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Associations Between Duration of Breast Feeding and Neurocognitive Development of the Offspring

Jean Golding [1,*], Kate Northstone [1], Caroline Taylor [1,2], Pauline Emmett [1,2], Yasmin Iles-Caven [1,2], Jacqueline Gregory [3], Steven Gregory [1,2] and Neil Goulding [1,2]

[1] Population Health Sciences, Bristol Medical School, University of Bristol, Canynge Hall, 39 Whatley Road, Bristol BS8 2PS, United Kingdom

[2] Centre for Academic Child Health, Bristol Medical School, University of Bristol, Bristol

[3] Bristol Veterinary School, University of Bristol, Bristol

* Correspondence: jean.golding@bristol.ac.uk

Abstract

There is considerable evidence that breast feeding has a beneficial effect on neurocognition of the child. However, most studies have confined their attention to the IQ of the offspring rather than other aspects of neurodevelopment. Here we have compared children who were breast fed for at least six months with children who have never been breast fed concerning 373 different neurocognitive outcomes measured from infancy to late adolescence using data collected by the Avon Longitudinal Study of Parents and Children (ALSPAC). We first examined unadjusted regression associations and selected 152 of the 373 variables where the P-value for comparison between the two groups was <0.0001. These 152 outcomes were then adjusted for seven social and other factors, revealing 42 outcomes with adjusted associations at P<0.001: specifically, these included associations with full-scale IQ at ages 8 and 15 years (adjusted mean difference (MD), [95% confidence interval (CI)] were +4.11[95%CI 2.83, 5.39] and +5.12 [95%CI 3.57, 6.67] IQ points respectively. As well as the components of IQ, the other phenotypes that were strongly related to having been breast fed for 6 months were measures of academic ability including reading, use of the English language and mathematics. In line with the literature, we show that children who were breast fed are more likely to be right-handed. We conclude that breast feeding for at least 6 months has beneficial effects on a number of neurocognitive outcomes that are likely to play a major part in the offspring's future life choices. We point out, however, that this study has not yet considered other potential long-term biological benefits of breast feeding.

Keywords: breast feeding; cognition; behaviour; IQ; educational attainment; attention; speech; memory; personality; handedness

1. Introduction

There have been many studies concerning the neurocognitive benefits to the child who had been breast fed compared to children who had received no breast milk, with mixed findings. Nevertheless, there has been convincing evidence, particularly from the PROBIT clustered RCT of advice concerning exclusive breast feeding to mothers in Belarus where follow up of the children to age 6.5 years showed that the children born at hospitals randomised to the intervention had increased vocabulary, verbal IQ, and similarities, and the teachers rated their reading and writing as better than children born at hospitals without the intervention [1]. The PROBIT children were tested again at age 16 and showed increases in memory and verbal function in the intervention group compared with the control group [2]. Conversely no differences were found between the two groups regarding the children's behaviours [3].

Systematic reviews of the association between breast feeding and IQ have also shown evidence of positive associations [4]. Subsequent systematic reviews found small but positive associations with

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cognition, behaviour and executive function [5]. Hou and colleagues used a ratio of means analysis and showed positive associations with IQ when comparing any breast feeding with none, and with breast feeding of over 6 months compared with less than or equal to 6 months [6].

Large observational studies that have used other neurocognitive outcomes include a study of 177,000 children in Scotland which showed that those children who had been exclusively breast fed for 6-8 weeks had a lower risk of having Special Educational Needs due to learning difficulties when compared with those who had had no breast milk; however, the children who were breast fed for 6-8 weeks, but not exclusively, were as unlikely to have such an outcome as were the children who had been exclusively breast fed [7]. In Japan, a longitudinal study of 77,000 children found that breast feeding for at least 6 months resulted in a lower risk of developmental delay at 12 months; the authors also showed similar results using pairs of siblings [8]. An Australian Longitudinal Study of 8560 children showed positive associations between the duration of breast feeding with language skills and non-verbal intelligence but not with executive function [9].

Thus, the literature indicates repeated support for an association between breast feeding and IQ, but there have been few studies showing consistent findings with other neurocognitive outcomes using large datasets. The aim of this set of analyses is to take advantage of the wealth of neurocognitive outcomes recorded on the children taking part in the Avon Longitudinal Study of Parents and Children (ALSPAC) to determine the types of neurocognitive outcomes that differ between children who were breast fed for at least 6 months and those who were not breast fed at all.

2. Material and Methods

2.1. The ALSPAC Pre-Birth Cohort

In April 1990, in the English county of Avon, the Avon Longitudinal Study of Parents and Children (ALSPAC), a pre-pregnancy longitudinal study, began with the aim of identifying the factors (both environmental and genetic) that influence a child's health and well-being [10]. The study was designed to enrol all pregnant women resident in the defined area with an expected date of delivery between 1st April 1991 and 31st December 1992 inclusive. Approximately 75-80% (n = 14,541) of eligible women joined the study [11,12].

Data were collected using self-completed questionnaires, posted directly to the mothers. A questionnaire for her partner (with a reply-paid envelope) was sent to the mother to hand to her partner if she so wished. This arrangement was made on the advice of the study's Ethics Committee (see [13] for further details of the discussions and decisions made).

Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. Implied consent from participants for the use of data collected via questionnaires and clinics was assumed following the recommendations of the ALSPAC Ethics and Law Committee at the time [13].

Please note that the study website contains details of all the data that are available through a fully searchable data dictionary and variable search tool: http://www.bristol.ac.uk/alspac/researchers/our-data/.

2.2. Details of Breast Feeding

Mothers were sent questionnaires in which details of infant feeding were obtained when the children were aged 4 weeks, 6 months and 15 months. Although details of other foods given to the baby were collected, for this study we do not use any dietary data other than whether the mother was breast feeding at the time the 6- and 15- month questionnaires were completed. Thus, we do not include any other nutrients as confounders, nor do we distinguish between those exclusively and non-exclusively breast fed.

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2.3. Confounders

The following confounders were used: Maternal education level achieved (5-point scale from No qualifications to University degree); Paternal education (using similar scale); Maternal age at time of birth of child since young age is associated with both failure to breast feed successfully and with their children to perform at a lower level; whether the child was first-born or not – since the first-born tends to perform less well academically and the mother is more likely to have difficulties breast feeding; tenure of their home (owned / mortgaged v. rented / other) is included as a marker of social (dis)advantage; delivered by Caesarean section; Mother smoked at 18 weeks of pregnancy. The reason for these choices were that: (i/ii) parental education levels are related to both choosing to breast feed and the child's cognitive abilities; (iii) Age of the mother at birth of the child since young ages are associated with failure to breast feed successfully, and for their children to be more likely to perform less well intellectually; (iv) whether the child was first born is important since the first born child in a family tends to perform less well academically, and the mother is more likely to have difficulties breast feeding; (v) tenure of the home is included as a marker of social (dis)advantage; (vi) prolonged breast feeding is less likely after delivery by Caesarean section [14]; (vii) Maternal prenatal smoking since it is associated both is associated with both the child's cognition [15] and low breast feeding rates [16].

