# Effects of health and nutrition on cognitive and behavioural development in children in the first three years of life

# Part 1: Low birthweight, breastfeeding, and protein-energy malnutrition

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## Abstract

*The following paper and its accompanying paper (Grantham-McGregor SM, et al. Effects of health and nutrition on cognitive and behavioural development in children in the first three years of life. Part 2: Infections and micronutrient deficiencies: iodine, iron, and zinc. Food Nutr Bull 1999;20:76–99) review the literature on the conditions that are prevalent and considered to be likely to affect child development and are therefore of public health importance. The reviews are selective, and we have generally focused on recent work, particularly in areas that remain controversial. The reviews are restricted to nutritional and health insults that are important in the first three years of life. Where possible, we have discussed the better studies. This paper considers the effects of low birthweight (focusing on small-for-gestational-age babies) and early childhood protein-energy malnutrition on mental, motor, and behavioural development. We have also included a section on breastfeeding because of its importance to child health and nutrition programmes.*

## Introduction

In developing countries, millions of young children suffer from nutritional deficiencies and frequent infections. There is now a large and increasing body of evidence to indicate that nutrition and health affect children's cognitive, motor, and behavioural development, both pre- and postnatally. The impact of a biological insult depends on the stage of a child's development, as well as the severity and duration of the insult. However, because nutritional deficiencies and infections frequently occur together, the problems resulting from any one insult may be exacerbated by the presence of another, and the effects can be cumulative.

The situation is further complicated in that children who suffer from nutritional deficiencies and infections usually come from poor sociocultural environments and suffer from a myriad of deprivations and disadvantages that could themselves be detrimental to intellectual and behavioural development [1, 2]. These conditions include poor physical resources, such as overcrowded homes with poor sanitation and water supply, few household possessions, and low income. In addition, parents may have limited education and intelligence, and little knowledge of child development and the importance of play [1]; they may also suffer from depression [3]. Stimulation in the home is generally poor, with few toys or books and infrequent participation by the parents in play activities. Since nutritional deficiencies nearly always occur in the presence of these disadvantages, demonstrating a direct causal link between poor nutrition and poor development is difficult and requires a randomized controlled trial in which nutrition supplementation is given to undernourished children. Although establishing independent causality is important, it may not reflect the real-life situation, because there is increasing evidence that interactions exist among environmental conditions, a child's biological status, and various biological insults. Thus, in order to understand the true situation, these many factors should be studied together.

In studies evaluating the effects of poor nutrition on a child's development, investigators traditionally focus on motor and cognitive development. However, it is critical to evaluate social and emotional development as well, because these factors may be equally, if not more, important to an individual's success in life.

## Low birthweight

Almost 25 million low-birthweight (LBW) infants (<2,500 g) are born each year, 95% of them in developing countries [4]. In developing countries, LBW infants are more likely to be born at term than those in

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developed countries and more likely to be small due to intrauterine growth retardation (IUGR) secondary to maternal undernutrition and infection [5]. The diagnosis of IUGR requires longitudinal measures of intrauterine growth. As these are rarely available in low-income countries, we will restrict this review to infants born at term but small for gestational age (SGA).

A recent review of 80 studies, mostly in developed countries, showed that LBW children generally have poorer levels of development than normal-birthweight (NBW) infants [6]. Fewer studies exist of SGA infants, and they suffer from many design problems. Probably the greatest problem is that researchers have used different definitions for SGA, and there is no generally accepted definition, although the World Health Organization (WHO) recommends using the 10th centile for gestational age [7]. There are also several confounding variables that are frequently not taken into account adequately. SGA babies have a greater incidence of perinatal complications than NBW babies [8, 9], which may detrimentally affect their subsequent development [10]; they also come from poorer homes than NBW children and are less likely to be breastfed. A further problem is that samples of SGA children have often been small and had a large percentage of drop-outs [11, 12] that is often biased [13]. The babies from the poorest homes and those who have the poorest development are the most likely to drop out. It is surprising that so few studies have been undertaken in developing countries, where SGA infants are more common and the children are exposed to more deprived environments, so that their development may be very different. All aspects of the development of SGA babies were recently reviewed at a meeting of the International Dietary Energy Consultative Group [14–17]. SGA infants were found to suffer from more infections and higher mortality rates in the first year of life than NBW babies [18].

## Studies of children in the first two years

Most studies evaluating SGA children before 12 months have failed to find differences in developmental levels between SGA and NBW infants [19–22] (table 1) [15, 19–24]. However, a recent Brazilian study showed that SGA babies scored significantly lower on the Bayley mental and motor subscales at 6 months and that the difference increased by 12 months [15].

Four other studies compared SGA and NBW children between 12 and 24 months, and all found deficits in the mental development of SGA children [20, 21, 23, 24], but in most cases the differences were attributed to particularly vulnerable subgroups. For instance, in a study of American toddlers, only male or African-American SGA children showed a deficit [23]. Others reported that the deficits were almost entirely found in children who had neonatal asphyxia or congenital anomalies [24], and that children with birthweights below 2,300 g were entirely responsible for the deficits in the SGA group [21]. In the remaining study, the difference between groups was only significant in those who had appropriate ponderal indices (API) at birth, indicating that the foetus may have been undernourished in early pregnancy [20].

## Studies of children two to seven years of age

Some studies followed the children for several years, and the findings sometimes changed with the age of follow-up. In American children who were assessed at 4, 5, and 7 years of age, IQ, language development, and reading readiness were worse in LBW children when gestational age was controlled for, even without differences at 8 months of age [19]. Similarly, SGA Guatemalan children who had not been different from NBW children before 12 months had significantly poorer developmental levels in their second year and had lower scores on a cognitive battery verbal factor score than the NBW group at 3 years of age [20, 26]. Differences between the groups disappeared on subsequent evaluations at 4 and 5 years [26].

Details of studies of children 3 to 8 years of age, mostly from developed countries, are given in table 2 [11, 17, 20, 26–31]. Children who were SGA generally performed worse than those who were NBW in tests of cognition [20, 26], IQ [11, 17, 28–32], and language [27]. In two studies the SGA group performed worse than the NBW group, but the difference did not reach significant levels, perhaps because the sample sizes were small [28, 31].

## Studies of children 7 to 17 years of age

Hack's comprehensive review [16] identified 12 long-term follow-up studies of SGA children under 18 years of age, all but one [33] from developed countries. All studies in which IQ was measured showed that SGA children had lower scores [34–36] or higher rates of mental retardation [37] or learning deficits [38] than adolescents who were NBW, although the differences were sometimes small and not significant [39]. Studies of older adolescents or adults have had inconsistent findings and suffer from a large number of drop-outs [16].

The only other study from a developing country in which SGA children were followed up to this age was in Guatemala; surprisingly, no long-term effects of SGA on cognition were found [40]. It may be that the definition used for SGA (10th centile for gestational age) is too high for an index of risk or that undernutrition and other disadvantages in childhood overwhelm the relatively small effect of SGA. One study attempted to

TABLE 1. Studies of term SGA babies in the first two years of life

| Study | Definition | SGA | NBW | Age at follow-up (mo) | Tests | Results |
|---|---|---|---|---|---|---|
| Rubin et al. (1973) USA [19] | >2,500 g | 46 | 85 | 8 | Bayley | NS |
| Parmelee & Schulte (1970) Germany [22] | 10th centile | 22 | 25 | 10 | Gesell | NS |
| Nelson et al. (1996) USA [23] | 15th centile | 373 | 576 | 12 | Fagan<br>Bayley PDI* | NS<br>MDI NS |
| Low et al. (1978) Canada [21] | 10th centile (6 preterm) | 86 | 97 | 612 | Bayley<br>Bayley & Behaviour | NS<br>PDI*, MDI* activity* & energy |
| Villar et al. (1984) Guatemala [20] | 10th centile | 59 | 146 | 6, 15<br>24 | Infant scales<br>Infant scales | NS<br>SGA, API infants' MDI*, PDI NS |
| Tenovuo et al. (1988) Finland [24] | 2.5 centile | 519 | 3,375 | 24 | Denver & abnormal* | More doubtful |
| Grantham-McGregor (1998) Brazil [25] | >2,500g | 131 | 131 | 612 | Bayley<br>Bayley Behaviour | PDI* & MDI*<br>PDI* & MDI* Less happy* cooperative*, responsive*, & vocal* |

* SGA significantly lower or worse than NBW.

