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Infant feeding and childhood cognition at ages 3 and 7 years: effects of breastfeeding duration and exclusivity

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Abstract

Importance—Breastfeeding may benefit child cognitive development, but few studies have quantified breastfeeding exclusivity or duration, nor has any study examined the role of maternal diet during lactation on child cognition.

Objectives—(1) To examine associations of breastfeeding duration and exclusivity with child cognition at 3 and 7 years; and (2) to examine the extent to which maternal fish intake during lactation modifies associations of infant feeding with later cognition

Design—Prospective cohort study

Setting—Project Viva, a U.S. pre-birth cohort that enrolled mothers from 1999-2002 and followed children to age 7 years

Participants—1312 Project Viva mothers and children

Main exposure—Duration of any breastfeeding to 12 months

Main outcome measures—Child receptive language assessed with the Peabody Picture Vocabulary Test (PPVT-III) age 3 years; Wide Range Assessment of Visual Motor Abilities (WRAVMA) at 3 and 7 years; and Kaufman Brief Intelligence Test (KBIT) and Wide Range Assessment of Memory and Learning (WRAML) at 7 years.

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Conflicts of interest: None

Results—Adjusting for sociodemographics, maternal intelligence, and home environment in linear regression, longer breastfeeding duration was associated with higher age 3 PPVT-III scores (0.21 points/month, 95% CI: 0.03, 0.38) and greater age 7 intelligence (0.35 verbal KBIT points/month, 95% CI: 0.16, 0.53; 0.29 non-verbal KBIT points/month, 95% CI: 0.05, 0.54). Breastfeeding duration was not associated with WRAML scores. Beneficial effects of breastfeeding on the WRAVMA at age 3 appeared greater for women who consumed ≥2 fish servings/week (0.24 points, 95% CI: 0.00, 0.47) vs. <2 servings/week (-0.01 points, 95% CI: -0.22, 0.20); interaction p-value 0.16.

Conclusions and relevance—Our results support a causal relationship of breastfeeding duration with receptive language and verbal and non-verbal intelligence later in life.

Introduction

Strong evidence supports the association of breastfeeding with health benefits in infancy, including prevention of gastrointestinal infections and otitis media.[1] The extent to which breastfeeding leads to better cognitive development is less certain. While observational studies[1-4] have reported positive associations of breastfeeding with later intelligence, breastfeeding is strongly predicted by determinants of child intelligence such as maternal intelligence and developmental stimulation received by the child; residual confounding by such shared determinants may have led observational studies to overestimate the impact of breastfeeding on child intelligence.[1, 2, 5] Another limitation of prior studies is the classification of infant feeding as “ever” vs. “never” breastfed.[4] Failure to account for partial vs. exclusive breastfeeding or breastfeeding duration could lead to underestimation of the true effect of breastfeeding on child intelligence. Both detailed data regarding breastfeeding exposure and adequate control for confounding factors are necessary for valid estimates of the association of breastfeeding with later intelligence, but to date no study has fulfilled these requirements.

Nutrients in breast milk, such the n-3 fatty acid docosahexaenoic acid (DHA), may benefit the developing brain. A major determinant of breast milk DHA content is the mother's diet,[6] and fish is a rich source of DHA. In pregnancy, greater maternal fish intake – particularly fish low in mercury contamination -- is associated with better childhood cognitive outcomes,[7] but the extent to which maternal fish intake during lactation accounts for the association of breastfeeding with cognition has not been reported.

The aims of our study were: 1) to examine associations of breastfeeding duration and exclusivity with child cognition at 3 and 7 years; and 2) to examine the extent to which maternal fish intake during lactation accounts for the association of infant feeding with later cognition.

Methods

Participants

We studied participants in Project Viva, a prospective, longitudinal cohort study designed to examine prenatal factors in relation to pregnancy and child health. From 1999-2002, Project Viva enrolled pregnant women attending prenatal care at 8 obstetrical offices of a multi-

specialty group practice in eastern Massachusetts. Exclusion criteria included: multiple gestation; inability to answer questions in English; gestational age ≥ 22 weeks at initial prenatal care appointment; and plans to move away from the area prior to delivery. Details of recruitment and follow-up at birth,[8] 6 months,[9] and 3 years[10] have been reported. Age 7 follow-up was completed in December, 2010. Human subjects committees of Harvard Pilgrim Health Care, Brigham and Women's Hospital, and Beth Israel Deaconess Medical Center approved the study and mothers of all participating children gave written informed consent.