2.4. Outcome Measures

The ALSPAC neurocognitive data include measurements, mainly using scales, some of which were completed by the mother, others by the child's teachers, and some by the children themselves. Additional in person studies were completed by ALSPAC staff either overseeing completion of tests/scales on-line by the child or by direct examination. In order to maximise statistical power, we concentrated on the scales which were continuous, of which 373 were available for detailed analysis (see Supplementary material for details).

2.5. Statistical Analyses

Since there were a large number of outcomes considered, in order to minimise both the Type I and Type II error rates we started by selecting for further analysis only the scales for which the unadjusted association with breast feeding at 6 months was at $P<0.0001$. This resulted in confining the analyses to 152 of the 373 outcomes. When considering breast feeding relationships at 6 months, we confined the analyses to outcomes ascertained beyond 6 months.

Initial adjusted analyses took account of the confounders outlined above (Model 1). Further adjustment was then made for maternal smoking at 18 weeks gestation (Model 2). In general, since each outcome was measured on a continuous scale, multivariable linear regression was employed, using the raw scores of each outcome, and taking account of the confounders. The details of effect sizes for each outcome that resulted in $P<0.001$ after adjustment are highlighted in the tables.

2.6. Missing Data

We have not modelled using missing data techniques as the data are unlikely to be missing at random. The proportion of missing data varies for each variable, but can be readily ascertained from the ALSPAC study data dictionary (www.bristol.ac.uk/alspac/researchers/our-data); it varies from 0% for the sex of the child to 62% for the IQ measure at age 15.

3. Results

3.1. Breast Feeding Prevalence

In total 11,337 mothers completed a question when the child was 6 months old concerning whether he/she had been breast fed: 28.7% were still being breast fed; 24.4% had never been breast fed and 46.9% had started but stopped breast feeding before the child was six months of age. Among

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those breast feeding at 6 months the frequency of feeds varied from one to 10 times a day, reflecting the fact that many women were still feeding on demand. We use all children who were receiving breast milk at 6 months as the focus of this set of analyses which assesses the ways in which their subsequent development differed from children who had never received breast milk. Those children who received breast milk for less than 6 months are omitted from the analyses. The ways in which the two groups of women (breastfeeding for 6 months and never breast fed) differ from one another is shown in the Supplementary material.

3.2. Child Development

During the pre-school period there were two scales that were used to assess child development: the Griffiths tests [17], which were administered to the children at 18 months by trained psychologists – these assessed five attributes (locomotor, social/personal, hearing/speech, hand/eye coordination, and performance) together with a total score. Of these six scales, prior to adjustment, three were positively associated at P<0.0001 with breast feeding at 6 months (social/personal, hearing/speech and the total score) . After adjustment, although the associations were still positive, none were associated at P<0.001 (Table 1).

A similar set of scales had been developed for completion by the child's main carer (usually the mother) based on the Denver screening inventories [18]. These were asked at 18, 30, 42 and 57 months and comprised scales for social skills, fine motor ability, communication skills, gross motor skills and then a total score. Of the 25 scales tested, six of the associated associations with breast feeding were at P<0.0001 (Table 1), but only two survived adjustment at P<0.001. both were related to fine motor skills. Note that none of the age-related Denver total development scores were associated at P<0.0001.

Thus, of the 31 preschool developmental assessments using our stringent P-value criteria, the only associations that survived adjustment concerned fine motor skills at 30 and 42 months of age.

Table 1. Unadjusted and adjusted comparisons of associations between children breast fed for 6 months with those never breast fed concerning measures of child development (results at P<0.001 are in bold).

Measure	UMD [95%CI][a]	N	AMD [95% CI][b]	N	P	AMD [95%CI][c]	N	P
Griffiths Tests								
At 18 months								
Social/personal	**+0.98 [0.52, 1.44]**	510	+0.59 [0.03, 1.15]	510	0.037	+0.57[0.01, 1.13]	509	0.048
Hearing/speech	**+1.50 [0.81, 2.19]**	510	+0.90 [0.06, 1.73]	510	0.037	+0.87[0.03, 1.72]	509	0.043
Total score	**+4.04 [2.18, 5.90]**	510	+2.37 [0.11, 4.64]	510	0.040	+2.27[-0.01,4.55]	509	0.051
Denver Tests								
Social Skills								
At 57 months	**-0.45[-0.66, -0.24]**	4383						
Fine motor skills								
At 18 months	**+0.48 [0.32, 0.64]**	5450	+0.29 [0.09, 0.49]	4752	0.005	+0.28[0.07, 0.48]	4740	0.007
At 30 months	**+0.71 [0.50, 0.91]**	5076	**+0.51 [0.25, 0.78]**	4464	<0.001	**+0.51[0.25, .78]**	**4452**	**<0.001**
At 42 months	**+0.80 [0.57, 1.02]**	4961	+0.50 [0.22, 0.78]	4381	0.001	**+0.51[0.22, 0.79]**	**4368**	**<0.001**
At 57 months	**+0.98 [0.81, 1.16]**	4377						
Communication skills								
At 57 months	**+0.31 [0.20, 0.42]**	4556	+0.05 [-0.09, 0.19]	4047	0.488	+0.05[-0.09,0.19]	4036	0.507
Gross motor skills								
At 18 months	**-0.40[-0.56, -0.25]**	5447	-0.13 [-0.33, 0.06]	4749	0.171	-0.12[-0.31, 0.07]	4732	0.219
At 30 months	**-0.31[-0.44, -0.17]**	5068	-0.06 [-0.23, 0.11]	4457	0.490	-0.04[-0.22, 0.13]	4445	0.609

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[a] P<0.0001 for each measure; **** = P<0.0001; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [b] adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c] additionally adjusted for maternal smoking mid-pregnancy.