Abbreviations: API, appropriate ponderal index; LPI, low ponderal index; MDI, mental development index of the Bayley Scale; NBW, normal birthweight; NS, not significant; PDI, psychomotor development index of the Bayley Scale; SGA, small for gestational age.

Source: modified from ref. 15.

address this point [31]; Indian children who were chronically undernourished and were LBW were compared with similarly undernourished children who were NBW. The groups' scores on cognitive tests were not significantly different, but the LBW group's scores were consistently lower, suggesting that a small disadvantage remained. However, further research on this point is needed for more certainty. Both groups' scores were markedly lower than a third of the adequately nourished group.

## Other outcomes

Apart from poorer cognition, SGA children have other disadvantages. Few studies have looked at behaviour, but most of those that have looked at behaviour have found behavioural differences. In the first two years, SGA children were found to be less active, vocal, responsive, happy, and cooperative [15, 21]. At school age, they were more fidgety or active [39, 41], were more anxious and less happy [21, 41], and had a poor attention span [21, 39, 41]. These behaviours themselves could lead to poor development. More than half of the studies looking at school achievement found that SGA children performed less well than controls. They were also more likely to have minimal neurological dysfunction [17].

## Interactions with the environment

Several studies have found that birthweight interacts with other conditions and that generally the effects of SGA are greater in children from poor homes. In a recent study in Brazil [25], the development of SGA infants was affected by the stimulation in the home, whereas the development of NBW infants was not. Similarly, the SGA infants were detrimentally affected by

TABLE 2. Studies of term SGA children 3–8 years of age

| Study | Definition of SGA | Samples | Age (yr) | Tests | Results |
|---|---|---|---|---|---|
| Villar et al. (1984) Guatemala[20] | 10th centile API & LPI | 59 SGA 146 NBW | 3 | Cognitive battery | Both API* & LPI* lower than NBW, API lower than LPI in 7 of 8 tests |
| Gorman & Pollitt (1992) Guatemala [26] | 10th centile API | 41 SGA 85 NBW | 3–5 | Cognitive battery forming memory & verbal factors | Verbal factor score* Memory factor score*, SES SGA, & growth in 1st year SGA significant |
| Walther & Ramaekers (1982) Netherlands [27] | 10th centile, PI <10th centile | 25 SGA 25 NBW | 3 | Reynell language | SGA lower scores* |
| Pryor (1992) New Zealand [11] | 3rd centile 44 NBW | 67 SGA | 4 | Stanford-Binet | SGA lower IQ* |
| Babson & Kangas (1969) USA [28] | 2,000–2,700 g 43 NBW | 43 SGA | 4 | Stanford-Binet | NS |
| Fancourt et al. (1976) UK [29] | 10th centile & ultrasound | SGA; 13 IUGR <26 wk; 18 IUGR 26–34 wk; 10 IUGR >34 wk; 19 no IUGR | 4 | Griffiths | IUGR <26 wk significantly lower scores; other groups NS |
| Harvey et al. (1982) UK [30] | Same samples as above | 51 SGA 50 NBW | 5 | McCarthy scales | IUGR <26 wk significantly lower scores; other groups NS |
| Fitzhardinge & Steven (1972) Canada [31] | –2 SD 36 NBW siblings | 96 SGA, | 4 | Hearing, vision, speech | Increased speech & hearing problems* |
| | | | 4–8 | Stanford-Binet | NS |
| | | | | WISC | NS |
| | | | | School achievement | School failure increased in SGA* |
| Goldenberg et al. (1998) USA [17] | 15th centile | 196 SGA 303 NBW | 5 | WPPSI | SGA lower scores* |

* SGA significantly lower score than NBW.

Abbreviations: API, appropriate ponderal index; IUGR, intrauterine growth retardation; LPI, low ponderal index; NBW, normal birthweight; NS, not significant; PI, ponderal index; SES, socio-economic status; SGA, small for gestational age; WISC, Weschler Intelligence Scale for Children; WPPSI, Wechsler Preschool and Primary Scale of Intelligence.

Source: modified from ref. 15.

having illiterate mothers and frequent diarrhoea, whereas the NBW babies were not. This finding suggests that SGA babies are more vulnerable to the environment.

## Conclusions about the effects of IUGR on development

Studies of SGA have had many design problems, making it difficult to draw conclusions. Cognitive effects tend to vary by age; they are less likely to be apparent in the first year of life and more likely to be apparent in middle childhood. In developed countries, cognitive deficits are usually small but may be important on a population scale. In late adolescence and adulthood, the findings are inconsistent. In addition to poorer cognitive function, children often have behaviour problems, minimal neurological dysfunction, and poor school achievement. The effect of birthweight sometimes varies according to the quality of the environment and the health and nutrition of the child. There are only two long-term studies from developing countries, too few to draw any conclusions about the long-term effects of SGA. In view of the large number of children affected, more information is required.

From a policy perspective, these children are at risk for poor health and nutrition as well as poor development; therefore, integrated programmes including stimulation, health, and nutrition would be the most useful. Programmes of increased stimulation for LBW babies in early childhood have been successful in the United States [42, 43] and should be helpful in developing countries.

## Breastfeeding

According to UNICEF figures for 1990–1996, 44% of children in developing countries are exclusively breastfed from 0 to 3 months, 45% are breastfed while receiving complementary foods at 6 to 9 months, and 50% are still breastfed at 20 to 23 months [44]. Values from developing countries for exclusive breastfeeding up to 3 months range from 2% in Nigeria to 90% in Rwanda, whereas values for breastfeeding at later ages are much more consistent across countries. These data suggest that cultural, country-specific variables may influence the exclusivity but not the basic practice of breastfeeding.

## Study design

One major difficulty that emerges when comparing studies of the effects of breastfeeding on mental development and behaviour is defining what it means for a baby to have been breastfed. Several variables are critical, including length and exclusivity of breastfeeding. Whereas some studies have strict definitions and multiple possible categories for length and exclusivity, some use length of breastfeeding as a continuous variable, some rely on dichotomous definitions with 1 day of breastfeeding valued the same as 6 months, and others compare exclusively, extensively breastfed with exclusively, extensively bottle-fed infants. The studies are also inconsistent in their reports of bottled-milk composition, making it difficult to compare direct nutrient intake and to make direct comparisons. Some studies compare babies who are breastfed with babies who are fed enriched pre-term formula, whereas others compare babies who are breastfed with babies fed unmodified, diluted cow's milk [45] or condensed milk [46].

The studies are also difficult to compare because they vary in their exclusion criteria, with some studies setting particular cut-offs for birthweight, Apgar scores (an indicator of intrapartum stress, comprising a rating of colour, tone, irritability, heart rate, and respiratory effort of the baby at birth), gestational age, or health at birth, and others including all children born during a particular time period. If these factors are not controlled for in the study design, bias may be introduced, because children who are sick at birth are less likely to breastfeed. Similarly, the studies vary in terms of their inclusion of covariates in the analyses. Breastfeeding is positively correlated with several familial characteristics, including maternal education level [47–49], paternal education level [45], maternal age [50], and socio-economic status [45, 47, 50–56], and is negatively correlated with family size [45, 48], birth rank [45], maternal smoking [48, 54], and crowding [51, 52]. Since these factors have been shown to have an independent, positive effect on cognition and development [57], it is difficult to separate the direct effects of breastfeeding from the indirect effects of the familial characteristics associated with breastfeeding. Although some studies have attempted to control for these variables in design and analyses, most studies have included only a limited number of these factors.