Of the 2128 women who delivered a live infant, we excluded 45 children born at <34 weeks' gestation; 325 who were missing breastfeeding status at 6 months and breastfeeding duration at 12 months; and 446 who were missing cognitive measures at 3 and 7 years. Thus, our sample for this analysis was 1312 (1224 at 3 years and 1037 at 7 years).

Measurements

Breastfeeding—When the participating child was 6 and 12 months old, we asked the mother the questions listed in Table 1. To determine breastfeeding exclusivity, at 6 and 12 months, we asked detailed questions about the age at which solid foods and non-breast milk liquids were introduced.

Cognition—When children were 3 years old, trained research staff administered the Peabody Picture Vocabulary Test, 3rd edition (PPVT-III), a test of receptive language highly correlated (Pearson R=0.90) with intelligence tests such as the Weschler Intelligence Scale for Children III (WISC-III).[11] We also administered the Wide Range Assessment of Visual Motor Abilities (WRAVMA)[12] pegboard (fine motor), matching (visual spatial), and drawing (visual motor) subtests. Subtest scores are reported individually and combined as a visual motor composite score.

At age 7 years, we administered the WRAVMA drawing scale and the Kaufman Brief Intelligence Test, 2nd edition (KBIT-II), which measures verbal and non-verbal intelligence and is highly correlated with the WISC-III (Pearson R=0.89).[13] Additionally, we assessed memory and learning with the Wide Range Assessment of Memory and Learning (WRAML)[14] design memory and picture memory tests. Scores were summed to yield a visual memory combined score.

Study staff administering cognitive tests were unaware of the children's breastfeeding status. The PPVT-III, WRAVMA, and KBIT-II are scaled to a mean score of 100 and SD of 15.

Covariates—We collected data from mothers regarding parental and child demographic, social, economic, and health information through self-administered questionnaires and interviews in pregnancy and shortly after delivery.[15] At 6 months postpartum, we administered a brief, validated food frequency questionnaire[16] including questions about the mother's average weekly fish intake (canned tuna fish; dark meat fish e.g. mackerel, salmon, sardines, bluefish, or swordfish; shellfish; and other fish, e.g. cod, haddock, or halibut) since the infant's birth. To measure maternal intelligence, we administered the PPVT to mothers when the child was 3 years old and at 7 years, the KBIT. We also administered the Home

Observation Measurement of the Environment short form (HOME-SF),[17] which measures cognitive stimulation and emotional support in the child's environment. Higher scores indicate more favorable environments (range, 0-22).

Analysis—Our main exposures were: (1) duration of any breastfeeding in months; (2) duration of exclusive breastfeeding in months, defined as feeding breast milk but no solid foods or non-breast milk liquids (except water) to 6 months; and (3) breastfeeding status at 6 months, categorized as 'formula only, never breast fed,' 'formula only, weaned,' 'mixed formula and breast milk,' and 'breast milk only (no formula).' Our outcomes were the age 3 PPVT-III and WRAVMA scores and the age 7 KBIT-II, WRAVMA, and WRAML scores. To examine the effect of potential confounders on estimated associations of breastfeeding measures with cognitive outcomes, in linear regression we adjusted models for the following: model 0, child age and sex; model 1, covariates in model 0 plus gestational age and birth weight z-score;[18] model 2, covariates in model 1 plus child race/ethnicity, maternal age, parity, smoking status, parental education level and marital status, annual household income, maternal depression at 6 months post-partum, maternal employment and child care at age 6 months, and primary language; model 3, covariates in model 2 plus HOME-SF score; and model 4, covariates in model 3 plus maternal PPVT or KBIT score.

To compare our results with other studies, we estimated the difference in cognitive test scores in children "ever" vs. "never" breast fed. To examine the extent to which maternal fish intake modified associations of breastfeeding with outcomes, we stratified by fish intake (<2 vs. ≥2 servings per week) and also calculated the p-value for an interaction term (breastfeeding duration*fish intake) in linear regression.