3.3. Measures of Cognition Using IQ Scales

Tests using the scales from the Weschler group of tests were undertaken in a standardised setting by trained ALSPAC staff (mostly psychologists). At age four years, a 10% representative subsample known as the Children in Focus were administered the *Wechsler Preschool and Primary Scale of Intelligence* [19]. At 8 years, the whole sample were invited to attend for an abbreviated form of the UK version of the Wechsler Intelligence Scale for Children (WISC) [20], for which alternative items of each scale were used. At 15 years, all original offspring were invited for a further IQ test - The Wechsler Abbreviated Scale of Intelligence (WASI-II) [21] which was designed for individuals between 6 and 90 years of age. Because of shortage of finance at the time, only two of the four subtests were administered: the verbal comprehension index and the perceptual reasoning index. The sum of these resulted in the total IQ. Further descriptions of each of these tests can be found in the Supplementary Material.

All unadjusted associations were positive at P<0.0001. In addition, with the exception of the 4-year tests, where numbers for adjusted analyses were small (≤ 450), all adjusted analyses remained positive at P<0.0001. This was true of verbal, performance and total IQ measures as well as for specific subtests (Table 2).

Table 2. Unadjusted and adjusted comparisons of associations between children breast fed for 6 months with those never breast fed concerning components of measures of IQ (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
At age 4								
Performance IQ	**+6.97 [4.28, 9.66]**	445	+2.40 [-.67, +5.48]	446	0.125	+2.20 [-.87, 5.27]	445	0.159
Verbal IQ	**+7.64 {5.07, 10.22]**	445	+3.32 [0.46, 6.19]	444	0.023	+3.36 [0.48, 6.23]	443	0.022
Full-Scale IQ	**+8.50 [5.81, 11.19]**	445	+3.48 [0.50, 6.45]	444	0.022	+3.40 [0.41, 6.38]	443	0.026
At age 8								
Performance IQ	**+7.79 [6.62, 8.96]**	3455	**+3.04 [1.65, 4.44]**	3110	****	**+3.00 [1.60, 4.40]**	3100	****
Verbal IQ	**+10.76 [9.62, 11.90]**	3460	**+4.13 [2.83, 5.44]**	3113	****	**+4.23[2.92, 5.54]**	3103	****
Full scale IQ	**+10.60 [9.49, 11.72]**	3442	**+4.06 [2.79, 5.33]**	3098	****	**+4.11[2.83, 5.39]**	3088	****
Verbal comprehension	**+7.20 [6.43, 7.97]**	3426	**+2.80 [1.92, 3.68]**	3084	****	**+2.85 [1.96, 3.73]**	3074	****
Perceptual organisation	**+5.13 [4.37, 5.89]**	3262	**+2.27 [1.37, 3.18]**	2937	****	**+2.26 [1.34, 1.17]**	2927	****
Freedom of distractibility	**+2.65 [2.23, 3.08]**	3353	+0.82 [0.32, 1.33]	3020	0.001	+0.85 [0.34, 1.36]	3010	0.001
At age 15								
Vocabulary	**+7.86 [6.90, 8.82]**	2493	**+3.38 [2.32, 4.43]**	2282	****	**+3.37 [2.31, 4.43]**	2279	****
Matrix reasoning	**+3.72 [3.01, 4.42]**	2492	**+1.71 [0.88, 2.54]**	2280	****	**+1.72 [0.89, 2.55]**	2277	****
Total IQ (sum of 2 tests)	**+9.02 [7.93, 10.10]**	2490	**+5.12 [3.57, 6.66]**	2279	****	**+5.12 [3.57, 6.67]**	2276	****

[a] P<0.0001 for each measure; **** = P<0.0001; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [a]djusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy.

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3.4. Memory

At 8 years of age, the digit span test, using both forward and backward formats, was administered to the children as part of the WISC test of IQ [20]. It measures both short-term and working memory. At the same 8-year assessment, an adaptation of the Nonword Repetition Test [22] was used to assess the children's working memory. This comprised twelve nonsense words, four each of 3, 4 and 5 syllables and conforming to English rules for sound combinations. The child was asked to listen to each word via an audio cassette recorder and then repeat each item. This was also used in a standardised situation at ages 9, 12 and 13 years. At age 10 years working memory was assessed using the Counting Span Task [23] which requires the simultaneous processing and storage of information as well as working memory (see the Supplementary Information for details).

Although there were strong positive unadjusted associations between all memory tests among children who had been breast fed for 6 months compared with those who had never been breastfed: after adjustment the P-values all exceeded 0.001 with the exception of the non-word repetition measure at age 8 which continued to show a strong association after adjustment (Table 3).

Table 3. Unadjusted and adjusted comparisons of associations between children breast fed for 6 months with those never breast fed concerning measurements of memory. (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
Digit span								
At 8 years	**+1.02 [.80, 1.24]**	3369	+0.27 [.01, .54]	3034	0.043	+0.27 [.00, .53]	3024	0.047
Forward at 8y	**+0.30 [.22, .37]**	3389	+0.08 [-.01, .18]	3048	0.075	+0.08 [-.01, .18]	3038	0.090
Backwards at 8y	**+0.16 [.10, .22]**	3375	+0.04 [-.03, .11]	3040	0.310	+0.04 [-.04, .11]	3030	0.310
Working memory								
At 8y[d]	**+1.02 [.80, 1.24]**	3455	**+0.50 [0.30, 0.70]**	**3111**	**<0.001**	**+0.49 [0.29, 0.70]**	**3102**	**<0.001**
At 10y	**+0.20 [.14, .26]**	3286	+0.05 [-.02, .13]	2956	0.181	+0.04 [-.03, .12]	2946	0.244
At 9y[d]	**+0.83 [.66, 1.01]**	6605	+0.98 [.21, 1.75]	3358	0.012	+1.02 [.25, 1.80]	3347	0.009
At 12y[d]	**+3.03 [1.69, 4.37]**	1651	+0.31 [-1.27, 1.90]	823	0.701	+0.44[-1.14, 2.03]	820	0.585
At 13y[d]	**+3.42 [2.66, 4.19]**	4633	+1.32 [.41, 2.23]	2386	0.004	+1.30 [.39, 2.22]	2381	0.005

[a] P<0.0001 for each measure; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [a]djusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [a]dditionally adjusted for smoking mid-pregnancy; [d] measured using non-word repetition.