With these limitations in mind, studies of the effects of breastfeeding on mental and behavioural development will be reviewed. All studies reviewed tested the basic hypothesis that breastfed infants have advantages over bottle-fed infants. The review is divided into short-term (0–24 months) and long-term (3–50 years) effects of breastfeeding. We have presented detailed information about each study in the tables and limited discussion in the text to the main points only. Mechanisms will also be discussed, followed by conclusions and programmatic implications of the current data.

## Short-term effects of breastfeeding

We found eight studies assessing the concurrent effects of breastfeeding on development; these papers review research on children 24 months old and younger (table 3) [Morris S, personal communication, 1998; 49; 52; 54; 56; 58–60]. Most studies in this category used correlational analyses, which means that there are limits to the conclusions that can be drawn from the data. However, the studies are comparable in their fairly consistent use of the Bayley Scale of Infant Development as the major outcome measure, although they varied in their use of the mental development (MDI) and psychomotor development (PDI) subscales. Some of these studies controlled extensively for socio-economic and maternal characteristics [Morris S, personal communication, 1998; 52; 54; 58], whereas others had limited measures [49, 56, 59, 60].

Of the five studies [Morris S, personal communication, 1998; 54; 56; 58; 59] evaluating infants at 6 months, two showed significant differences between infants who had been breastfed and those who had not [Morris S, personal communication, 1998; 54]. In all other studies, the breastfed infants scored higher, albeit non-

TABLE 3. Studies of the effects of breastfeeding on physical and mental development in children 0–2 years of age

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Morris (1998) Brazil [personal communication] | *n* = 208<br>BF: frequency of feeds recorded by observer<br>Born at ≥37 wk<br>Family income below set standard<br>No congenital or neurological abnormalities<br>Assessed at 6 & 12 mo | Bayley Scale (MDI & PDI)<br>Other variables: family income, household resources, housing/ sanitation/water index, parental literacy | 6 mo: positive correlation between MDI & average number of feeds in 1st 4 wk*; weaker correlation with PDI<br>12 mo: no association with control for SES |
| Young et al. (1982) Italy [56] | *n* = 1041 (divided analyses by sex, M/F)<br>VLBF: >7 mo<br>LBF: mixed (formula after 2 mo)<br>NBF: no BF<br>Retrospective study with infants divided into 3 SCs (high, middle, low)<br>Assessed at 6, 8, 10, 12, 14, 16 mo | Bayley Scale (MDI & PDI)<br>General physical examination<br>SC | VLBF> LBF & NBF at all ages, variable significance<br>6 mo: NS<br>8 mo: $p<.02$ (M, low SC)<br>10 mo: $p<.05$ (F, high SC)<br>12 mo: $p<.05$ (F, low SC)<br>14 mo: $p<.01$ (F, low SC)<br>16 mo: $p<.05$ (F, low SC) |
| Morrow-Tlucak et al. (1988) USA [58] | *n* = 219<br>VLBF: >4 mo (*n* = 23)<br>LBF: 1 wk–4 mo (*n* = 39)<br>NBF: no BF (*n* = 157)<br>Born at ≥37 wk<br>No neonatal problems<br>No maternal narcotic use<br>Assessed at 6, 12, 24 mo | Bayley Scale (MDI)<br>Home environment (HOME)<br>Other variables: maternal IQ (PPVT), maternal age, child-rearing techniques (authoritarian family ideology), race, birth order | VLBF>LBF>NBF at all ages, significant at 12 mo & 2 yr<br>No. of weeks of breastfeeding entered as continuous variable predicting MDI<br>6 mo: NS<br>12 mo: $p = .018$ (11.7% var.)<br>24 mo: $p = .009$ (5.6% var.)<br>Controlled for SES |
| Rogan & Gladen (1993) USA [59] | *n* = 855 at enrolment<br>*n* = 788 (6 mo), 720 (12 mo), 676 (18 mo), 670 (24 mo)<br>*n* values from enrollment:<br>VLBF: >20 wk BF (*n* = 177)<br>LBF: 5–19 wk BF (*n* = 294)<br>MBF: 0–4 wk BF, late weaning (*n* = 184)<br>SBF: 0–4 wk BF, early weaning (*n* = 97)<br>NBF: no BF (*n* = 103)<br>Assessed at 6, 12, 18, & 24 mo | Bayley Scale (MDI & PDI)<br>Other variables: maternal age, race, occupation, education, smoking, alcohol use<br>Child's sex, birthweight, birth order | All BF>NBF<br>6 mo: NS<br>12 mo: NS<br>18 mo: NS<br>24 mo: MDI*/PDI* when all covariates controlled for |

*continued on next page*

significantly, than non-breastfed infants.

Of the five studies assessing infants at 12 months, two found a clear, significant effect [54, 58], and one found an effect limited to girls of the lowest social class [56]. In the other two studies [59] (S. Morris, personal communication, 1998), although the breastfed infants had higher developmental scores, the difference was not significant. At 18 months, breastfed infants per-

TABLE 3. Studies of the effects of breastfeeding on physical and mental development in children 0–2 years of age *(continued)*

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Ounsted et al. (1988) UK [53] | *n* = 137 SGA<br>BF: any BF at all (*n* = 96–114)<br>NBF: no BF (*n* = 20–21)<br>BW < –2 SD below mean gestational age & sex<br>Assessed at 6 & 12 mo | Neurological development: "neurobehavioural score," "motor score," "social score" (assortment of various tests)<br>Other variables: maternal age, weight, height, smoking, & several factors about pregnancy, BW, birth order | Neurobehavioural score: 6 mo: BF>NBF*; 12 mo: BF>NBF*<br>Motor score: 12 mo: BF>NBF**<br>Social score: 12 mo: BF>NBF NS<br>No control for SES |
| Florey et al. (1995) UK [48] | *n* = 592<br>BF: any BF at all<br>NBF: no BF<br>Firstborn singletons<br>Stratified into 5 SCs<br>Assessed at 18 mo | Bayley Scale (MDI & PDI)<br>Other variables: maternal smoking & alcohol use, SC, education, age, height | MDI: BF>NBF for all SCs except V<br>PDI: no clear effect |
| Temboury et al. (1994) Spain [51] | *n* = 229<br>BF: ≥3 mo (*n* = 130)<br>NBF: BF <1 mo (*n* = 99)<br>Born at >36 wk<br>BW >2,400 g<br>Apgar >7<br>No major health problems<br>Assessed at 18–19 mo | Bayley Scale (MDI & PDI)<br>Other variables: SC (Graffard Test); mother's education, job, age, number of children, psychosocial risk; child's behaviour | Lower score on MDI predicted by bottle-feeding (OR = 1.97, *p* = .019)<br>Other significant factors: lower SC, having siblings, temper tantrums |
| Morley et al. (1988) UK [60] | *n* = 771 LBW<br>BF: mother's choice BF in 1st 72 h (*n* = 227–245)<br>NBF: mother's choice no BF in 1st 72 h (*n* = 469–513)<br>BW: <1,850 g<br>Assessed at 18 mo | Bayley MDI, DP II<br>Other variables: SC, parental occupation & education, birth rank | BF>NBF<br>MDI: 103.3>95.4***<br>DP: 108.3>101.5***<br>After inclusion of covariates, advantage of 4.3 points** |

* $p < .05$, ** $p < .01$, *** $p < .001$.

