Associations between breastfeeding and cognitive function in children from early childhood to school age: a prospective birth cohort study

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Research

Keywords: Breastfeeding, Cognitive development, Childhood, School-age children

DOI: https://doi.org/10.21203/rs.3.rs-16984/v2

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Abstract

Background: Despite the evident benefits of breastfeeding for preventing acute physical illnesses in infants, the evidence for the benefit of breastfeeding on long-term cognitive development is not yet convincing.

Methods: The data of nationwide representative sample of 1,752 children born between 2008 and 2009 in Korea were prospectively assessed from the fetal period to examine the benefits of breastfeeding and cognitive development. Breastfeeding duration was prospectively assessed by parents. The Korean Ages and Stages Questionnaire and the Korean version of Denver II were used to assess early development annually from 5.5 to 26.2 months of age. Language development at 3 years of age was assessed with Receptive and Expressive Vocabulary Tests. Cognitive function at 8 years of age was assessed using multifactorial intelligence test.

Results: Children who were breastfed 1–3 months displayed significantly higher odds ratios for delayed development assessed at 14.1 months than those breastfed for 3–6 months. Children who were breastfed for >3 months also scored significantly higher on the communication and problem-solving subscales at 14.1 and 26.2 months of age, the expressive language subscale at 3 years, and the vocabulary and language inference vocabulary subscales at 8 years of age than children who were breastfed for <3 months.

Conclusion: We found that cognitive development was improved in children that were breastfed for >3 months. Although these results are supported by previous studies, it is important to note that other factors were larger determinants of cognitive development than breastfeeding. Future studies that examine the underlying mechanism for the association between breastfeeding and cognitive development are warranted.

Background

Breastfeeding is an important component of nutrition for infants and it provides various health benefits to the child and mother [1]. Breastfeeding has clear short-term benefits for reducing morbidity and mortality from infectious disease in infants [2]. Breastfeeding provides health benefits and prevention of acute physical illnesses including gastrointestinal illnesses, otitis media, respiratory tract infections, and neonatal necrotizing enterocolitis to infants [1, 3]. Breastfeeding may also prevent infants from developing chronic diseases such as asthma, allergies, and obesity [1].

Cognitive development in children has been another effect examined in breastfeeding research. The topic was first studied by Hoefer and Hardy in 1929 and multiple other studies have since examined the associations between breastfeeding and cognitive function of children with consistently reported positive associations [4]. A meta-analysis of 11 studies reported that infants who were breastfed had higher intelligence quotients (IQ) by 5.32 points (unadjusted) and 3.16 points when adjusted for covariates [5]. In addition, the higher levels of cognitive function observed in breastfed infants were stable across successive ages. A more recent meta-analysis of 17 studies on the relationship between breastfeeding and intelligence reported that breastfed subjects presented a higher IQ by 3.44 points or by 2.62 points when controlled for maternal IQ [6].

A randomized experiment performed with consideration of the concerns raised regarding previous observational studies also reported significantly higher verbal IQ, performance IQ, and full-scale IQ in the breastfed group by 7.5, 2.9 and 5.9 points, respectively [7]. The breastfed group also scored higher in teacher ratings of both reading and writing. Likewise, cross-population studies of British and Brazilian cohorts reported that longer breastfeeding duration was related to higher IQ scores by 3–6 points [8]. The cognitive benefits of breastfeeding were reported to persist into adulthood. IQ scores at the age of 30 were 3.76 points higher in participants who were breastfed for >12 months compared to those who were breastfed for <1 month [9].