3.5. Speech and Language

There were 44 tests of speech and language as the child developed, including both testing face-to-face by trained ALSPAC employees (n=20) and maternal responses to detailed questionnaires concerning the child's vocabulary and grammatical skills (n==24). The face-to-face assessments included the verbal comprehension and alveolars subtest of the Reynell Developmental Language Scales [24] on the 10% subgroup – the Children in Focus at 25 and 61 months, and the UK version of the Weschler Objective Language Dimensions Manual (WOLD) [25] to which the whole cohort were invited at 8 years. Children breast fed for 6 months compared with those never fed breast milk showed a positive unadjusted association in the comprehension test at P<0.0001 but failed to reach P<0.0001 on adjustment. All other tests shown in Table 4 were completed by the mother at various ages. Of note are the associations with the sets of questions that are part of the Children's Communication Checklist (CCC) [26], many of which showed positive associations with breast feeding at 6 months, even after adjustment. This checklist was developed specifically to identify children with pragmatic speech impairments. ALSPAC coded the subtest scores so that the positive scores were all positive (good) outcomes. Thus, the positive mean differences found here after adjustment for inappropriate initiation, stereotyped conversation, use of conversation, and pragmatic

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use of conversation, indicate more appropriate initiation of conversation, less stereotyped conversation, improved use of conversation; in general, the higher the score on pragmatic use of conversation, the better the child's conversation.

Table 4. Unadjusted and adjusted comparisons of associations between children breast fed for 6 months with those never breast fed concerning measures of speech and language (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
Reynell								
At 25 months								
Verbal comprehension[d]	**+4.68 [3.24, 6.12]**	538	+2.77 [1.06, 4.49]	491	0.002	+2.83 [1.10, 4.55]	490	0.001
At 61 months								
Incorrect alveolars[d]	**-0.60 [-0.88, -0.32]**	475	-0.25 [-0.55, 0.06]	438	0.117	-2.30 [-0.54, .08]	437	0.148
CCC at 9 years								
Syntax score	**+0.11 [.07, .14]**	3882	+0.04 [-0.00, 0.09]	3499	0.066	+0.04 [-0.01, 0.09]	3487	0.082
Inappropriate initiation	**+0,92 [.77, 1.07]**	3878	**+0.51 [0.33, 0.70]**	3495	**<0.001**	**+0.50 [0.31, 0.69]**	**3483**	**<0.001**
Coherence	**+0.28 [.15, .42]**	3882	-0.10 [-0.10, 0.24]	3498	0.402	+0.05 [-0.12, 0.22]	3486	0.554
Stereotyped conversation	**+0.85 [.67, .99]**	3865	**+0.50 [0.30, 0.70]**	**3487**	**<0.001**	**+0.50 [0.30, 0.70]**	**3487**	**<0.001**
Use of conversation	**+0.85 [.71, .99]**	3822	**+0.41 [0.24, 0.57]**	**3451**	**<0.001**	**+0.39 [0.23, 0.56]**	**3439**	**<0.001**
Pragmatic aspects of conversation score	**+2.99 [2.46, 3.51]**	3807	**+1.41 [0.77, 2.05]**	**3437**	**<0.001**	**+1.34 [0.70, 1.98]**	**3425**	**<0.001**
WOLD[d] at 8 years								
Comprehension	**+0.75 [.61, .89]**	3457	+0.23 [.07, .40]	3112	0.005	+0.23 [.07, .40]	3103	0.006
Mother at 24 months								
Vocabulary	**+15.06 [11.99, 18.13]**	8814	**+8.19 [4.37, 12.01]**	**4502**	**<0.001**	**8.11 [4.27, 11.95]**	**4487**	**<0.001**
Grammar 1	**+0.36 [.22, .51]**	8814	+0.16 [-.02, .34]	4501	0.081	0.18[-0.00, 0.36]	4487	0.056
Plurals	**+0.29 [.15, .43]**	8814	+0.14 [-.04, .32]	4502	0.122	+0.14[-0.03,0.32]	4487	0.114
Grammar 2	**+1.81 [.94, 2.67]**	8196	+1.20 [.11, 2.29]	4185	0.031	1.20 [0.11, 2.30]	4173	0.032
Mother at 38 months								
Vocabulary	**+7.47 [5.69, 9.25]**	8700	**+4.64 [2.44, 6.84]**	**4434**	**<0.001**	**+4.71 [2.50, 6.92]**	**4421**	**<0.001**
Plurals	**+0.48 [.35, .61]**	8619	**+0.29 [.13, .45]**	**4393**	**<0.001**	**+0.28 [.12, .44]**	**4381**	**<0.001**
Past tense	**+2.05 [1.46, 2.63]**	8578	**+1.46 [.72, 2.21]**	**4371**	**<0.001**	**+1.50 [0.75, 2.24]**	**4358**	**<0.001**
Word combination	**+1.56 [1.28, 1.84]**	8566	**+0.73 [.39, 1.07]**	**4362**	**<0.001**	**+0.77[0.43, 1.11]**	**4349**	**<0.001**
Language	**+9.38 [7.31, 11.45]**	8410	**+6.16 [3.61, 8.71]**	**4281**	**<0.001**	**+6.21 [3.65, 8.78]**	**4268**	**<0.001**

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[a] P<0.0001 for each measure; **** = P<0.0001; AMD = adjusted mean difference; UMD = unadjusted mean difference; [b]adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy; [d]tested by trained psychologists.

3.6. Reading, Spelling and English Language

There were 18 tests of reading ability. Just as shown with measures of IQ, most of the measures of reading ability (for description of tests see [27]) were shown to be strongly related to breast feeding at 6 months, the exception being the child's own perception of their reading ability which was not different at P<0.001 from their peers who had not had any breast milk. The increased reading ability of the breast-fed group applied to the five tests administered by the ALSPAC team between the ages of 7 and 13 years, as well as the standard test on school entry and the National tests at SATS3 (ages 15-16 years). The associations with spelling, although positive. were less convincing and failed to reach our stringent P-value after adjustment. National tests involving the English language and writing ability, however, both showed positive associations with breast feeding and survived adjustment at P<0.001 (Table 5).