Abbreviations: BF, breastfeeding; BW, birthweight; DP, developmental profile; IQ, intelligence quotient, LBF, long breastfeeding; LBW, low-birthweight; MBF, moderate breastfeeding; MDI, mental development index of the Bayley Scale; NBF, no breastfeeding; NS, not significant; PDI, psychomotor development index of the Bayley Scale; PPVT, Peabody Picture Vocabulary Test; SBF, some breastfeeding; SC, social class; SES, socio-economic status; SGA, small for gestational age; VLBF, very long breastfeeding; VVLBF, very, very long breastfeeding.

formed significantly better than non-breastfed infants on the Bayley MDI [49, 52, 60], but not in all cases [59].

At 24 months, infants breastfed exclusively for more than 3 months appeared to have a significant advantage over non-breastfed infants, even when socio-economic variables were controlled for [52, 58, 59]. Although the socio-economic variables often made significant contributions to the children's development, the results suggest that breastfeeding had an independent effect. There is some evidence that a positive linear relationship exists between time of breastfeeding and test score [59].

In summary, breastfed infants appear to have a small but consistent advantage over non-breastfed infants in mental development at all time points up to 24 months. The effects are more consistently statistically significant at the later ages, although benefits were shown as early as 6 months in some studies. The reason for differential significance over time may be that the Bayley is not sensitive enough to detect developmental delays affected by breastfeeding in the first 12 months of life [61]. There is no clear evidence of a differential effect of breastfeeding in different social classes, because in some cases the higher social classes benefited [49, 56], whereas in others, the lower classes did [56].

## Long-term effects of breastfeeding

We located 14 papers evaluating the longitudinal effects of breastfeeding on mental development and behaviour, with assessments when the children were 4 to 18 years of age (table 4) [45–48, 50, 51, 53, 55, 59, 62–68]. In evaluating the longitudinal effects of breastfeeding, two additional problems emerge. First, it is difficult to validate breastfeeding recall techniques. Specifically, some studies have been careful to collect breastfeeding frequency data from many sources (e.g., hospital records, parental questionnaires), whereas others have relied solely on maternal recall several years later. Second, since the age range in this section is so large, the tests varied considerably. Although most of the studies included some general measure of IQ, the specific tests are not always comparable, and some looked only at neurological function [67] or behaviour [66].

All studies we found, which included follow-up of people 3 to 50 years old, indicated a small yet consistent developmental benefit to those who had been breastfed. In most studies, the benefit of breastfeeding remained significant with the inclusion of socio-economic factors as covariates [45, 48, 50, 51, 55, 59, 62, 68]. However, the results of some studies lost significance when socio-economic factors were taken into consideration [47, 51, 63], and some did not include any control for social factors in the analyses [46, 64, 65].

In order to compare the effect sizes of these studies, we calculated the difference between groups in terms of cognitive outcome as a percentage of the standard deviation. As is evident in figure 1, the effect of breastfeeding ranges from 6% to 66% SD, with an approximate mean of 22%. The largest effect [55] was evident in children born to mothers who had "high-risk" pregnancies, suggesting differential vulnerability to the effects of breastfeeding according to health status at birth. Extensive breastfeeding (>12 months) has been shown to have a detrimental effect on mental development when it is exclusive [46] but not when it is non-exclusive [51].

Unfortunately, no longitudinal studies have been undertaken in developing countries. It is very likely that the benefits of breastfeeding on mental and behavioural development may be greater in developing countries, particularly with poor formula alternatives.

## Mechanism

The benefits of breastfeeding may be a consequence of several different but related pathways. There may be a directly beneficial effect of the nutrient composition, particularly fatty acid consumption, or there may be indirect benefits from the increased immune response or mother–child interaction associated with breastfeeding.

### Fatty acids

The brain is composed largely of lipids, a large proportion of which are long-chain polyunsaturated fatty acids (PUFAs), which are critical because of their role in membrane phospholipid composition (reviewed in [69]). The most important PUFAs are docosahexaenoic acid (DHA, 22:6n-3) and arachidonic acid (AA, 20:4n-6), which are derived from the parent compounds linoleic acid (LA, 18:2n-6) and linolenic acid (LnA, 18:3n-3). During the last trimester of pregnancy and for many months after birth, the uptake of DHA and AA by the fetal brain and retina increases dramatically in humans [70]. LA and LnA are considered essential fatty acids (EFA) because they cannot be synthesized de novo in any mammals and must be provided in the diet.

Breastmilk is a rich source of EFAs [71]. In contrast, EFA concentration in formula is generally insufficient for infants [72, 73], as evidenced by studies showing

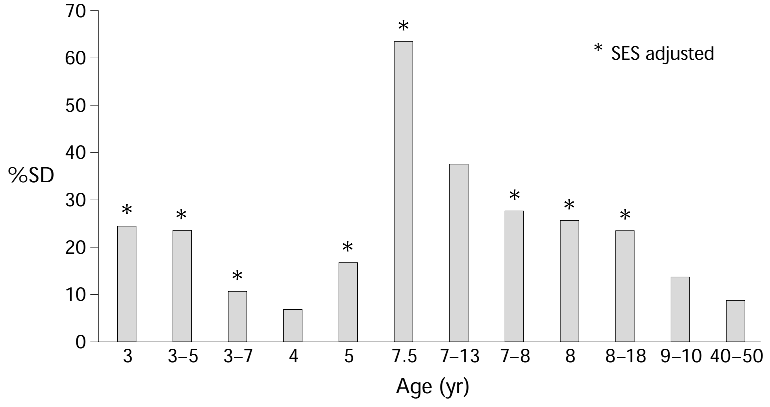


FIG. 1. Long-term effects of breastfeeding. The figure shows the difference in IQ between breastfed and non-breastfed children expressed in standard scores [45–48, 50, 51, 53, 55, 59, 62, 63, 68]

TABLE 4. Studies of the long-term effects of breastfeeding (organized by age of assessment)

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Niemelä & Järvenpää (1996) Sweden[47] | $n = 726$<br>LBF: ≥5 mo BF ($n = 363$)<br>SBF: <5 mo BF ($n = 363$)<br>Born at term, hospital <14 days, no chronic disease or "severe anomaly"<br>Groups matched for sex & maternal education<br>Assessed at 56 mo | General cognitive capacity<br>1. Non-verbal (Columbian Mental Maturity Scale)<br>2. Visual motor-integration (Beery Test)<br>3. Active vocabulary<br>Other variables:maternal education, parents' living status, maternal smoking habits | LBF > SBF<br>1. 50.0 > 47.6**<br>2. 7.5 > 7.1*<br>3. 50.5 > 49.5<br>With control for SES |
| Rogan & Gladen (1993) USA [59] | $n = 855$ at enrollment<br>$n = 645$ (3 yr), 628 (4 yr), 636 (5 yr)<br>($n$ values from enrollment)<br>VLBF: >20 wk BF ($n = 177$)<br>LBF: 5–19 wk BF ($n = 294$)<br>MBF: 0–4 wk BF, late wean ($n = 184$)<br>SBF: 0–4 wk BF, early wean ($n = 97$)<br>NBF: no BF ($n = 103$)<br>Assessed at 3, 4, 5, 7, 8–10 yr | Mental development:<br>McCarthy (3, 4, & 5 yr)<br>Report cards (8–10 yr)<br>Other variables: maternal age, race, occupation, education, smoking, alcohol use. Child's sex, BW, birth order. Prenatal exposure to polychlorinated biphenyls & dichlorodiphenyl dichloroethane | Any BF always > NBF in McCarthy & report cards, higher scores associated with increased BF<br>Controlled for SES |
| Fergusson et al. (1982) New Zealand [62] | $n = 1,037$ (3 yr), 991 (5 yr), 954 (7 yr)<br>LBF: ≥4 mo BF ($n = ?$)<br>SBF: 0–4 mo BF ($n = ?$)<br>NBF: no BF ($n = ?$)<br>Assessed at 3, 5, 7 yr | Mental development<br>3 yr: PPVT; 5 yr: Stanford-Binet IQ; 7 yr: WISC<br>Language development<br>3 & 5 yr: Reynell Developmental Language Scales; 7 yr: Illinois Test of Psycholinguistic Abilities<br>Articulation 5 & 7 yr: Dunedin Articulation Screening Scale<br>Other variables: maternal intelligence, education level, training in child rearing, "child experiences," family SES, child's BW & gestational age | LBF > SBF > NBF for all unadjusted scores at all ages (LBF/NBF difference, 2–5 points)<br>Range of differences (from 3 tests adjusted for all other variables)<br>(LBF vs NBF): 3 yr, 1.85**–2.71***; 5 yr, 1.54**–2.53***; 7 yr, 0.63NS–2.31**<br>Difference between LBF & SBF NS |
| Jacobson & Jacobson (1992) USA [63] | $n = 323$<br>BF: 5 categories (not described, but average of 26 wk)<br>NBF: no BF<br>White, middle-class<br>Assessed at 4 yr | Mental development:<br>McCarthy Scales, PPVT-R<br>Other variables: maternal IQ, SES, parenting style, mother-child interaction | BF > NBF<br>McCarthy: 105.3 >100.7*<br>PPVT-R: 104.4 > 98.0*<br>NS after inclusion of maternal IQ & parenting score |

