 | Narrative review | Includes systematic reviews, narrative reviews, and observational studies that focused on the impact of exclusive Breastfeeding on Neurocognitive development in infants and young children. | not mentioned | Breast milk has a positive impact on brain development. It underscores the importance of conducting additional research to understand how Breastfeeding specifically influences neurodevelopment. | Chade et al, 2024, Brazil, South America[14] |
| 12 | Association | n=129 | Cross- | The inclusion criteria were: | not mentioned | Compared to children who | Zheng et al, |

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| | between breastfeeding duration and neurodevelopment in Chinese children aged 2 to 3 years | 0 | sectional survey | (1) healthy children who had lived locally at the survey site for more than 6 months (2) gestational age ≥ 37 weeks; (3) birth weight ≥ 2500 g (4) not a twin or multiple birth (5) having no serious illnesses or chronic health problems. (6) children aged 2–3 years | | were never breastfed, those breastfed for 7–12 months showed increases of 3.59 points in gross motor development, 3.73 points in fine motor skills, and 2.87 points in language development. Breastfeeding for over 12 months was linked to a 3.77-point improvement in fine motor skills | 2023, China[15] |
| 13 | Breastfeeding duration and brain-body development in 9-10-year-olds: modulating effect of socioeconomic levels | n = 7511 | Cross-sectional survey | Children aged 9-10 years old | At 9 years & 10 years of age | Extended duration of breastfeeding is correlated with reduced adiposity indices as well as increased cortical and subcortical gray matter volume and greater cortical surface area during peri-adolescence. . | Rajagopalan et al, 2024, Switzerland[16] |
| 14 | The impact of ever breastfeeding on children ages 12 to 36 months: A secondary data analysis of the standardization study of the Dominican system for evaluating early childhood development | n= 699 | Secondary Data analysis | Children aged 12-36 months of age SIMEDID (a screening tool) measures four areas of development: gross-motor, fine-motor, language, and socioemotional development | not mentioned | The results indicate that children who were ever breastfed demonstrated higher overall early childhood development (ECD) scores compared to those who were never breastfed, with language and fine motor development contributing most to this difference. The group that was never breastfed exhibited a higher risk of developmental delay in fine motor and socioemotional domains. | Vincitore et al, 2024, Dominican Republic, North America[17] |
| 15 | Advantages of breastfeeding for the mother-infant dyad | n= 63 articles | Review study | including observational studies, clinical trials, and meta-analysis studies in the English language. | not mentioned | For infants, it offers optimal nutrition, strengthens immunity, and lowers the risk of infections, obesity, allergies, and chronic diseases. For mothers, it supports faster postpartum recovery, aids weight loss, reduces risks of breast and ovarian cancers and heart disease, and strengthens emotional bonding. Together, these benefits foster a positive mother-infant relationship | Maciejewska et al, 2024, Poland [18] |
| 16 | Sustained breastfeeding associations | n=3810 | Observational Prospectiv | Initial recruitment at 9 & 10 years of age Follow up after 2 years, 11- | Collection of Breastfeeding duration data at | The duration of breastfeeding demonstrated a positive association with | González et al, 2025, Los Angeles, |