Table 5. Unadjusted and adjusted measures of associations between breast feeding for 6 months and academic results in reading, spelling and other English language. (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
Reading[d]								
Reading at 7	**+4.38 [3.75, 5.00]**	6619	**+1.82 [1.08, 2.56]**	**3366**	**<0.001**	**+1.54 [1.08, 2.57]**	**3555**	**<0.001**
Word Reading at 9	**+1.08 [.91, 1.25]**	6257	**+0.36 [0.16, 0.56]**	**3186**	**<0.001**	**+0.34 [0.14, 0.54]**	**3176**	**<0.001**
Comprehension at 9	**+7.05 [6.21, 7.89]**	5672	**+2.03 [1.07, 3.00]**	**2899**	**<0.001**	**+1.97 [1.00, 2.94]**	**2890**	**<0.001**
Speed at 9	**+6.43 [5.55, 7.32]**	5661	**+2.23 [1.19, 3.26]**	**2891**	**<0.001**	**+2.23 [1.18, 3.27]**	**2882**	**<0.001**
Accuracy at 9	**+6.98 [6.03, 7.93]**	5672	**+2.27 [1.15, 3.39]**	**2899**	**<0.001**	**+2.23 [1.10, 3.35]**	**2890**	**<0.001**
Fluency at TF1	**+3.23 [1.75, 4.72]**	1653	-0.20 [-1.93, 1.53]	824	0.819	-0.04 [-1.77, 1.69]	821	0.967
Fluency at TF2	**+4.00 [3.17, 4.84]**	4644	+1.27 [0.28, 2.25]	2391	0.012	+1.27 [0.29, 2.26]	2386	0.011
Phoneme deletion at 7	**+3.00 [2.36, 3.64]**	6605	+0.98 [0.21, 1.75]	3358	0.012	+1.02 [0.25, 1.80]	3347	0.009
National Tests								
Entry assessment[e]	**+0.42 [.37, .47]**	6921	**+0.17 [0.10, 0.23]**	**2386**	**<0.001**	**+0.16 [0.10, .23]**	**3344**	**<0.001**
SATS 3 reading	**+4.23 [3.87, 4.60]**	7639	**+1.63 [1.20, 2.06]**	**3735**	**<0.001**	**+1.59 [1.16, 2.02]**	**3722**	**<0.001**
SATS 3 Shakespeare	**+1.99 [1.78, 2.19]**	7565	**+0.79 [0.54, 1.03]**	**3695**	**<0.001**	**+0.77 [0.52, 1.01]**	**3685**	**<0.001**
Self-perception of reading at 9y	**+1.30 [.97, 1.62]**	3461	+0.21 [-0.18, 0.60]	3127	0.290	+.22 [-0.17, .62]	3117	0.265
Spelling[d]								
At 7	**+1.37 [1.07, 1.67]**	6522	+0.31 [-0.05, 0.67]	3311	0.089	+0.31 [-0.05,.67]	3300	0.089
At 9	**+1.24 [1.00, 1.47]**	6238	+0.37 [0.09, 0.65]	3177	0.010	+0.35 [0.07, .63]	3167	0016
National test KS2	**+1.13 [.82, 1.44]**	1783	+0.28 [-0.12, 0.67]	852	0.167	0.30 [-0.10, .69]	849	0.139

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English Language	**+10.36 [.29, .42]**	6920	+0.68 [-.01, .15]	3352	0.107	0.07 [-0.02, .15]	3342	0.121
SATS 3	**+11.89 [10.89, 12.88]**	7559	**+4.45 [3.29, 5.60]**	**3699**	**<0.001**	**+4.30 [3.14, 5.46]**	**3688**	**<0.001**
Writing ability								
- school entry[e]	**+0.28 [.22, .33]**	6922	+0.07 [-.00, .13]	3353	0.050	+0.06 [-0.00, .13]	3343	0.068
- SATS3	**+5.66 [5.11, 6.21]**	7605	**+2.03 [1.37, 2.68]**	**3721**	**<0.001**	**+1.95 [1.29, 2.61]**	**3710**	**<0.001**

[a] P<0.0001 for each measure; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [b]adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy; [d]tested by ALSPAC staff ; [e] tested by teacher at school entry.

3.7. Mathematics and Science

Tests of arithmetic were administered to the children at ages 4 and 8; Although the unadjusted associations with breast feeding were positive at P<0.0001, on adjustment neither association survived. There were three separate tests, developed for ALSPAC; they were devised to identify mathematical understanding and were administered by the children's schoolteacher. All showed positive associations with breast feeding, that administered at age ten surviving adjustment. In contrast, the two National tests of mathematics both showed strong positive adjusted associations with breast feeding (Table 6).

Two scientific tests were administered by the schoolteacher. They measured scientific reasoning and scientific comprehension respectively. Although both showed positive results with breast feeding, neither result survived adjustment at P<0.001 (Table 6).

Table 6. Unadjusted and adjusted measures of associations between breast feeding for 6 months and Mathematics and Science test results (results at P<0.001 are in bold).

Measure	**UMD [95% CI][a]**	**N**	**AMD [95% CI][b]**	**N**	**P**	**AMD [95%CI][c]**	**N**	**P**
Arithmetic								
At 4y	**+1.31[0.82, 1.80]**	487	+0.38 [-.17, .92]	446	0.172	+0.39 [-0.16,0.94]	4450	0.163
At 8y	**+1.24 [1.00, 1.48]**	3431	+0.54 [.20, .88]	3116	0.002	+0.57 [0.22, 0.91]	3106	0.001
Maths Comprehension								
At 8 years	**+1.56 [1.31, 1.81]**	**3854**	+0.43 [0.12, 0.75]	1936	0.006	+0.42 [0.10, 0.73]	1931	0.009
At 10 years	**+4.06 [3.60, 4.52]**	**5807**	**+1.56 [1.00, 2.13]**	**2902**	**<0.001**	**+1.55 [0.98, 2.12]**	**2895**	**<0.001**
At 12 years	**+4.25 [3.48, 5.02]**	**2113**	+1.37 [0.45, 2.29]	1073	0.004	+1.41 [0.43, 2.33]	1071	0.003
National maths tests								
SATS2	**+12.34 [11.21, 13.46]**	**8806**	**+3.22 [1.89, 4.55]**	**4362**	**<0.001**	**+3.26 [1.92, 4.59]**	**4349**	**<0.001**
SATS3	**+12.42 [11.18, 13.67]**	**7729**	**+5.29 [3.77, 6.81]**	**3779**	**<0.001**	**+5.30 [3.77, 6.83]**	**3768**	**<0.001**
Science								
Reasoning	**+1.30 [1.13, 1.47]**	**5819**	+0.34 [0.14, 0.55]	2902	0.001	+0.33 [0.13, 0.54]	2896	0.002
Comprehension	**+0.33 [0.28, 0.38]**	**5813**	+0.11 [-0.22, 0.45]	2900	0.511	+0.14[-0.20, 0.48]	2894	0.418

[a] P<0.0001 for each measure; **** = P<0.0001; AMD = adjusted mean difference; UMD = unadjusted mean difference; [b]adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy.

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3.8. Temperament Pre-School

The mother was given a number of questionnaires to assess the temperament of her child. These included the Carey scales at 6 and 24 months of age each of which assessed nine different temperaments [28,29]. We have not considered the 6-month Carey measures here since the mother was still feeding at this time. At 3, 4 and 5 years the Emotionality Activity Sociability Temperament Survey (EAS) was used [30]. This identified four different temperaments at each age. As can be seen from Table 7, of the 21 different age/temperament combinations originally tested, eight were initially associated with breast feeding at P<0.0001, but only three survived adjustment to P<0.001; these comprised negative associations with activity at 3, 4 and 5 years implying that the breast fed children were less active (or less hyperactive) than those who had not had breast milk.