All covariates were not observed on all subjects. Using only subjects with all data observed would have resulted in a smaller sample size, with most excluded participants missing only one or two values, leading to lost information and possibly a selected subset. We therefore used multiple imputation to generate several plausible values for each missing value.[19] To generate imputation datasets, we used a set of variables chosen from the thousands available in Project Viva to reflect demographic and other factors that we deemed plausibly related to potential missingness mechanisms and to the exposures and outcomes. A "completed" data set includes the observed data and one imputed value for each missing value. The analysis was replicated across completed data sets and then combined in a structured fashion that accurately reflects the true amount of information in the observed data. This method assumes that the exposures and outcomes are missing completely at random, given the observed variables and the imputed covariates. This is a reduced assumption relative to that made in papers that use only complete cases. Using Proc MI ANALYZE in SAS version 9.3 (SAS Institute, Cary NC), we generated 50 complete data sets and combined multivariable modeling results for all 2128 participants in the Project Viva cohort. For this analysis, we excluded participants <34 weeks' gestation and those missing observed exposure or outcome data.

Results

Table 2 shows characteristics of participants included at age 3 and 7 years, and the excluded participants. Compared with those included in the analysis, mothers of excluded participants were less educated, had lower income, were more likely to be of non-white race/ethnicity, and breastfed for a shorter duration. For the 1224 participants included at age 3, the mean duration of any breastfeeding was 6.4 months and of exclusive breastfeeding 2.4 months; numbers were similar for participants included at age 7 years. At 3 years, the mean PPVT-III score was 103.7 and at 7 years, the mean KBIT-II verbal score was 112.5.

Table 3 shows the effect of covariate adjustment on estimated associations of breastfeeding duration with child cognitive outcomes. At age 3, adjusting for child age and sex (Model 0), longer breastfeeding duration was associated with higher PPVT-III scores [0.58 points per month breastfed, 95% confidence interval (CI): 0.40, 0.76]. This association was similar with additional adjustment for fetal growth and gestational age (Model 1), and attenuated with adjustment for demographic variables (Model 2), and HOME score (Model 3). With further adjustment for maternal IQ (Model 4), the association diminished to 0.21 points per month (95% CI: 0.03, 0.38). We observed a similar pattern of attenuation for the KBIT-II verbal and non-verbal scores at age 7.

In Table 4, we show fully adjusted associations of any and exclusive breastfeeding with all cognitive test scores at 3 and 7 years. Associations of breastfeeding duration (any and exclusive) with the PPVT-III and KBIT-II verbal and non-verbal scores were positive and 95% confidence intervals excluded 0. Figure 1 shows the adjusted age 7 KBIT-II scores by category of any breastfeeding duration (<1, 1-3, 4-6, 7-9, 10-11, ≥12 months). Associations of breastfeeding duration with WRAVMA scores were null with narrow 95% CI's.

Estimated mean cognitive test score differences according to breastfeeding status at age 6 months are shown in Table 5. Compared with children fed breast milk only, the age 3 PPVT-III score was ~3 points lower for children never breastfed and ~2 points lower for weaned children and those receiving mixed feedings (trend p=0.01). We observed a similar trend for the KBIT-II verbal and non-verbal scores at age 7, but no appreciable trend for the WRAVMA or WRAML scores.

As compared with children who were never breastfed, for children who were ever breastfed the fully adjusted PPVT-III score at age 3 was 1.45 (95% CI: -0.98, 3.87) points higher; and the KBIT-II verbal score at age 7 was 3.75 (95% CI: 1.17, 6.33) points higher. WRAVMA and WRAML scores were not statistically different (data not shown).

Stratifying by maternal postpartum fish intake (<2 vs. ≥2 servings/week), the association of breastfeeding duration with the WRAVMA score at age 3 appeared stronger in children of women with higher vs. lower fish intake (Table 6) but the interaction was not statistically significant (interaction P-value 0.16). For other cognitive outcomes, associations with breastfeeding duration were not appreciably stronger among children of women who consumed more fish.