Despite the evidence for the positive associations between breastfeeding and cognitive development by multiple studies within various populations, there are few studies that have employed multiple assessment tools and retrospective assessment of cognitive development at multiple points. In addition, previous studies in the Korean population, especially using prospective methods, are sparse. A study of the Korean population reported significantly higher IQ by 4.07 points in breastfed children compared to non-breastfed children assessed at age of 9 years [10]. Kim et al. reported that breastfed Korean children had significantly higher learning quotient scores in speaking, reading, writing, spelling, and mathematical calculation than children who were never-breastfed [11]. However, these studies were based on a cross-sectional sample and retrospective information on breastfeeding; therefore, the causal relationship between breastfeeding and learning skills cannot be drawn and recall bias is possible in these studies. The present study aims to examine the associations between breastfeeding and cognitive development in Korean children from ages of 1–8 years using multimodal and multi-informant assessment and a prospective study design.

Methods

Participants

The present study utilized data collected from the Panel Study on Korean Children (PSKC). The PSKC is an ongoing longitudinal panel study conducted by the Korea Institute of Child Care and Education since 2008. The participants in PSKC were assessed by stratified multistage sampling using resident registration data to represent all nationwide household populations. A total of 2,150 children born between 2008 and 2009 in Korea were enrolled in the study from the fetal period and evaluated prospectively for breastfeeding and cognitive development at 5.5 (T1), 14.1 (T2), 26.2 (T3), 38.7 (T4), and 99.2 (T9) months of age. Because of the challenges of longitudinal cohort studies, there was some missing data for the follow-
up assessments. In our study, we analyzed data collected from 1,752 children whose assessments of breastfeeding and K-ASQ at T3 (26.2 months) were present. The number of participating children and data in each assessment is presented in Table S1.

Measurements

Demographic variables including the child’s sex, age, gestational period, birth weight, parents’ education level, and household income were assessed by paper and pencil interviews and computer-assisted personal interviews. Breastfeeding data from T1 (5.5 months) to T4 (38.7 months) was prospectively collected by computer-assisted personal interviews.

Early development

To assess early cognitive development at T1 (5.5 months), T2 (14.1 months), and T3 (26.2 months), the participants were assessed using the Korean Ages and Stages Questionnaires (K-ASQ) and the Korean version of Denver II, which are widely used screening tools for early development. K-ASQ is a screening tool for the developmental progress of infants and toddlers as rated by parents [12]. K-ASQ consists of 30 items rated on three-point Likert scales under five subdomains [13]. Examples of questions for each subdomain of K-ASQ are listed here. (1) Communication: Does your child point out and express what they want? Does your child express “yes” or “no” by nodding or shaking their heads? (2) Gross motor: Does your child hold the device and lower his/her posture without falling or falling? Does your child hold furniture with one hand and walk with its support? (3) Fine motor: Does your child hold a string (such as a string hanging from a toy) with his/her thumb or index finger after 1–2 attempts? Does your child place a small toy down (and not drop it) and then release the toy? (4) Problem-solving: Do your children perform a clapping-like with small objects? Does your child place small toys in a container such as a box or bowl? (5) Personal–social: Does your child play with dolls or animal toys? If you reach out and ask for a toy, does the child hand it over to you? Scores that were two standard deviations below average in each subdomain were coded as atypical. Denver II is another screening tool for early development with a validated Korean version [14, 15]. Denver II codes the development of children to the dichotomous outcomes of “normal” or “suspicious” based on the assessment scores. Examples of items to check in each category of the Denver II screening tool include the following: (1) personal–social: use a spoon or fork, remote garment, and feed doll; (2) fine motor/adaptive: place a block in a cup, scribble, and build towers using two cubes; (3) language: combine words and name one picture; and (4) gross motor: walk backward and climb staircase.

Cognitive function in middle childhood and school age

Language abilities at T4 (38.7 months) were assessed by the Receptive and Expressive Vocabulary Test (REVT), which is comprised of 185 Korean vocabulary items and two subscales of receptive and expressive language tests [16]. The REVT results were coded as percentile scores of 1 (under 10%) to 11 (100%). The cognitive function of school-age children at T9 (99.2 months) was assessed in terms of intelligence and academic performance. The intelligence of children was assessed using the multifactorial intelligence test (M-FIT). The M-FIT is comprised of six subdomains (vocabulary, language inference, schematization, calculation, spatial perception, and reasoning), each with 20 item tests. The scores of M-FIT are presented with the T-score and percentile score (0–100) based on normative data. Our analysis used the T-score, which is a standardized score of 50 ± 10 points.