Table 7. Unadjusted and adjusted measures of associations between breast feeding for 6 months and the child's temperament (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
Carey Scores at 24 months								
Rhythmicity	**-0.69 [-1.01, -0.37]**	**8838**	+0.12 [-0.29, 0.53]	4524	0.566	+0.11[-0.30, 0.52]	4509	0.606
Approach	**-1.04 [-1.46, -0.61]**	**8839**	-0.38 [-0.92, 0.16]	4526	0.168	-0.38[-0.92, 0.17]	4511	0.173
Difficult temperament	**-2.36 [-3.31, -1.40]**	**8798**	-1.40 [-2.62, -0.18]	4502	0.025	-1.29[-2.51, -0.06]	4487	0.040
EAS scores								
Activity at 38m	**-0.74 [-0.92, -0.56]**	**8655**	**-0.54 [-0.77, -0.32]**	**4411**	**<0.001**	**-0.52[-0.75, -0.30]**	**4398**	**<0.001**
Emotionality at 4y	**+0.43 [0.23, 0.63]**	**8160**	+0.21 [-0.04, 0.45]	4155	0.097	+0.20[-0.05, 0.45]	4144	0.110
Activity at 4y	**-1.03 [-1.20, -0.86]**	**8161**	**-0.71 [-0.92, -0.49]**	**4156**	**<0.001**	**-0.69[-0.90, -0.47]**	**4145**	**<0.001**
Emotionality at 5y	**+0.43 [0.22, 0.64]**	**7550**	+0.19 [-0.06, 0.45]	3878	0.137	+0.19[-0.07, 0.44]	3866	0.153
Activity at 5y	**-0.97 [-1.15, -0.79]**	**7549**	**-0.63 [-0.85, -0.40]**	**3879**	**<0.001**	**-0.62[-0.84, -0.39]**	**3867**	**<0.001**

[a] P<0.0001 for each measure; **** = P<0.0001; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [b]adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy.

3.9. Behaviour

The major set of scales completed by the mother, the teacher and the children themselves in adolescence, was the Strengths and Difficulties Questionnaire (SDQ) [31]. This comprises six scales: prosocial behaviour, hyperactivity, peer problems, emotional and conduct problems together with total behaviour difficulties. These six scales were obtained on seven occasions. Of the 42 behaviours 19 were associated with breast feeding prior to adjustment, and only one after adjustment (a negative association with hyperactivity).

At age 7, the Developmental and Well-being Assessment (DAWBA) [32] was completed by the mother and partially by the teacher. Of the 30 scales, only five were unadjusted at P<0.0001 and none survived adjustment (Table 8).

Additional behaviours asked were not included in Table 8 if they did not achieve P< 0.0001 in the unadjusted association with breast feeding.

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Table 8. Unadjusted and adjusted measures of associations between breast feeding for 6 months and the child's behaviour (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
SDQ								
Prosocial at 9y[de]	**-0.31 [-0.42, -0.20]**	**6789**	**-0.24 [-0.38, -0.10]**	**3485**	**<0.001**	**-0.24[-0.38, -0.11]**	**3473**	**<0.001**
Hyperactivity at 47m[d]	**-0.80 [-0.93, -0.66]**	**8266**	**-0.36 [-0.53, -0.19]**	**4202**	**<0.001**	**-0.35 [-0.52, 0.18]**	**4189**	**<0.001**
Hyperactivity at 6y[d]	**-0.61 [-0.75, -0.46]**	**7385**	-0.26 [-0.44, -0.08]	3824	0.005	-0.23[-0.41, -0.05]	3811	0.011
Hyperactivity at 9y[d]	**-0.40 [-0.54, -0.25]**	**6787**	-0.06 [-0.24, 0.12]	3483	0.484	-0.04[-0.22, 0.14]	3471	0.683
Hyperactivity at 11y[d]	**-0.46 [-0.61, -0.30]**	**6226**	-0.21 [-0.39, -0.02]	3198	0.030	-0.19[-0.38, -0.01]	3187	0.042
Hyperactivity at 7y[e]	**-0.82 [-1.02, -0.62]**	**4718**	-0.30 [-0.55, -0.05]	2321	0.017	-0.27[-0.51, -0.01]	2314	0.033
Hyperactivity at 10y[e]	**-0.71 [-0.88, -0.53]**	**5397**	-0.12 [-0.34, 0.10]	2669	0.287	-0.10[-0.33, 0.12]	2661	0.362
Emotional symptoms								
At 10y[e]	**-0.27 [-0.40, -0.14]**	**5397**	-0.05 [-0.21, 0.11]	2669	0.543	-0.05 [-0.21, 0.12]	2661	0.583
Conduct problems								
At 47m[d]	**-0.19 [-0.27, -0.12]**	**8266**	-0.01 [-0.11, 0.09]	4202	0.853	+0.01[-0.09, 0.11]	4189	0.777
At 7y[e]	**-0.34 [-0.44, -0.24]**	**4715**	-0.09 [-0.21, 0.04]	2318	0.173	-0.09[-0.21, 0.04]	2318	0.173
At 10y[e]	**-0.31 [-0.42, -0.20]**	**5395**	-0.05 [-0.17, 0.08]	2669	0.471	-0.07[-0.19, 0.06]	2311	0.289
Peer difficulties								
At 47m[d]	**-0.26 [-0.35, -0.18]**	**8266**	-0.10 [-0.21, 0.01]	4202	0.076	-0.09[-0.20,0.02]	4189	0.094
Total difficulties								
At 47m[d]	**-1.30 [-1.55, -1.04]**	**8266**	-0.50 [-0.82, 0.17]	4202	0.003	-0.46[-0.79, -0.14]	4189	0.005
At 6y[d]	**-0.70 [-0.99, -0.41]**	**7377**	-0.07 [-0.43, 0.29]	3822	0.691	-0.01 [-0.37, 0.35]	3809	0.950
At 9y[d]	**-0.68 [-1.00, -0.36]**	**6763**	-0.03 [0.43, 0.36]	3473	0.866	+0.02[-0.37, 0.42]	3461	0.908
At 11y[d]	**-0.84 [-1.17, -0.50]**	**6236**	-0.29 [-0.10, 0.12]	3202	0.163	-0.28[-0.69, 0.13]	3191	0.177
At 7y[e]	**-1.54 [-1.95, -1.12]**	**4718**	-0.64 [-1.16, -0.13]	2321	0.014	-0.58 [1.09, -0.07]	2314	0.027
At 10y[e]	**-1.34 [-1.74, -0.95]**	**5397**	-0.14 [-0.61, 0.34]	2669	0.579	-0.09 [-0.57, 0.39]	2661	0.711
DAWBA at 91m[d]								
No. general anxiety symptoms	**+0.21 [.11, 0.30]**	**7070**	+.00 [-0.11, 0.12]	3665	0.942	+0.01[-0.11, 0.12]	3653	0.923
No. activity symptoms	**-0.47 [-.64, -0.31]**	**1108**	-0.20 [-0.41, 0.01]	3684	0.056	-0.19[-0.40, 0.02]	3672	0.077
Activity symptoms score	**-0.61 [-.84, -0.39]**	**7083**	-0.26 [-0.54, 0.02]	3673	0.069	-0.24 [-0.52, 0.04]	3662	0.087
Total no. attention/activity symptoms	**-0.70 [-1.01, -0.39]**	**7116**	-0.24 [-0.63, 0.15]	3690	0.221	-0.20 [-0.59, 0.18]	3678	0.301
Attention/activity score	**-0.93 [-1.36, -0.50]**	**7096**	-0.33 [-0.85, 0.20]	3682	0.221	-0.29 [-0.82, 0.24]	3670	0.286