*continued on next page*

TABLE 4. Studies of the long-term effects of breastfeeding (organized by age of assessment) *(continued)*

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Taylor & Wadsworth (1984) UK [50] | *n* = 13,135<br>LBF: >3 mo BF<br>MBF: 1–3 mo BF<br>SBF: <1 mo BF<br>NBF: no BF<br>Assessed at 5 yr | Mental development (EPVT, copying designs)<br>Speech problems<br>Child behaviour (maternal report)<br>Other variables: child sex, BW, birth order, maternal age, smoking, "social index" | All BF > NBF in EPVT* & copying*<br>SES controls<br>No clear effect on behaviour or speech |
| Broad (1979) New Zealand [64] | *n* = 319<br>BF: not defined (*n* = 133)<br>NBF: not defined (*n* = 186)<br>Assessed at 5–6 yr | Speech ability<br>Reading ability | BF improves speech clarity***, tonal quality**, & reading ability* in boys<br>No difference in girls<br>No SES control |
| Pollock (1994) UK [65] | *n* = 3,838<br>BF: >3 mo exclusively (*n* = 353)<br>NBF: >3 mo bottle (*n* = 3,485)<br>Mother >17 yr, gestation >36 wk, BW >2,538 g, no incubation, father lives with baby<br>Assessed at 5 & 10 yr | Mental development<br>5 yr: EPVT, copying & drawing tests<br>10 yr: BAS, school achievement, EPVT<br>Other variables: huge number of socio-economic variables, e.g., parental background, education, "circumstance," pregnancy duration, labour intensity | 5 yr: EPVT score of BF above average for combined groups*; drawing & copying NS<br>10 yr: benefit in BAS*; school achievement NS<br>EPVT NS<br>No control for covariates |
| Fergusson et al. (1987) New Zealand [66] | *n*=772–1,064<br>Duration of BF<br>assessed at 6, 7, 8 yr | Child behaviour:<br>(Rutter Behaviour Questionnaire: conduct disorder, timidity, hyperactivity, social isolation)<br>Other variables: social background, maternal IQ, "stability" | Maternal rating: small association between increased BF & reduced levels of conduct disorder<br>Teacher rating: no consistent association |
| Hoefer & Hardy(1929) USA [46] | *n* = 383<br>VVLBF: 10–20 mo BF exclusively (*n* = 190)<br>LBF: 4–9 mo BF exclusively (*n* = 77)<br>MBF: ≤3 mo BF exclusively (*n* = 78)<br>NBF: no BF (*n* = 38)<br>Assessed at 7–13 yr | Mental development (IQ: Stanford-Binet, EQ: "educational quotient," PQ: Pintner-Patterson performance test of nonverbal intelligence)<br>Age of talking (mo) | LBF > NBF/MBF/VVLBF<br>IQ: 107.6 > 102.3/101.9/100.6<br>EQ: 112.1 > 106.5/109.6/105.5<br>PQ: 128.3 > 122.0/125.3/121.5<br>Talking: 13.7 < 15.2/13.7/14.5<br>No SES control |

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TABLE 4. Studies of the long-term effects of breastfeeding (organized by age of assessment) *(continued)*

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Ounsted et al. (1984) UK [55] | *n* = 239<br>BF: >2 mo BF (*n* = 21)<br>NBF: no BF (*n* = 218)<br>Study of "high-risk" pregnancies<br>Assessed at 7.5 yr | Mental development: (reading quotient, Holborn reading test, BAS, reasoning, spatial imagery, perceptual maturity, memory, retrieval knowledge)<br>Other variables: 15 maternal, foetal, perinatal, postnatal, & environmental factors | NBF associated with decreased scores on all mental development tests, with control for social class<br>Reading quotient*, "reasoning" subscale* when SES controlled |
| Lucas et al. (1992) UK [53] | *n* = 300 who had been LBW<br>BF: mother's choice BF in 1st 72 h (*n* = 227–245)<br>NBF: mother's choice no BF in 1st 72 h (*n* = 469–513)<br>BW: <1,850 g<br>No major congenital malformations<br>Assessed at 7.5–8 yr | WISC-R<br>Other variables: social class, parental occupation & education, birth rank, gestational age, mother's age, days of ventilation | BF > NBF when controlling for SES<br>Dose-related advantage |
| Rodgers (1978) UK [45] | *n* = 2101 (1st assessment)<br>*n* = 1961 (2nd assessment)<br>BF: BF exclusively (*n* = 1291) (95% had weaned by 12 mo)<br>NBF: no BF (*n* = 1133)<br>Singletons, born to married mother, bias to include those born to non-manual & agricultural workers<br>Assessed at 8 & 15 yr | 8 yr: picture intelligence, mechanical word reading<br>15 yr: reading attainment, sentence completion, non-verbal ability, mathematics<br>Other variables: BW, birth order, social class, parental educational background, parental interest in schooling, home conditions | When covariates controlled for:<br>8 yr: BF > NBF: picture intelligence***;<br>15 yr: BF > NBF: reading attainment***, sentence completion***, non-verbal ability***, mathematics*** |
| Lanting et al. (1994) Netherlands [67] | *n* = 526<br>BF: ≥3 wk BF exclusively (*n* = 135)<br>SBF: BF + formula <3 wk (*n* = 33)<br>NBF: no BF (*n* = 358)<br>Gestational age ≥37 wk<br>No admission to pediatric or neonatal ward after birth<br>Assessed at 9 yr | Neurological examination | BF rated better at follow-up neurological examination than (SBF & NBF)** |
| Malloy & Berndes (1998) USA [47] | *n* = 518<br>BF: >1 day BF (*n* = 342)<br>NBF: no BF (*n* = 176)<br>High SES<br>Assessed at 9–10 yr | WISC-R (IQ) verbal performance subscales<br>Other variables: maternal education, paternal education, annual income | BF > NBF<br>Verbal IQ: 122.4 > 117.6***<br>Performance IQ: 116.6 > 114.3<br>Total IQ: 121.9 > 117.8**<br>Significance lost with inclusion of covariates |

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TABLE 4. Studies of the long-term effects of breastfeeding (organized by age of assessment)

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Horwood & Fergusson (1998) New Zealand [68] | $n$ = 772–1,064<br>VLBF: ≥ 8 mo<br>LBF: 4–7 mo<br>MBF: <4 mo<br>NBF: no BF<br>Assessed at 8–18 yr | Mental development: 8–9 yr: WISC-R; 10–18 yr: reading, comprehension, mathematical reasoning, school achievement tests, attainment on school-leaving examinations<br>Other variables: maternal age, SES, family living standards, maternal smoking | VLBF > LBF > MBF > NBF for all time points, 8–18 yr<br>10 of 12 tests significant when covariates controlled for<br>Linear relationship between duration of breastfeeding & cognitive ability |
| Gale & Martyn (1996) UK [51] | $n$ = 994<br>BF: BF exclusively ($n$ = 658) (80% weaned by 12 mo)<br>SBF: ($n$=283)<br>NBF: no BF ($n$=53)<br>Singleton, born to married mother<br>Assessed at 40–50 yr | Mental development AH4 IQ test (logical, verbal, arithmetic reasoning)<br>Other variables: BW, maternal age, father's social class, birth order, pacifier (dummy) use | BF > NBF > SBF<br>IQ: 22.3 > 21.5 > 20.8 (difference between 3 feeding groups*)<br>Significance lost with inclusion of covariates |

*$p < .05$, **$p < .01$, ***$p < .001$.