Comment

We found that a longer duration and greater exclusivity of breastfeeding were associated with better receptive language at age 3 and verbal and non-verbal IQ at age 7. At age 7, the effect size of 0.35 verbal IQ points/month of any breastfeeding translates to 4.2 points or almost 1/3 of a standard deviation over 12 months whereas the effect of exclusive breastfeeding (0.80 points/month) translates to almost 5 points over 6 months. Effects were similar in direction but somewhat weaker in magnitude for non-verbal IQ and for receptive language at 3 years. We found no important main association of breastfeeding with visual motor skills or visual memory.

While numerous studies have demonstrated associations of breastfeeding with later cognition, many have had methodologic flaws.[1, 4, 5] In particular, adequate control for confounding factors is critical, since breastfeeding and child cognition share many determinants, including maternal characteristics and environmental factors. A 2007 meta-analysis[1] specifically identified maternal intelligence and the home environment as key confounders that are frequently overlooked and identified only one prior study[5] with appropriate adjustment, an analysis of data from the U.S. National Longitudinal Survey of Youth (NSLY) in which the association of breastfeeding (ever vs. never) with achievement scores at 5-14 years was attenuated from 4.7 to 1.3 points after adjustment for maternal intelligence, and diminished to only 0.5 points after adjustment for sociodemographic and other variables including the HOME score. We also adjusted for maternal intelligence and the HOME score, as well as numerous other potential confounders, and nevertheless found a substantially stronger association of ever vs. never breastfed with verbal IQ at age 7 (3.75 points).

It is possible that differences in the degree of breastfeeding exclusivity explain why we observed a stronger association of breastfeeding with cognition than was seen in NSLY. By classifying breastfeeding as “ever” vs. “never,” the NSLY study may have included in their breastfed group a substantial number of infants who received formula and breast milk, biasing results toward the null, but they did not report the degree of mixed feedings. Differences in breastfeeding duration may also explain our discrepant results. In a secondary analysis, the NSLY study found that the achievement scores of children breastfed for ≥29 weeks was 1.5 points higher than children never breastfed (p=0.01), but they considered their data about breastfeeding duration “less reliable” than data about whether or not a child was ever breastfed. Finally, different outcomes (achievement test score in NSLY vs. IQ in our study) may explain our different results.

We identified 4 additional observational studies that adjusted for maternal intelligence and the HOME score.[20-23] While we found a modest association of breastfeeding with verbal intelligence at age 3, neither of the other 2 preschool studies found an important association with cognitive outcomes (McCarthy General Cognitive Index[21, 22] and PPVT-R[22] at age 4). Of the studies reporting school age outcomes, one[21] found a 1.3 point advantage (95% CI -2.3, 4.9) of ever vs. never breastfeeding on the Weschler Full Scale IQ at age 7; another[23] found a 0.7 point advantage (95% CI 0.2, 1.3) on the same outcome at age 11; and the other[22] found no association with either verbal or performance IQ at age 11 (effect estimate

not reported). All of those effect estimates are smaller than ours, but none of the studies accounted for breastfeeding duration or exclusivity.

Studies of cohorts with different confounding patterns are also informative. Brion et al.[24] analyzed associations of breastfeeding duration with IQ at age 8 in 2 cohorts. In one (ALSPAC, UK), both breastfeeding duration and child IQ were strongly predicted by measures of socioeconomic position, whereas in the other (Pelotas, Brazil), child IQ was predicted by socioeconomic factors but breastfeeding duration was not. In both cohorts, child IQ was strongly associated with breastfeeding duration, suggesting that confounding alone did not explain the relationship.

The results of our study are also consistent with a large cluster randomized trial of breastfeeding promotion[25] in which verbal IQ at 6.5 years was 7.5 points (1/2 of a standard deviation) higher in the breastfeeding promotion group. By design, that study minimized confounding by both measured and unmeasured factors, however non-blinding of clinicians assessing the cognitive outcomes to participant breastfeeding status suggests the potential for bias. Taken together, the well-controlled observational studies (including ours), analysis of cohorts without social patterning of breastfeeding (e.g. Pelotas), and the large randomized trial suggest that confounding does not account fully for the observed association of breastfeeding with later cognition.