[a] P<0.0001 for each measure; AMD = adjusted mean difference; UMD = unadjusted mean difference; [b]Adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy; [d]completed by the mother; [e]completed by the child's teacher; [e]Negative mean score indicates that the breast fed children are more social.

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3.10. Personality and Other Attributes

In Table 9 are descriptions of the associations between breast feeding until 6 months with: (i) Locus of control (using the Nowicki scales [33] at 8 and 16 (the higher the score, the more extraverted); (ii) personality using the Big Five scales [34]: Extraversion, Agreeableness, Conscientiousness, Emotional stability and Intellectuality; (iii) 32 measures of Motor coordination and balance; (iv) 39 tests of attention, inhibition and executive function; (v) 12 measures related to addictions, and (vi) two of cognitive style [35]. Of these, only two survived adjustment: locus of control at age 8, where the children who had been breast fed were more internal, and a scale indicating that the breast fed were more likely to be right-handed (scale completed at 42 months (see Supplementary material).

Table 9. Unadjusted and adjusted measures of associations between breast feeding for 6 months and other attributes of the child (results at P<0.001 are in bold).

Measure	UMD [95% CI][a]	N	AMD [95% CI][b]	N	P	AMD [95% CI][c]	N	P
Locus of control								
At 8y	**-0.87 [-1.02, -0.71]**	**5286**	**-0.33 [-0.52, -0.15]**	**2684**	**<0.001**	**-0.33 [-0.51, -0.14]**	**2674**	**<0.001**
At 16	**+0.44 [.26, 0.62]**	**4037**	-0.01 [-0.22, 0.20]	2124	0.940	-0.01 [-0.22, 0.20]	2119	0.931
Self-esteem at 9y	**-3.58 [-4.93, -2.23]**	**4624**	-2.90 [-4.56, -1.24]	2353	0.001	-2.93 [-4.59, -1.26]	2324	0.001
Cognitive style								
Complete item total	**+4.56 [2.33, 6.79]**	**2818**	+3.46 [0.79, 6.13]	1484	0.011	+3.61 [0.93, 6.29]	1478	0.008
Achievement events	**+2.89 [1.94, 3.85]**	**2818**	+1.94 [0.81, 3.08]	1484	0.001	+ 2.00 [0.87, 3.14]	1478	0.001
Personality at 13y								
Agreeable	**+1.25 [.84, 1.66]**	**4802**	+0.13 [-0.36, 0.63]	1460	0.595	+0.16 -0.34, 0.65]	2454	0.527
Intellectual	**+1.96 [1.51, 2.42]**	**4780**	+0.74 [0.20, 1.27]	2459	0.007	+0.79 [0.25, 1.33]	2453	0.004
Sensation seeking at 18	**+2.22 [1.42, 3.01]**	**2805**	+1.08 [0.14, 2.02]	1481	0.025	+1.10 [0.15, 2.04]	1475	0.023
Motor coordination								
Handedness at 42m	**+0.09 [0.06, 0.12]**	**8584**	**+0.08 [0.04, 0.12]**	**4364**	**<0.001**	**+0.08 [0.04, 0.12]**	**4351**	**<0.001**
Heel to toe at 7y	**+0.41[0.26, 0.57]**	**5922**	+0.23 [0.06, 0.41]	3026	0.010	+0.24 [0.06, 0.42]	3018	0.009
Standing on R leg, eyes open at 10y	**+0.65 [0.37, 0.93]**	**6010**	+0.44 [0.10, 0.78]	3079	0.012	+0.46 [0.11, 0.80]	3069	0.009
Balance score at 10y	**-0.66 [-0.93, -0.40]**	**5887**	-0.30 [-0.62, 0.02]	3023	0.064	-0.29 [-0.61, 0.03]	3013	0.078
Motor task								
Time at 8y	**-.1.76 [-2.35, -1.16]**	**6032**	-1.20 [1.94, -0.46]	3090	0.001	-1.17 [-1.91, -0.43]	3080	0.002
Task at 8y	**-0.10 [-0.13, -0.07]**	**5982**	-0.07 [-.011, -0.03]	3064	0.001	-0.06 [-0.10, -0.02]	3054	0.001
Time at 11y	**-1.09 [-1.54, -0.64]**	**5826**	-0.60 [-1.15, -0.05]	2950	0.034	-0.63 [-1.18, -0.07]	2941	0.027

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Task at 11y	**-0.06 [-0.08, -0.03]**	**5806**	-0.04 [-0.07, -0.01]	2943	0.021	-0.04 [-0.07, -0.01]	2934	0.016
Opposite world time at 11y	**-0.39 [-0.58, -0.21]**	**5592**	+0.02 [-0.20, 0.24]	2825	0.833	+0.03 [-0.19, 0.25]	2816	0.806
Executive function								
Inhibition 1st block reaction time	**-4.60 [-6.89, -2.32]**	**5741**	-1.77 [-4.60, 1.05]	2944	0.218	-1.78 [-4.62, 1.06]	2934	0.220
Addictions								
Alcohol								
No. drinks to feel tipsy when starting to drink	**-0.45 [-0.63, -0.27]**	**2801**	-0.25 [-0.47, -0.03]	1471	0.024	-0.25 [-0.47, -0.03]	1466	0.023
Current no. drinks at 20y	**-0.59 [-0.86, -0.31]**	**2916**	-0.36 [-0.69, -0.03]	1520	0.031	-0.36 [-0.69, -0.03]	1516	0.035
AUDIT score	**+1.17 [0.64, 1.70]**	**3346**	+0.63 [-0.01, 1.28]	1739	0.054	+0.64 [-0.01, 1.28]	1734	0.053

[a] P<0.0001 for each measure; **** = P<0.0001; AMD = Adjusted mean difference; UMD = unadjusted mean difference; [b]adjusted for maternal education, paternal education, maternal age, whether firstborn, Caesarean birth, tenure of housing; [c]additionally adjusted for maternal smoking mid-pregnancy.