Abbreviations: BAS, British Ability Scales; BF, breastfeeding; BW, birthweight; EPVT, English Picture Vocabulary Test; IQ, intelligence quotient; LBF, long breastfeeding; MBF, moderate breastfeeding; NBF, no breastfeeding; NS, not significant; PPVT, Peabody Picture Vocabulary Test; PPVT-R, Peabody Picture Vocabulary Test—Revised; SBF, some breastfeeding; SES, socio-economic status; VLBF, very long breastfeeding; VVLBF, very, very long breastfeeding; WISC, Weschler Intelligence Scale for Children; WISC-R, Weschler Intelligence Scale for Children—Revised.

that infants born pre-term who are fed EFA-supplemented formula have better visual acuity [74–76] and higher plasma levels of EFA than infants fed unsupplemented formula. However, the limited data comparing the developmental outcome of pre-term infants supplemented with EFA suggest no clear results [73, 77, 78]. The one intervention study comparing pre-term infants fed pre-term formula, term formula, and expressed breast milk [53] found a significant increase in the MDI of breastfed babies at 18 months, but only in comparison with those infants receiving term formula.

## Growth

Improved development may also be related to improved growth. However, the effects of breastfeeding on linear growth are not consistent. In developing countries, increased breastfeeding has been associated with increased weight-for-age at 6 to 12 months of age [46, 51, 79–83] and mid-upper-arm circumference at 18 months [84]. However, other studies have shown no benefit to growth in the first 6 months [85], and increases in malnutrition related to breastfeeding during the second year [86–90], particularly in the presence of other risk factors, such as low food intake and high diarrhoeal morbidity [90]. On the basis of an excellent Peruvian study examining the causality of the relationship between linear growth retardation and breastfeeding, it appears that poor growth and ill health lead to increased breastfeeding, rather than prolonged breastfeeding leading to malnutrition [91].

## Immune response

In both developing and developed countries, breastfeeding has been associated with an increased infant immune response [92], resulting in decreased levels of gastrointestinal illness [93], respiratory tract and ear infections [94–98], diarrhoea (particularly in the first year of life) [95, 96, 98–102], and chronic constipation [47]. Protection against infection in infancy appears to be dose-related [95], implying that even small amounts of breastmilk can have a beneficial effect. It is very likely that the increased health status of breastfed infants and children may have a positive effect on mental and motor development.

## Maternal–child interaction

Breastfeeding promotes maternal–child responsivity [58]. Children who have temper tantrums are more likely to be bottle-fed [52]. The effects of a secure attachment between mother and child may be that the child has improved behaviour, which could then lead to improved learning and responsivity in school

## Conclusions and policy implications

Most studies of the effects of breastfeeding on mental development have used correlational analyses, which means that there are limits to the conclusions that can be drawn from the data, particularly because of the numerous confounding variables. However, the consistency of the data suggests that there is a small benefit to children's development. There is a surprising lack of information from developing countries, where the benefits from breastfeeding for mental development are likely to be more substantial, in the context of all the other health benefits of breastfeeding.

There is no doubt that programmes to promote breastfeeding should be encouraged. An example of such programmes is the Baby-Friendly Hospital Initiative (BFHI), a UNICEF-WHO initiative designed to transform maternity hospitals around the world so that they offer breastfeeding support. BFHI has outlined 10 steps to successful breastfeeding [103] (table 5).

According to UNICEF reports [44], the BFHI has been extremely successful and has helped transform over 12,700 hospitals in 114 countries into centres of breastfeeding support in just six years. According to UNICEF, BFHI has resulted in substantial health gains. For instance, the Ministry of Health in Panama reported that in one year in one health facility, the BFHI resulted in a 58% reduction in respiratory infections and a 15% reduction in diarrhoea in infants. Similar results have been reported in Brazil, Gabon, Chile, China, Iran, Cuba, and the Republic of Moldova [44].

## Protein-energy malnutrition

It is estimated that 19% of children under five years old in South Asia and 10% of children in sub-Saharan Africa are severely underweight (weight-for-age below −3 SD of the reference) [44]. Although the prevalence of moderately (weight-for-age below −2 SD of the reference) and severely underweight children is estimated to have declined globally from 38% in 1980 to 34% in 1990 to 30% in 1997, not all countries have shown this decline.

Although the term protein-energy malnutrition is used to classify kwashiorkor, along with marasmus and milder forms of malnutrition, it is recognized that many nutrient deficiencies are present in protein-energy malnutrition. There have been propositions to replace the term "protein-energy malnutrition" with "energy-nutrient malnutrition." However, protein-energy malnutrition is still the standard term in use. Waterlow and Rutishauser [104] suggested that protein-energy malnutrition be classified by the degree of wasting and stunting. Wasting (weight expressed as a percentage of the expected weight-for-height) indicates current or recent nutritional conditions, whereas stunting (height-for-age) indicates nutritional experiences over a longer period of time. It is probable that the duration of malnutrition is more highly related to children's mental development than short-term severity.

TABLE 5. Ten steps to successful breastfeeding

| |
|---|
| Every facility providing maternity services and care for newborn infants should: |
| 1. Have a written breastfeeding policy that is routinely communicated to all health care staff |
| 2. Train all health care staff in skills necessary to implement this policy |
| 3. Inform all pregnant women about the benefits and management of breastfeeding |
| 4. Help mothers initiate breastfeeding within a half-hour of birth |
| 5. Show mothers how to breastfeed and how to maintain lactation even if they should be separated from their infants |
| 6. Give newborn infants no food or drink other than breastmilk, unless medically indicated |
| 7. Practice rooming-in: allow mothers and infants to remain together 24 hours a day |
| 8. Encourage breastfeeding on demand |
| 9. Give no artificial teats or pacifiers to breastfeeding infants |
| 10. Foster the establishment of breastfeeding support groups and refer mothers to them on discharge from the hospital or clinic |
| In addition, facilities should refuse to accept free and low-cost supplies of breastmilk substitutes, feeding bottles, and teats. |

## Severe malnutrition

The literature on the effects of severe protein-energy malnutrition on child development mostly concerns children who were in hospital with kwashiorkor, marasmus, or marasmic-kwashiorkor based on the old Wellcome classification [105]. These studies were recently reviewed in depth [106]. The main conclusions were, in spite of limitations of study design, that the evidence was strong but not unequivocal that severe malnutrition in early childhood leads to deficits in cognitive development and behaviour differences if the children return to poor environments. However, marked improvements are possible with vast improvements to the children's environment, such as occurs in adoption. More feasible simple interventions in the children's own homes can produce some benefits. However, the evidence for this is limited. The policy implications are that wherever severely malnourished children are being treated, attention should be paid to promoting the children's mental development

## Moderate stunting and wasting

It is estimated that 37% of children under five years of age in developing countries, and up to 55% in South-East Asia, are moderately stunted [44] (height-for-age below −2 SD of the median of the reference population [107]). The prevalence of moderate wasting (weight-for-height below −2 SD) in children under five years of age in developing countries is 11% [44]. In this review we will focus particular attention on stunting, because it is highly prevalent and there is controversy as to whether it affects development. Height reflects the genetic potential of a population as well as the socio-economic, health, and nutritional conditions affecting the population [108]. The role of the environment is illustrated by the secular improvements in average height shown by populations over the last century in both European and non-European countries [109, 110]. The age of onset of stunting varies but is usually in the first two to three years of life [111, 112].