Statistical analysis

Although the criterion for breastfeeding duration to group participants vary widely in previous studies, many studies included “never,” “1 month,” “3 months,” “6 months,” and “12 months” as the duration criteria [17]. In our study, participants were grouped by the following breastfeeding durations according to previous studies [18, 19]: “never,” “up to 1 month,” “1–3 months,” “3–6 months,” “6–12 months,” “12–18 months” and “over 18 months.” We used logistic regression to investigate the odds ratio for delayed development of the early period (T1, 5.5 months to T3, 26.2 months) assessed by Denver II and K-ASQ. To compare the outcomes of K-ASQ as continuous variables, language ability at T4 (38.7 months), and intelligence and academic function at T9 (99.2 months) among the groups of breastfeeding duration, analysis of variance and analysis of covariance (ANCOVA) were utilized. In all analyses, the adjusted model included the children’s sex, age, gestational age, birth weight, parents’ education level, and household income as covariates. To adjust for multiple comparisons included in our analysis, we performed the Benjamini–Hochberg test with a false discovery rate threshold of 0.05 for the crude and adjusted models, respectively [20]. Statistical analyses were conducted using the software package SPSS 25.0 for Windows (IBM Co., Armonk, NY, USA).

Ethics

We provided parents with information on the purpose and procedure of the study and written informed consent was obtained from parents before enrollment. This study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The study protocol was approved by the Institutional Review Board of the Korean Institute of Child Care of Education (KICCEIRB-2016-07).

Results

Demographic characteristics and prevalence of breastfeeding
In the final sample of 1,752 children whose assessment findings for breastfeeding and K-ASQ at the age of 14 months were present, 1,632, 1,704, 1,752, 1,630, and 1,398 children were included in the analysis of each assessment wave at 5.5 (T1), 14.1 (T2), 26.2 (T3), 38.7 (T4), and 99.2 (T9) months of age, respectively, due to some missing assessments and dropout at follow-up. The demographic characteristics of participants are presented in Table 1. Of the total participants, 893 (51%) children were male, 52 (3.0%) children were born preterm and 49 (2.8%) children were born with low birth weights. The prevalence and duration of breastfeeding are presented in Table 2. The proportion of children who were ever-breastfed in our study was 97.4%. The proportion of never-breastfed children was 2.6% and children who were breastfed for ≤1 month was 15.8%. The proportion of children who continued breastfeeding after 6 months was 61.8%.

Table 1. Demographic characteristics of the participants.

| Variables                        | n (%)          |
|----------------------------------|----------------|
| Sex                              |                |
| Male                             | 893 (51.0)     |
| Female                           | 859 (49.0)     |
| Gestational age (days)           |                |
| <259 (preterm)                   | 52 (3.0)       |
| ≥259 (term)                      | 1638 (93.5)    |
| Unknown                          | 62 (3.5)       |
| Birth weight (g)                 |                |
| <2,500                           | 49 (2.8)       |
| ≥2,500                           | 1647 (94.0)    |
| Unknown                          | 56 (3.2)       |
| Household income                 |                |
| ≤2000                            | 432 (24.7)     |
| >2000 and ≤3000                  | 532 (30.4)     |
| >3000 and ≤4000                  | 315 (18.0)     |
| >4000 and ≤5000                  | 193 (11.0)     |
| >5000                            | 111 (6.3)      |
| Unknown                          | 169 (9.6)      |
| Paternal educational level (years)|                |
| ≤12                              | 520 (29.7)     |
| >12 and <16                      | 486 (27.7)     |
| ≥16                              | 680 (38.8)     |
| Unknown                          | 66 (3.8)       |
| Maternal educational level (years)|            |
| ≤12                              | 454 (25.9)     |
| >12 and <16                      | 362 (20.7)     |
| ≥16                              | 809 (46.2)     |
| Unknown                          | 127 (7.2)      |
| Age at each assessment (months; mean; SD) |         |
| T1                               | 5.5 (1.2)      |
| T2                               | 14.1 (1.0)     |
| T3                               | 26.2 (1.3)     |
| T4                               | 38.7 (1.4)     |
| T9                               | 99.2 (1.4)     |
after multiple comparisons, the differences were significant only in the problem-solving subscale of the crude model.