4. Discussion

This detailed analysis of 373 neurocognitive measures, with very strict rules concerning the P-values at the two stages of analysis has resulted in the identification of just 42 neurocognitive traits being associated on at least two measures with being breast fed for at least six months. These can be categorised as follows: positive results for traits related to IQ, reading ability, fine motor skills pre-school, development of speech including conversational abilities, ability in mathematics, and reduction in risk of hyperactive behaviour. The relationships with IQ, reading and speech mirror the findings of the large RCT in Belarus. However, the RCT showed no association with child behaviour [1,2] whereas we found a reduced association with active temperament in the pre-school period, as well as of hyperactive behaviour when at school age. This lower level of hyperactivity with prolonged breast feeding is similar to that found in a systematic review [36]. Other associations for which there was only one result satisfying our restrictive P-values included: working memory at age 8 (but not at other ages), prosocial behaviour at 9 (but not at other ages), locus of control at 8 (but not 16).

We had not predicted an association with handedness, but there have been publications from Britain and Ireland [37] that had found this association to be related to duration of breast feeding, and a subsequent systematic review also found that infants who had been breast fed for 3 months or more were more likely to be right-handed at P<0.0001 [38]. Thus, our main findings are supported by the literature.

It is convincing to know that our results in general have been confirmed by other studies – particularly the RCT in Belarus. However, the stringent P-values that we applied may well have resulted in the elimination of results that are valid, causal and potentially important.

There is often discussion concerning associations with breast feeding concerning whether the results are more to do with the physical and emotional closeness between the breast-feeding mother and her child rather than social or other factors. However, the well-designed comparison GUSTO study in Singapore compared (a) the development of children fed breast milk by bottle with those fed artificial milk by bottle and showed that the breast milk group had a higher IQ. Conversely, (b) they compared children fed breast milk by bottle with those breast-fed – the latter were found to have an improved memory [39]. On this evidence it seems likely that breast milk ingestion is the important factor rather than contact between mother and child, although it would be more convincing if there were other similar studies to confirm the GUSTO findings.

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A further explanation of our findings is likely to be the associations between the presence of specific nutrients in breast milk and their association with brain development during the infants' early months of life. Some authors have attempted to determine whether specific components of breast milk are responsible for neurocognitive benefits to the child by comparing children of those mothers who were randomised to take specific nutrient supplements or placebo during breast feeding – but no clear conclusions have yet been reached [40]. However, there is evidence that breast milk can reflect the nutrients present in the nursing mother's diet [42]. Kim [43] and others [44]outlined the various nutrients present in breast milk and concluded that human breast milk 'is the most important source of nutrition for infants and includes microbiomes and miRNAs for growth, development, and immunity'. Among other nutrients mentioned [42] were fatty acids that were the precursors to the omega-3 fatty acids such as DHA (docosahexaenoic acid) and EPA (eicosapentaenoic acid) which are also components of fish which have been shown to be associated with the child's IQ when consumed by the mother during pregnancy [44]. Other components of breast milk that are included in breast milk and have been shown to have an effect on the child's neurocognitive function when consumed in pregnancy involve dietary vitamin B_{12} [27] suggests that future studies should be carried out to determine whether children breast fed by mothers who consume various nutrients have neurocognitive benefits compared with children whose breast feeding mothers consume lower levels of such nutrients during the time they breast feed.

Strengths and Limitations

The strengths of this study are: (i) that the data are concerned with a whole geographic population, not restricted to births in a particular hospital or mothers with a particular social background; (ii) the data on cognitive background was obtained from sources that were blind to whether the child had been breast fed or not – including teacher reports on behaviour and abilities, in-house testing, and linkage to results from standard national assessment tests; (iii) the data available within ALSPAC allowed for detailed analyses taking account of appropriate confounders; (iv) other studies have controlled for maternal but not paternal cognition, using tests administered to the mother. This has received criticism as to its accuracy [45], and is mainly why we have preferred to use the level of education achieved; (v) breast feeding was recorded at several time points during infancy and therefore is not affected by recall bias.

Among the limitations are those common to most longitudinal cohort studies, including attrition. We did not attempt to compensate for this since there was no evidence that the missing data were missing at random. An additional limitation is that the study population largely comprised parents who were of White European origin, which was true of the whole of the study area at the time that the study children were born (the early 1990s). Consequently, the results cannot be extrapolated worldwide or even to elsewhere in Britain or Europe.

A further limitation is the choice of confounders, which may not have been adequate or appropriate for each outcome. The choice of outcomes may also be criticised – by concentrating solely on conditions that are measured in ALSPAC on a continuous scale we have ignored non-linear associations as well as categorical ones. It should be noted also that this set of analyses is concentrated on neurocognitive outcomes, and therefore that conclusions in this group of outcomes in regard to the benefit of breast feeding may not be appropriate for physiological outcomes such as obesity, asthma, eczema or allergies. These will be considered in further detailed sets of analyses elsewhere.

5. Conclusions

These analyses confirm findings in the literature of the long-term intellectual benefits of breast feeding for 6 months on the development of the offspring, including their ability to exceed in academic tests of reading, math, and science. Although there is little sign of benefit to the child's overall behaviour, or mental health, there was an increased chance of being right-handed.

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Informed consent Ethical approval for the study was obtained from the ALSPAC Ethics and Law Committee and the Local Research Ethics Committees. Implied consent from participants for the use of data collected via questionnaires and clinics was assumed following the recommendations of the ALSPAC Ethics and Law Committee at the time [Birmingham 2019].

Data availability: ALSPAC data is available to researchers for particular projects, provided no attempt is made to reveal the identities of the subjects. Guidelines for access are found on the ALSPAC website: www.bristol.ac.uk/alspac/researchers .

Conflicts of interest: Three of the authors have received funding in the past from Nestlé concerning components of infant diet. None of them were influenced in any way concerning publication of the results at the time – or now - which invariably have shown the benefits of breast feeding.

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