In analyses stratified by fish intake, the beneficial effects of breastfeeding on visual motor ability at age 3 appeared greater for women who consumed ≥2 vs. <2 servings per week, although the interaction was not statistically significant. This observation is consistent with the hypothesis that one or more nutrients in fish transfer to breast milk and account for some of the observed beneficial effect, and is relevant to optimizing the maternal diet during lactation. DHA is incorporated in large amounts into cell membranes of the developing retina and brain. Its content in breast milk is highly variable[26] and depends on DHA sources in the maternal diet[6, 27] including fish; infant DHA status in turn depends on the DHA content of ingested breast milk [27]. Randomized trials of DHA supplementation during lactation have found beneficial effects of DHA on early motor skills[28] and sustained attention[29], but not visual motor function or general cognition.[28, 30] Our observation may be explained by DHA or nutrients in fish other than DHA. It may also be a chance finding.

Strengths of our study include a prospective design, detailed contemporaneous measurement of both exclusivity and duration of breastfeeding, and measurement of numerous potential confounding variables including the home environment and maternal IQ. As in all observational studies, confounding by unmeasured factors is still possible and may have led us to overestimate of the true effect of breastfeeding, although our results are consistent with data from a randomized trial of breastfeeding promotion which eliminates confounding by design. We measured cognition at school age, which tends to be relatively stable through adulthood,[31] as compared with measurement in preschool or earlier. The relatively high socioeconomic status and high breastfeeding rate of our cohort may limit generalizability. Additionally, we followed only a subset of the original Project Viva cohort to 3 and 7 years. The children we followed tended to be of higher socioeconomic status and were less likely to be of minority race or ethnicity than the children we did not follow, which could have led

to overestimates if the effect of breastfeeding on cognition was much weaker or in the opposite direction in those who dropped out, situations we find unlikely. Finally, for the statistically significant associations of breastfeeding with later cognition, 95% confidence intervals were narrow and exclude a null result but the lower confidence limits do include values with little clinical importance.

In summary, our results support a causal relationship of breastfeeding in infancy with receptive language at age 3 and verbal and non-verbal IQ at school age. These findings support national and international recommendations to promote exclusive breastfeeding through 6 months of age and continuation of breastfeeding through at least one year.

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Abbreviations

DHA docosahexaenoic acid

HOME-SF	Home Observation Measurement of the Environment, short form
KBIT-II	Kaufman Brief Intelligence Test, 2nd edition
NLSY	National Longitudinal Survey of Youth
PPVT-III	Peabody Picture Vocabulary Test, 3rd edition
WISC-III	Weschler Intelligence Scale for Children, 3rd edition
WRAML	Wide Range Assessment of Memory and Learning
WRAVMA	Wide Range Assessment of Visual Motor Abilities

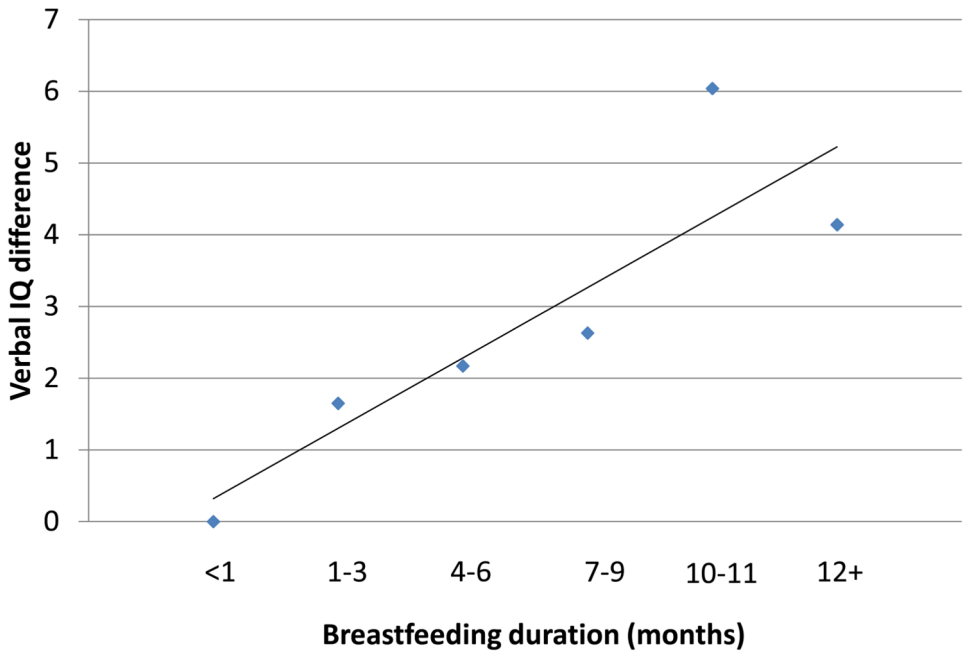

Figure 1.