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| | with brain structure and cognition from late childhood to early adolescence | | e ongitudina l cohort | 12 years of age . | specific intervals, 0, 1–6, 7–12, and >12 months. | cortical thickness in 31 regions, surface area in 45 regions, and fluid cognition (all p values < 0.05). Additionally, greater cortical myelin was observed in four regions and increased at follow-up in 12 regions (all p values < 0.05). The relationship between breastfeeding and fluid cognition was mediated by surface area (β = 0.008, CIboot95% = 0.005, 0.012). | USA[19] |
| 17 | Breastfeeding Duration and Child Development | n= 570532 childre n | Observatio nal Retrospecti ve cohort study | Participants were children born between January 2014 and December 2020 after at least 35 weeks' gestation without severe morbidity and with at least 1 follow-up surveillance visit at 2 to 3 years of age. | not mentioned | . In this cohort study, exclusive or extended breastfeeding was associated with lower odds of developmental delays as well as language or social neurodevelopmental conditions. | Goldshtein et al, 2025, Israel [20] |
| 18 | Exclusive breastfeeding modifies the association between maternal education and child development: a cross-sectional study nested in a cohort | n=269 | Cross-sectional study | Infants born with FTNVD Moderation analyses using the Mann-Whitney test examined the effect of EBF at 6 months (effect modifier) on the relationship between Bayley-III cognitive, language, and motor scores, as well as Bayley Global Score (BGS) (outcomes), and maternal education (independent variable). | At 12 months of age | Exclusive breastfeeding (EBF) was significantly associated with higher cognitive ($p < 0.01$), language ($p < 0.02$), and Bayley Global Scores (BGS) ($p < 0.001$). EBF altered the impact of low maternal education (defined as less than 10 years and 10–12 years of education) on both cognitive scores and BGS. In mothers with more than 10 years of education, EBF was linked to a large effect size on the Bayley Global Score (r = 0.51) and a medium effect size in the cognitive domain (r = 0.38). | Ford et al, 2025, Brazil[21] |
| 19 | Breastfeeding and Health Outcomes for Infants and Children: A Systematic Review | n= ESRs (existin g system atic review ) =29 Primar y studies =145 | Systematic Review | Systematic literature searches in MEDLINE, Embase, and CINAHL for English-language articles published from 2006 to August 14, 2024. | not mentioned | There was no clear threshold of Breastfeeding duration that appeared to be most beneficial for any outcome | Patnode et al,2025, Portland, Oregon, USA[22] |
| 20 | Breastfeeding: The Multifaceted Impact on | n= 190 articles | Review study | Clinical studies, systematic reviews, and meta-analyses were included. | not mentioned | Breastfeeding has significant positive effects on both child development and maternal well-being, impacting | Purkiewicz et al, 2025, Poland, Europe[23] |

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| | Child Development and Maternal Well-Being | | | | | various aspects from neurological development and immune function to emotional and physical health. | |

### 3.2 Global Distribution of Studies

The included studies encompassed research from a global perspective, with the United States contributing the largest proportion of publications. Of the 20 studies reviewed, eight (40%) originated from the U.S., followed by three from Brazil (15%), two each from Poland and Switzerland (10% each), and one each from Canada, Greece, Australia, China, and Israel (5% each).

The predominance of U.S.-led research underscores significant investigation into the neuroprotective effects of breast milk within that country. Brazil emerged as the second most active contributor, indicating growing research engagement. Switzerland and Poland also made notable contributions, while countries such as Israel, China, Greece, Canada, and Australia were represented by single studies.

Overall, the geographic distribution demonstrates concentrated research activities in the United States and Brazil, with fewer studies emerging from other regions. This disparity underscores the need for increased research efforts in underrepresented areas to enhance the evidence base and ensure broader global relevance. Currently, the landscape remains weighted toward higher output from the United States and Brazil.

### 3.3 Evaluation metrics

The studies reviewing Breast milk and its influence on Neurocognitive development have applied multiple psychological test batteries, such as the Mann-Whitney Test, Bayley Global Scores, Area Deprivation Index (ADI), Early Childhood Development Questionnaire, Child Psychological Development Scale, medical imaging techniques like MRI scans, and electronic graphing tools including EEG, Spectro-microscopy, and gene ontology, as evaluation metrics for assessing neurocognitive abilities in human models. The neuropsychological domains assessed encompassed language milestones, socio-emotional maturity, fine motor skills, visual motor abilities, behavior, executive function, and eating behaviors. Additional advanced domains evaluated included hippocampal structure, fluid cognition, fractional anisotropy, total cortical surface area, total brain measures, and milk proteomics.