The aetiology of linear growth retardation is multifactorial but has been explained by three major factors: poor nutrition, high levels of infection, and problematic mother–infant interaction, which is closely related to the socio-economic status of the family [113]. In developing countries, poor nutrition plays a major role in the aetiology of stunting, although there is no clear consensus as to which nutrients are important. Energy, protein, zinc, and iron deficiencies have all been implicated [114], and the data implicating deficiencies of zinc [115] and protein [116] are the strongest. To a lesser extent, frequent or prolonged infections, particularly those causing diarrhoea, also play a role [114]. It is likely that the cause of stunting varies in different countries according to which nutrients are limiting for growth and morbidity prevalence.

Almost complete catch-up in growth can be achieved when children experience dramatic environmental change and an improved diet, such as occurs during adoption [117]. This phenomenon is very unusual in the context of the developing world, where poor conditions prevail and undernutrition is associated with several additional environmental disadvantages, such as poor housing and low maternal literacy [118]. In poor communities, even long-term nutritional supplementation of stunted children is unlikely to result in complete catch-up growth [119, 120], particularly in conditions of poverty [117, 121].

Stunting in poor populations is usually associated with poor mental development. However, the many sociocultural and economic disadvantages that coexist with stunting [108] may also detrimentally affect mental development, making it difficult to determine whether the poor development of stunted children is due to nutritional deficiency or whether stunting is just an indicator of poverty.

To understand the association between height and mental development in children, investigators have taken a variety of approaches. Some have examined cross-sectional correlations and have either disregarded or controlled for the children's socio-economic backgrounds, with varying degrees of rigour. Others have looked for longitudinal associations between change in height and change in mental development or have examined associations between height in early childhood and later mental development. A few investigators have conducted nutritional supplementation studies, which are probably the most efficient way to determine whether the link between stunting and poor mental development is related to nutritional factors.

### Cross-sectional associations between height and development

Most cross-sectional studies have found significant associations between height-for-age and children's cognitive development. Associations between height-for-age and school achievement have been found in older children without controlling for socio-economic status [122–124]. Even after controlling for socio-economic conditions, investigators found significant associations between height-for-age and IQ, cognitive function, or school achievement levels in school-aged children in many countries, including the Philippines [125], Jamaica [126, 127], Guatemala [128], Nepal [129], Kenya [130], Bangladesh [131], and India [132].

Significant associations have also been found between stunting and poor psychomotor development in young children in Guatemala [133], Chile [134], Jamaica [118], and Kenya [135] (table 6).

Only a few studies failed to find significant associa-

TABLE 6. Studies of associations between height-for-age and cognitive and motor development in infants and pre-school children

| Study | Sample | Measurements | Results |
|---|---|---|---|
| Positive findings | | | |
| Sigman et al. (1989) Kenya [130] | *n* = 110<br>18–30 mo | Height<br>Bayley Scales, MDI & PDI home observation of play | Bayley scores correlated positively with length ($r = .25$, $p < .05$)<br>Simple play correlated negatively with length ($r = -.24$, $p < .05$), & more advanced functional & symbolic play correlated positively ($r = .05$, $r = .13$, respectively) |
| Powell & Grantham-McGregor (1985) Jamaica [118] | *n* = 168<br>6–30 mo | Height-for-age<br>Griffiths Mental Development Scales, DQ | Height-for-age predicts DQ ($p < .01$, 33% variance explained) when child's age, sex, birth order, & family SES are controlled for |
| Lasky et al. (1981) Guatemala [133] | *n* = 418 assessed at 6 mo<br>Same infants assessed at 15 (*n* = 383) & 24 (*n* = 334) mo | Height<br>Mental & motor assessment: Composite Infant Scale | Mental & motor performance at 6, 15, & 24 mo correlated with length at 6, 15, & 24 mo (range, $r = 0.18$ to 0.35, $p < .01$ for all) |
| Mönckeberg (1972) Chile [134] | *n* = 118<br>1–3 yr | Height-for-age<br>General DQ | 1–3 yr: Positive correlation ($r = .56$, $p < .001$) |
| Negative findings | | | |
| Colombo et al. (1988) Chile [135] | *n* = 228<br>247–274 days | Height-for-age<br>DQ (Chilean scale) | No significant correlation<br>*n* = 42 |
| | 51–65 mo | Height-for-age<br>IQ (WISC) | No significant correlation |

Abbreviations: DQ, developmental quotient; IQ, intelligence quotient; MDI, mental development index of the Bayley Scale; PDI, psychomotor development index of the Bayley Scale; WISC, Wechsler Intelligence Scale for Children.

tions between height and measures of mental development or school achievement [136–139]. The reasons for the negative findings are not always clear, but small sample sizes may explain some findings [134]. In contrast to the findings with height-for age, weight-for-height has been only occasionally associated with children's development [130, 133, 140]. In most studies, severe and moderate stunting were much more common than severe and moderate wasting, which may partly explain this finding.

## Behaviour

A small number of studies have been undertaken assessing the behaviour of mildly to moderately underweight infants or school-aged children who were also stunted to some degree. The results are fairly consistent: unsupplemented young children have been described as more quiet, reserved, withdrawn, and timid, with great difficulty making up their minds and a fear of novel situations [141]. When they were older, the children spent less time on task in the classroom, and cried and slept more than the supplemented children. Underweight children tended to be more anxious, less imaginative in their problem-solving approaches, and less environmentally involved than children of normal weight [142].

In a more recent study, stunted children between 9 and 24 months of age were found to have behavioural differences, including decreased activity levels [143], and explored their environment with less enthusiasm and were less happy than non-stunted children [Meeks-Gardner JM, personal communication, 1998]. A subsample of these children at 8 years of age was also found to be more inhibited, less verbal, and less happy [144].

### Other functional associations

Stunting has also been associated with poor fine motor skills in children from Bangladesh [131] and Jamaica [126], and poor neurosensory integration in children from Mexico [145]. In the Mexican study, the association was present in poor rural children but not in middle-class children. The authors suggested that stunting in middle-class children was due mainly to genetic tendencies and thus was not associated with functional deficits, whereas stunting in poor rural children was attributed mainly to poor nutrition that was associated with consequent functional deficits.

Cognitive function is more likely to be detrimentally affected by short-term hunger in stunted children than in non-stunted children [146]. Preliminary data from Jamaica also suggest that stunted children have higher levels of stress hormones (cortisol) and higher heart rates, implying that they may be less able to cope with environmental stressors and may have heightened arousal of the hypothalamic-pituitary-adrenal or autonomic nervous systems [144]. It is unknown whether this study can be replicated in other populations.

## Longitudinal associations

In children who have recovered from marasmus, marasmic kwashiorkor, or kwashiorkor, height-for-age in the acute stage is usually a better predictor of mental development than weight-for-height or oedema [147, 148]. In both Guatemala [133] and Jamaica [149], change in height over a two-year period in the first three years of life was related to change in development.

## Supplementation studies

The most effective way to demonstrate a causal relationship is through a treatment trial, and several supplementation studies have been conducted, some preventive and some therapeutic.

### Preventive supplementation studies

Three preventive supplementation studies have been conducted in populations with endemic undernutrition. Although these studies were not planned specifically to examine stunting, the findings are relevant in cases in which both the height and development of the children improved. In three early studies of preventive supplementation in Guatemala [150], Colombia [151], and Mexico [152], pregnant women were given nutritional supplements and then their offspring were supplemented for three or more years. The supplemented children showed concurrent gains in height and cognition as compared with non-supplemented children.