Table 2. Proportion of the participants in each breastfeeding duration category

| Breastfeeding duration (months) | n  | %    |
|---------------------------------|----|------|
| Never breastfed                 | 45 | 2.6  |
| 1 month or less                 | 231| 13.2 |
| More than 1 month to 3 months or less | 281 | 16.0 |
| More than 3 months to 6 months or less | 205 | 11.7 |
| More than 6 months to 12 months or less | 445 | 25.4 |
| More than 12 months or 18 months or less | 381 | 21.7 |
| More than 18 months             | 164| 9.4  |
| Total                           | 1752| 100.0|

Odds ratios for delays in early development based on the duration of breastfeeding

The odds ratio for delayed development at T1 (5.5 months) to T3 (26.2 months) are presented in Table 3. In the six group comparison, odds ratios for delayed development assessed with K-ASQ at T2 (14.1 months) were significantly higher in children breastfed for 1–3 months by 2.21 (95% CI: 1.08–4.50; crude) or 2.63 (95% CI: 1.20–5.77; adjusted) folds, compared to the reference group (children breastfed for 3–6 months). The comparison of two groups at T3 (26.2 months) presented significantly higher odds ratios for delayed development by 1.45-fold (95% CI: 1.02–2.07; crude) in children breastfed for ≤3 months than those breastfed for >3 months. In some development assessments (i.e., Denver II at T1 and T3), children breastfed for ≤1 month presented lower odds ratios for development delay. However, these odds ratios did not reach significance.

Table 3. Odds ratio for delayed development at T1, T2, and T3 based on the duration of breastfeeding.