### 3.4 Summary of main findings

This systematic review and comprehensive analysis examined the impact of Breast milk on Neurocognitive domains of development. The review encompassed studies from the past five years, including 7 narrative reviews, 6 observational studies, 3 secondary analysis reports, 1 systematic review, and 3 cross-sectional studies.

We observed consistent evidence suggesting Breastfeeding, particularly exclusive and prolonged Breastfeeding, is positively associated with improved Neurocognitive outcomes in children. These findings reinforce existing recommendations for Breastfeeding in infants, highlighting its beneficial impact on higher brain functioning and decreasing the likelihood of developmental delay. While the magnitude of benefit may vary depending on genetic, socioeconomic, and environmental factors, most studies indicate that children who receive Breast milk tend to show better performance in measures of intelligence, fine motor milestones, language development, and academic achievement compared to those who are formula-fed. Additionally, the superiority of Breast milk in lowering adiposity indices, as well as increased cortical and subcortical gray matter volume and greater cortical surface area during peri-adolescence, underscores its crucial role in achieving optimal Neurocognitive outcomes during adolescence. The variability in demographic characteristics, testing times, and the diversity of assessments employed further complicated the analysis of this outcome. However, residual confounding factors (such as maternal education and home environment) cannot be completely excluded, and further high-quality longitudinal research is warranted to establish causal pathways.

### 3.5 Implications for practice

This systematic review provides robust support for current Breastfeeding recommendations, emphasizing its positive effects on cognitive abilities and reduced risk of neurodevelopmental disorders. Notably, our analysis demonstrates a clear association between Neurocognitive health and Human milk, a relationship that is increasingly concerning in the context of rising neurobehavioral disabilities. Recognizing breastfeeding as a modifiable determinant, it becomes imperative to enhance parental awareness of its neurodevelopmental benefits and to implement evidence-based strategies that increase breastfeeding prevalence, thereby mitigating associated risks

As Breastfeeding represents a modifiable factor, it is essential to educate parents on its neurodevelopmental benefits and to actively promote strategies that encourage increased Breastfeeding rates, which may serve to mitigate the associated risks.

## 4. CONCLUSION

The available evidence from a systematic review indicates that Human Milk plays a beneficial role in supporting Neurocognitive development in infants, particularly during the critical early years of life. Breastfed infants generally demonstrate modest but consistent advantages in measures of cognitive performance, language development, and academic achievement compared to those fed with formula. These benefits appear to be mediated not only by bioactive nutrients such as long-chain polyunsaturated fatty acids, oligosaccharides, and growth factors, but also by the psychosocial and environmental context of Breastfeeding. However, the magnitude of effect varies across studies due to differences in methodology, confounding variables (such as maternal education and socioeconomic status), and length of follow-up. While current evidence supports Breastfeeding as a positive influence on neurodevelopment, further high-quality, longitudinal studies are needed to disentangle biological effects from sociodemographic factors and to clarify the long-term impact into adolescence and adulthood.

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## 5. RECOMMENDATIONS

Implement randomized controlled trials where ethically possible (e.g., donor milk vs. formula in preterm infants) to establish causality rather than association. Examine how exclusivity, duration, and timing of Breastfeeding relate to Neurocognitive outcomes. Use experimental and animal models to clarify the biological pathways through which Human Milk impacts the brain. Furthermore, determining the minimum duration of Breastfeeding needed for measurable benefits may authenticate future research. Carefully account for socioeconomic status, parental IQ, maternal education, and home environment, which strongly influence cognitive outcomes. Use consistent, validated Neurocognitive assessment methods to improve comparability across studies. Finally, conducting large-scale, long-term follow-up studies to track cognitive outcomes from infancy through adolescence and into adulthood would enhance the credibility of the research.

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## 6. AUTHOR CONTRIBUTIONS

Conceptualisation S. A. A.; Methodology S. A. A.; Data curation and review, S. A. A., V. P.; Writing—original draft preparation, S. A. A.; Supervision, HP.S. All authors have read and agreed to the published version of the manuscript.

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