Difference in Kaufman Brief Intelligence Scale, 2nd edition (KBIT-II) verbal score at age 7 according to breastfeeding duration in months with linear trend line. Estimates are adjusted for child age, sex, fetal growth, gestational age, race/ethnicity, and primary language; maternal age, parity, smoking status, IQ, depression, employment, and child care at 6 months post-partum; and parental education level, annual household income, and HOME-SF score.

Table 1
Questions about breastfeeding at 6 and 12 months

At age 6 months
For all infants:
1 Have you ever breastfed your baby? By breastfeeding, we mean that you have put your baby to your breast, whether or not your baby actually received breast milk, or that you have fed your baby your breast milk.
2 Are you now feeding your baby any infant formula?
3 Are you now feeding your baby any breast milk?
For weaned infants:
How old was your baby when you stopped breastfeeding?
At age 12 months
For all infants:
Have you ever breastfed your child?
Are you still breastfeeding at all?
For weaned infants:
How old was your child when you stopped breastfeeding?

Table 2
Description of included and excluded Project Viva mothers and children

	N=1224 included at 3 years	N=1037 included at 7 years	N=771 excluded at 3 and 7 years*
Mother	*Mean (SE)*		
Age (years)	32.5 (0.1)	32.3 (0.2)	31.0 (0.2)
PPVT score	106.0 (0.4)	105.4 (0.5)	100.8 (0.8)
KBIT-II score	107.9 (0.5)	107.2 (0.5)	102.5 (0.7)
	Percent		
Fish intake ≥2 servings per week	55.0%	52.8%	50.1%
Parity			
0	47.5%	47.3%	47.6%
1	36.3%	36.4%	35.4%
≥2	16.2%	16.4%	17.0%
Smoking status			
Never	68.8%	70.1%	64.5%
Former	21.0%	20.1%	17.4%
During pregnancy	10.2%	9.8%	18.1%
Depression 6 months postpartum	8.8%	9.1%	11.0%
Education			
High school diploma or less	7.2%	8.6%	18.8%
Some college	20.2%	21.3%	26.9%
Bachelor's degree	37.7%	34.9%	32.7%
Graduate degree	34.9%	35.2%	21.6%
Employment 6 months postpartum			
Employed	66.0%	66.7%	56.0%
Employed, on maternity leave	6.0%	6.8%	6.2%
Not employed, looking	4.6%	5.3%	10.1%
Not employed, not looking	23.3%	21.3%	27.7%
Child	Mean (SE)		
Gestational age (weeks)	39.6 (0.04)	39.7 (0.04)	39.6 (0.05)
Birth weight (kg)	3.5 (0.01)	3.5 (0.02)	3.5 (0.02)
Birth weight for gestational age z-score	0.22 (0.03)	0.20 (0.0)	0.14 (0.04)
	Percent		
Female	50.4%	50.5%	47.7%
Race/Ethnicity			
Asian	2.7%	3.0%	5.8%
Black	11.9%	15.1%	21%
Hispanic	3.5%	3.7%	8%
White	70.1%	66.1%	55.4%
Other	11.8%	12.2%	9.8%
Primary English speaker	96.2%	98.7%	92.7%
Child care at 6 months			