| Breastfeeding duration (months) | 0 to ≤ 1 | 1 < and ≤ 3 | 3 < and ≤ 6 | 6 < and ≤ 12 | 12 < and ≤ 18 | over 18 | Two-group comparisona |
|---------------------------------|---------|-------------|-------------|-------------|-------------|---------|-----------------------|
| Crude (n)                       |         |             |             |             |             |         |                       |
| Denver II at T1 (n = 1429)      | 0.67 (0.32–1.44) | 1.07 (0.53–2.15) | Referent    | 1.16 (0.62–2.19) | 0.89 (0.46–1.73) | 0.88 (0.39–1.99) | 0.86 (0.57–1.30) |
| Denver II at T2 (n = 1608)      | 0.85 (0.55–1.30) | 1.04 (0.68–1.58) | Referent    | 0.88 (0.60–1.30) | 0.98 (0.66–1.46) | 0.91 (0.56–1.48) | 1.00 (0.79–1.27) |
| Denver II at T3 (n = 1731)      | 0.71 (0.39–1.30) | 0.98 (0.56–1.72) | Referent    | 0.84 (0.49–1.42) | 0.76 (0.44–1.32) | 1.23 (0.66–2.26) | 0.95 (0.68–1.32) |
| K-ASQ at T1 (n = 1632)          | 1.01 (0.42–2.45) | 1.41 (0.62–3.24) | Referent    | 0.88 (0.38–2.01) | 1.28 (0.57–2.85) | 1.14 (0.43–3.04) | 1.14 (0.72–1.81) |
| K-ASQ at T2 (n = 1704)          | 2.02 (0.98–4.15) | 2.21 (1.08–4.50)* | Referent    | 1.54 (0.77–3.09) | 1.94 (0.97–3.87) | 2.12 (0.97–4.64) | 1.28 (0.92–1.79) |
| K-ASQ at T3 (n = 1752)          | 1.73 (0.88–3.43) | 1.51 (0.75–3.01) | Referent    | 1.26 (0.65–2.44) | 0.99 (0.49–1.99) | 1.17 (0.52–2.63) | 1.45 (1.02–2.07)* |
| Adjusted (n)                    | 0.58 (0.26–1.30) | 0.82 (0.39–1.76) | Referent    | 1.10 (0.56–2.15) | 0.75 (0.37–1.53) | 0.66 (0.26–1.65) | 0.77 (0.49–1.22) |
| Denver II at T1 (n = 1264)      | 1.07 (0.66–1.73) | 1.24 (0.77–1.98) | Referent    | 1.10 (0.71–1.71) | 1.31 (0.84–2.05) | 1.08 (0.63–1.86) | 1.01 (0.77–1.31) |
| Denver II at T2 (n = 1455)      | 0.54 (0.27–1.09) | 0.96 (0.52–1.79) | Referent    | 0.86 (0.48–1.54) | 0.87 (0.48–1.57) | 1.27 (0.65–2.49) | 0.79 (0.54–1.16) |
| Denver II at T3 (n = 1472)      | 1.40 (0.46–4.21) | 2.09 (0.73–6.00) | Referent    | 1.38 (0.48–3.97) | 1.97 (0.70–5.53) | 1.63 (0.48–5.54) | 1.14 (0.67–1.93) |
| K-ASQ at T1 (n = 1436)          | 1.95 (0.86–4.42) | 2.63 (1.20–5.77)* | Referent    | 1.63 (0.75–3.53) | 2.03 (0.94–4.38) | 2.54 (1.09–5.90)* | 1.30 (0.90–1.88) |
| K-ASQ at T2 (n = 1461)          | 1.64 (0.76–3.52) | 1.61 (0.75–3.45) | Referent    | 1.40 (0.67–2.93) | 1.20 (0.56–2.56) | 1.10 (0.44–2.77) | 1.33 (0.89–1.99) |
| K-ASQ at T3 (n = 1491)          | 1.09 (0.52–2.26) | 1.51 (0.75–3.01) | Referent    | 1.26 (0.65–2.44) | 0.99 (0.49–1.99) | 1.17 (0.52–2.63) | 1.45 (1.02–2.07)* |

a: Odds ratio for development delay in children breastfed for three months or less compared to children breastfed for more than three months.

The adjusted model included children's sex, age, gestational age, birth weight, parents' education level and household income as covariates.

* p < 0.05

Comparison of cognitive function scores based on the duration of breastfeeding

The comparison of scores on each cognitive function test are presented in Table 4. The subscales of communication (F = 17.71; p < 0.001; Cohen's $d = 0.219$) and problem-solving (F = 11.26; p < 0.001; Cohen's $d = 0.175$) at T2 (14.1 months) were significantly higher in children breastfed for >3 months compared to children breastfed for ≤3 months. Those breastfed for >3 months also presented significantly higher scores on the subscales of communication (F = 6.13; p = 0.013; Cohen's $d = 0.127$) and problem-solving (F = 6.79; p = 0.009; Cohen's $d = 0.134$) at T3 (26.2 months). However, after multiple comparisons, the differences were significant only in the problem-solving subscale of the crude model.
Language development at T4 (38.7 months) assessed with REVT presented significantly higher scores on the expressive language subscale ($F = 12.85; p < 0.001; \text{Cohen's } d = 0.191$) in children breastfed for >3 months, compared to those breastfed for ≤3 months. However, there was no significant difference in scores on the receptive language subscale between the two groups. Children breastfed for >3 months scored significantly higher on the vocabulary ($F = 6.78; p = 0.009; \text{Cohen's } d = 0.151$) and language inference ($F = 5.62; p = 0.018; \text{Cohen's } d = 0.137$) subscales of the M-FIT assessment at T9 (99.2 months) in the crude model, and the differences in the language inference subscale were insignificant after adjustments for multiple comparisons. Moreover, these differences in the M-FIT subscales diminished to insignificance in the adjusted model ($F = 1.91, p = 0.167$ for vocabulary subscale; $F = 1.24, p = 0.266$ for language subscale).