All three studies have followed up the children. The Mexican study was extremely small, and the supplemented groups were separated by time. However, at follow-up at 18 years of age, supplemented boys had significantly higher scores on Raven's Matrices Test than non-supplemented boys; there was no difference between supplemented and non-supplemented girls [153]. In Bogota, Colombia, the children were studied at seven years of age, and the supplemented children had higher scores on tests of reading readiness but not in arithmetic and basic knowledge. Unfortunately, full details of this study have not been reported (Super CM, Herrera MG, Mora JO, personal communication, 1991). The Guatemalan study had the most in-depth follow-up [154]. The children were reassessed at 11 to 24 years of age, and the supplemented children were found to have small but wide-ranging benefits in tests of numeracy, knowledge, vocabulary, and reading achievement. The benefits were greatest among children from the poorest homes (fig. 2).

### Intervention with stunted or wasted children

The only supplementation study aimed specifically at stunted children was conducted among stunted Jamaican children 9 to 24 months of age [155]. On enrolment the development of the stunted children was already poorer than that of a matched, non-stunted group. The stunted children received nutritional supplementation for two years, with or without psychosocial stimulation. Supplementation and stimulation produced independent benefits to the children's mental and motor development. The benefits from a combination of supplementation and stimulation were additive, and only the children receiving both treatments caught up to the non-stunted control group in developmental levels. The implications of these findings are that at least part of the deficit in the development of stunted children is due to poor nutrition. However, both stimulation and supplementation are necessary to improve the development of stunted children to culturally appropriate levels.

Follow-up of the Jamaican children at seven years of age showed that only small global benefits from intervention remained [126]. However, even the control children showed marked catch-up in height, reflecting the improving nutritional status of the Jamaican

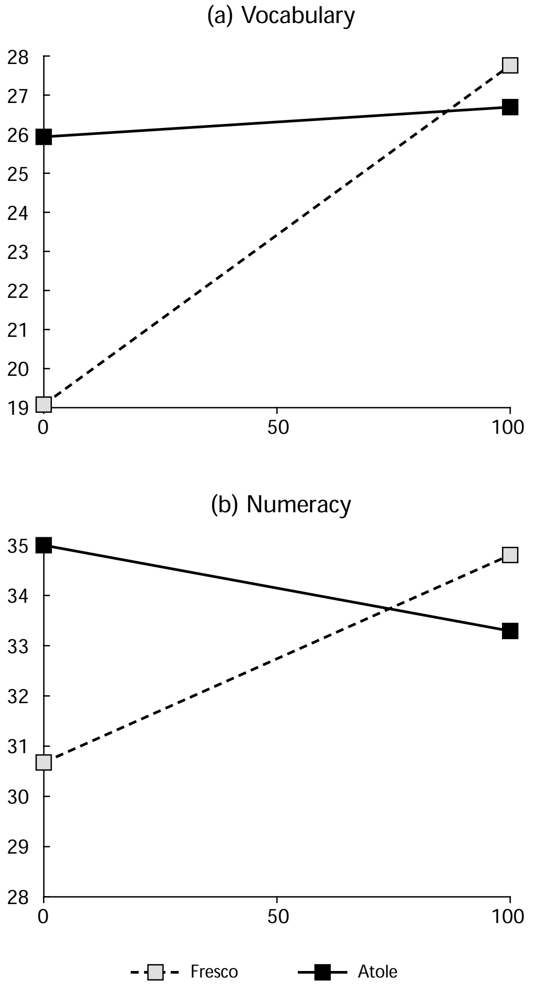


FIG. 2. Long-term benefits to (a) vocabulary and (b) numeracy of high-calorie, high-protein supplement (atole) compared with low-calorie supplement (fresco) according to children's socio-economic status [154]

population. A preliminary analysis of data from a further follow-up at 10 years shows a significant benefit in the stimulated children only. In the Guatemalan study [150], benefits from supplementation were not apparent at six years but were present at adolescence [154], suggesting that there is a sleeper effect and that larger benefits from supplementation in the Jamaican study may reappear at a later age.

Two other studies have been conducted with undernourished children. One in Indonesia [156] showed a weight but not a height response, and the other study in Cali, Colombia [157], had no control group that did not receive supplementation. In the Indonesian study, infants 6 to 20 months of age in day-care centres supplemented for only 3 months showed a benefit to their motor development but not their mental development. Their average height was below −2 SD on enrolment, but weight-for-height was not reported. At long-term follow-up [158], the authors reported the progress of all children who were supplemented when they were under five years of age, and there was no treatment effect. Post hoc analyses of the younger children showed benefits in one of several tests. Since height showed no response to initial supplementation, this benefit may be an effect of improving dietary intake sufficiently to improve wasting but not stunting.

## Vulnerable age

Evidence for a vulnerable period when nutrition is particularly important for mental development is not conclusive. In one supplementation study, children receiving supplements after 24 months of age showed fewer and smaller benefits than children receiving supplements earlier [154]. However, there were fewer children receiving supplements after 24 months. In the study with undernourished children in Cali, Colombia [157], an integrated programme of stimulation and supplementation was given to children for different periods of time, beginning at different ages. Those children receiving supplementation from the youngest age (42 months) showed the greatest and most sustained benefits. However, it was not possible to separate supplementation from stimulation, and age was confounded with duration of intervention.

We found four studies in which height in early childhood predicted cognitive development at a later age. In a Guatemalan study [159], the children's height at 3 years of age predicted their performance on tests of numeracy, literacy, general knowledge, and adolescent school grade attainment. Similarly, in a Kenyan study [160], height in children between 18 and 30 months of age predicted cognition scores at 5 years of age, and in a Jamaican study [161], height at 1 year of age predicted school achievement scores between 9 and 11 years of age in girls, but not in boys. In a recent study of stunted Jamaican children, height-for-age between 9 and 24 months of age predicted IQ at 7 years of age better than concurrent height [126]. These findings suggest that nutrition in the first 2 to 3 years is critically important to children's development.

## Mechanism

The precise mechanism linking stunting to poor mental development is unknown. It is possible that the mechanism varies according to which nutrients are deficient, or that several hypothesized mechanisms could act separately or together. One hypothesis is that undernutrition causes poor motor development and subsequent low activity levels. It also causes apathy and lack of interest in the environment. The children thus explore their environment less and fail to acquire skills at the normal speed [162]. These behaviours have been described in children with deficiencies of iron [163], zinc [164, 165], and energy [166, 167]. The caretakers may in turn be less stimulating towards an apathetic child, which may exacerbate the effects on development [152]. Another possible mechanism is that the children's small size could lead adults to treat them like younger children and not provide age-appropriate stimulation.

Undernutrition could have a direct effect on children's central nervous systems. There is a considerable amount of evidence for this from animal research [168]. Stunted children have small heads, and in one study, head size in early childhood was a stronger predictor of IQ at 7 years of age than other previous or current anthropometric measures [126]. Another hypothesis is that altered HPA and autonomic nervous system activity could lead to behavioural differences, but more research is needed to confirm these preliminary findings.

## Conclusions about mild-to-moderate stunting

Stunted children have multiple functional disadvantages that persist throughout childhood. Poor nutrition almost certainly plays a role, as well as poor environments. It is probable that nutrition in the first three years is particularly important. The poor development and educational level of stunted children is likely to limit economic productivity in individual adults and nations [169, 170]. Furthermore, low educational level in parents limits their ability to promote good development and health in their children [171–173], which in turn leads to an inter-generational effect.

## Policy implications and recommendations

In countries where stunting is highly prevalent, there is an urgent need to institute programmes to improve children's nutritional status. Such programmes are probably most effective if they are instituted among children in the first three years of life [154] and are integrated with child care and psychosocial interventions.

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