	N=1224 included at 3 years	N=1037 included at 7 years	N=771 excluded at 3 and 7 years*
Center	16.8%	17.2%	17.4%
Other home	26.1%	27.3%	24.8%
At own home	14.3%	13.6%	14.9%
None	42.8%	42.0%	43.0%
Breastfeeding status at 6 months			
Formula only, never breast fed	10.6%	10.1%	15.0%
Formula only, weaned	34.7%	35.1%	46.3%
Mixed formula and breast milk	26.4%	26.8%	19.5%
Breast milk only, no formula	28.2%	28.0%	19.2%
	Mean (SE		
Breastfeeding duration (months)			
Exclusive (to 6 months)	2.4 (0.1)	2.4 (0.1)	1.9 (0.1)
Any (to 12 months)	6.4 (0.1)	6.5 (0.1)	4.9 (0.2)
Child cognition			
3 years			
PPVT-III	103.7 (0.43)	N/A	
Total WRAVMA	101.8 (0.33)	N/A	
7 years			
KBIT-II verbal	N/A	112.5 (0.5)	
KBIT-II non-verbal	N/A	106.5 (0.5)	
WRAVMA drawing	N/A	92.2 (0.5)	
WRAML visual memory	N/A	16.9 (0.1)	
Family/Household			
HOME-SF score	18.4 (0.1)	18.4 (0.1)	
	Percent		
Income (1st trimester)			
<40,000	14.3%	16.2%	23.2%
40,001-70K	22.3%	21.2%	26.4%
>70,000	63.4%	62.6%	50.4%
Married/co-habitating (1st trimester)	93.6%	92.4%	89.3%
Mother's Partner			
Education			
High school diploma or less	13.3%	14.2%	22.1%
Some college	19.8%	20.5%	24.7%
Bachelor's degree	36.5%	35.7%	30.0%
Graduate degree	30.4%	29.6%	23.3%

PPVT-III is Peabody Picture Vocabulary Test, 3rd edition. KBIT-II is Kaufman Brief Intelligence Test, 2nd edition. WRAVMA is Wide Range Assessment of Visual Motor Abilities. WRAML is Wide Range Assessment of Memory and Learning. HOME-SF is Home Observation Measurement of the Environment, Short Form.

* excluded due to missing exposure or outcome data

Table 3

Effect of Covariate Adjustment on Estimated Associations of Breastfeeding Duration* with Child Cognition

	Age 3 years (n=1224)	Age 7 years (n=1037)	
	Points per month breastfed and 95% confidence interval		
	PPVT-III	**KBIT-II verbal**	**KBIT-II non-verbal**
Model 0: Child age & sex	0.58 (0.40, 0.76)	0.96 (0.77, 1.14)	0.65 (0.43, 0.87)
Model 1: Model 0 + fetal growth, gestational age	0.57 (0.39, 0.75)	0.95 (0.76, 1.14)	0.64 (0.42, 0.86)
Model 2: Model 1 + demographic variables†	0.29 (0.12, 0.47)	0.46 (0.28, 0.65)	0.38 (0.13, 0.62)
Model 3: Model 2 + HOME score	0.29 (0.11, 0.46)	0.46 (0.27, 0.64)	0.38 (0.13, 0.62)
Model 4: Model 3 + maternal IQ	0.21 (0.03, 0.38)	0.35 (0.16, 0.53)	0.29 (0.05, 0.54)

* any breastfeeding through 12 months of age

† child race/ethnicity, maternal age, parity, smoking status, parental education level and marital status, annual household income, maternal depression at 6 months post-partum, maternal employment and child care at age 6 months, and primary language

Table 4
Adjusted Associations of Breastfeeding Duration With Cognitive Test Scores

	Any breastfeeding to 12 months	Exclusive breastfeeding* to 6 months
	Points per month breastfed and 95% confidence interval	
Age 3 years		
PPVT-III	0.21 (0.03, 0.38)	0.50 (0.11, 0.89)
WRAVMA		
Drawing	0.01 (-0.15, 0.16)	-0.12 (-0.47, 0.22)
Pegboard	0.09 (-0.06, 0.24)	-0.03 (-0.37, 0.31)
Matching	0.09 (-0.10, 0.27)	0.00 (-0.42, 0.41)
Total	0.08 (-0.07, 0.23)	-0.07 (-0.40, 0.27)
Age 7 years		
KBIT verbal	0.35 (0.16, 0.53)	0.80 (0.38, 1.22)
KBIT non-verbal	0.29 (0.05, 0.54)	0.58 (0.01, 1.14)
WRAVMA drawing	-0.08 (-0.33, 0.18)	-0.05 (-0.62, 0.53)
WRAML visual memory	0.04 (-0.02, 0.11)	0.12 (-0.03, 0.27)

Estimates are adjusted for child age, sex, fetal growth, gestational age, race/ethnicity, and primary language; maternal age, parity, smoking status, IQ, depression, employment, and child care at 6 months post-partum; and parental education level, annual household income, and HOME-SF score.