The comparison of scores on cognitive function tests among the six groups of breastfeeding duration are presented in Table S1. The scores on the communication and problem-solving subscales of K-ASQ at T2 (14.1 months), expressive language subscale of REVT, and calculation subscale of M-FIT were significantly different among the six groups of breastfeeding duration.
### Table 4. Comparison of scores on intellectual function tests between children grouped based on breastfeeding duration.

| Breastfeeding duration | K-ASQ at T1 (n = 1632) | F | df | p | F | df | p | Cohen's d<sup>a</sup> |
|------------------------|------------------------|---|----|---|---|----|---|----------------------|
| 3 months or less       | Communiation            | 53.7 (8.9) | 0.03 | 1, 1630 | 0.855 | 0.01 | 1, 1418 | 0.922 |
|                        | Fine motor              | 54.3 (9.0) | 2.15 | 1, 1630 | 0.143 | 1.32 | 0.252 |
|                        | Gross motor             | 57.3 (6.6) | 0.23 | 1, 1630 | 0.632 | 0.14 | 0.707 |
|                        | Personal-social         | 54.2 (8.2) | 2.11 | 1, 1630 | 0.147 | 0.44 | 0.506 |
|                        | Problem solving         | 55.9 (7.3) | 0.29 | 1, 1630 | 0.591 | 0.00 | 0.978 |
| more than 3 months     | Communiation            | 53.8 (8.8) | 0.03 | 1, 1630 | 0.888 | 0.01 | 1, 1418 | 0.922 |
|                        | Fine motor              | 54.9 (8.6) | 2.15 | 1, 1630 | 0.143 | 1.32 | 0.252 |
|                        | Gross motor             | 57.5 (6.2) | 0.23 | 1, 1630 | 0.632 | 0.14 | 0.707 |
|                        | Personal-social         | 54.9 (8.1) | 2.11 | 1, 1630 | 0.147 | 0.44 | 0.506 |
|                        | Problem solving         | 56.1 (7.4) | 0.29 | 1, 1630 | 0.591 | 0.00 | 0.978 |
|                        | K-ASQ at T2 (n = 1704)  | 47.7 (11.9) | 17.71 | 1, 1702 | 0.001**.b | 8.75 | 1, 1443 | 0.003**.b |
|                        | Communiation            | 48.1 (11.7) | 3.17 | 1, 1702 | 0.075 | 2.13 | 1, 1443 | 0.145 |
|                        | Fine motor              | 56.4 (9.2) | 0.12 | 1, 1702 | 0.262 | 0.06 | 1, 1443 | 0.811 |
|                        | Gross motor             | 52.1 (11.1) | 1.01 | 1, 1702 | 0.315 | 1.73 | 1, 1443 | 0.189 |
|                        | Personal-social         | 50.2 (11.3) | 11.26 | 1, 1702 | 0.001**.b | 13.18 | 1, 1443 | <0.001**.b |
|                        | Problem solving         | 51.9 (11.3) | 6.13 | 1, 1750 | 0.013* | 4.75 | 1, 1470 | 0.029* |
|                        | K-ASQ at T3 (n = 1752)  | 51.9 (11.3) | 6.13 | 1, 1750 | 0.013* | 4.75 | 1, 1470 | 0.029* |
|                        | Communiation            | 52.6 (9.8) | 4.17 | 1, 1750 | 0.041 | 2.54 | 1, 1470 | 0.111 |
|                        | Fine motor              | 57.2 (6.7) | 0.12 | 1, 1750 | 0.727 | 0.12 | 1, 1470 | 0.731 |
|                        | Gross motor             | 54.3 (9.5) | 2.52 | 1, 1750 | 0.113 | 0.28 | 1, 1470 | 0.597 |
|                        | Personal-social         | 53.4 (8.2) | 6.79 | 1, 1750 | 0.009**.b | 4.18 | 1, 1470 | 0.041* |
|                        | Problem solving         | 53.4 (8.2) | 6.79 | 1, 1750 | 0.009**.b | 4.18 | 1, 1470 | 0.041* |
|                        | REV at T4 (n = 1630)    | 4.4 (3.1) | 12.85 | 1, 1628 | <0.001**.b | 5.55 | 1, 1377 | 0.019* |
|                        | Expressive              | 6.5 (3.6) | 6.4 (3.6) | 0.00 | 1, 1623 | 0.983 | 0.11 | 1, 1374 | 0.737 |
|                        | Receptive               | 6.5 (3.6) | 6.4 (3.6) | 0.00 | 1, 1623 | 0.983 | 0.11 | 1, 1374 | 0.737 |
|                        | M-FIT at T9 (n = 1396)  | 55.4 (10.5) | 6.78 | 1, 1396 | 0.009**.b | 1.91 | 1, 1180 | 0.167 |
|                        | Vocabulary              | 56.4 (9.8) | 5.62 | 1, 1396 | 0.018* | 1.24 | 1, 1180 | 0.266 |
|                        | Language inference      | 53.6 (9.8) | 3.73 | 1, 1396 | 0.054 | 0.56 | 1, 1180 | 0.453 |
|                        | Schematization          | 53.4 (9.8) | 1.43 | 1, 1396 | 0.232 | 0.28 | 1, 1180 | 0.600 |
|                        | Calculation             | 56.4 (10.2) | 1.48 | 1, 1396 | 0.223 | 0.32 | 1, 1180 | 0.572 |
|                        | Spatial perception      | 55.6 (10.8) | 0.58 | 1, 1396 | 0.447 | 0.41 | 1, 1180 | 0.523 |
|                        | Reasoning               | 55.6 (10.8) | 56.1 (11.1) | 0.58 | 1, 1396 | 0.447 | 0.41 | 1, 1180 | 0.523 |