* No solid foods or non-breast milk liquids (except water)

Table 5

Adjusted* Mean Difference (95% Confidence Interval) in Cognitive Test Scores at Ages 3 and 7 Years According to Breastfeeding Status at 6 Months

Cognitive test	Breastfeeding status				
	*Numbers are estimated cognitive test points (95% confidence interval)**				
Age 3 years	**Never**	**Weaned**	**Mixed†**	**Breast milk only‡**	***Trend P***
PPVT-III	-3.17 (-5.92,-0.41)	-2.26 (-4.22,-0.29)	-2.27 (-4.24,-0.30)	0.00 (ref)	0.01
WRAVMA drawing	-0.63 (-3.03, 1.78)	-0.01 (-1.74, 1.72)	-0.52 (-2.27, 1.22)	0.00 (ref)	0.80
WRAVMA pegboard	-1.96 (-4.31, 0.39)	-0.36 (-2.05, 1.34)	0.04 (-1.66, 1.74)	0.00 (ref)	0.18
WRAVMA matching	-1.93 (-4.82, 0.96)	-0.62 (-2.65, 1.41)	-1.13 (-3.21, 0.96)	0.00 (ref)	0.29
Total WRAVMA	-2.04 (-4.39, 0.30)	-0.47 (-2.13, 1.19)	-0.75 (-2.42, 0.93)	0.00 (ref)	0.19
Age 7 years					
KBIT-II verbal	-5.59 (-8.52,-2.67)	-2.96 (-5.05,-0.88)	-1.40 (-3.49, 0.68)	0.00 (ref)	0.0001
KBIT-II non-verbal	-2.71 (-6.62, 1.21)	-3.11 (-5.89,-0.33)	-1.33 (-4.08, 1.43)	0.00 (ref)	0.04
WRAVMA drawing	0.47 (-3.62, 4.55)	-0.14 (-3.03, 2.76)	-0.73 (-3.61, 2.15)	0.00 (ref)	0.87
WRAML visual memory	-0.67 (-1.72, 0.39)	-0.30 (-1.06, 0.45)	0.39 (-0.36, 1.14)	0.00 (ref)	0.15

*adjusted for child age, sex, fetal growth, gestational age, race/ethnicity, and primary language; maternal age, parity, smoking status, IQ, depression, employment, and child care at 6 months post-partum; and parental education level, annual household income, and HOME-SF score; p-values calculated in linear regression with breastfeeding category (1=never, 2=weaned, 3=mixed, 4=breast milk only) as a continuous exposure variable

†breast milk and formula

‡no formula

Table 6

Adjusted Associations of Breastfeeding Duration With Cognitive Test Scores at Ages 3 and 7 Years: Effect of Maternal Postpartum Fish Intake

	Fish <2 servings/week	Fish ≥2 servings/week	
Age 3 years	***Points per month breastfed and 95% confidence interval***		***Interaction P-value***
PPVT-III	0.10 (-0.15, 0.35)	0.30 (0.03, 0.58)	0.22
Total WRAVMA	-0.01 (-0.22, 0.20)	0.24 (0.00, 0.47)	0.16
Age 7 years			
KBIT-II verbal	0.31 (0.06, 0.56)	0.35 (0.05, 0.65)	0.82
KBIT-II non-verbal	0.36 (0.02, 0.69)	0.15 (-0.25, 0.56)	0.95
WRAVMA	-0.04 (-0.40, 0.32)	-0.06 (-0.47, 0.35)	0.92
WRAML	0.06 (-0.03, 0.16)	0.04 (-0.06, 0.14)	0.75

Estimates are adjusted for child age, sex, fetal growth, gestational age, race/ethnicity, and primary language; maternal age, parity, smoking status, IQ, depression, employment, and child care at 6 months post-partum; and parental education level, annual household income, and HOME-SF score