<sup>a</sup>: Cohen's d was calculated by the crude model without consideration of covariates. The number of samples corresponds to the crude model.

<sup>b</sup>: The adjusted model included children's sex, age, gestational age, birth weight, parents' education level, and household income as covariates.

* p < 0.05; ** p < 0.01

**Discussion**

**Prevalence of breastfeeding**

The present study investigated the association between breastfeeding and cognitive function in children from 5.5 months to 8 years of age using multiple assessment tools and a prospective design. The prevalence of breastfeeding in our study is comparable to previous studies. Despite
evidence of the beneficial effects of breastfeeding on the health of mother and child, the prevalence of breastfeeding was substantially different between countries, with a clear tendency of lower breastfeeding duration and prevalence in wealthier countries [21]. For instance, the proportion of children who were ever-breastfed in our study was 97.4%. The previously reported proportion of ever-breastfed children in most countries was over 90% and was especially high in low-income countries. However, some high-income countries such as France (63%), Spain (77%), Ireland (55%), and the United States (79%) had substantially lower proportions of ever-breastfed children [21]. The proportion of children who continued breastfeeding after 6 months was 61.8% in our study. The average proportion of children who continued breastfeeding after 6 months was lower than 50% in high-income countries, with especially low proportions in Denmark (13%), France (23%), Canada (30%), and the United Kingdom (34%) [21]. The previously reported proportion of breastfeeding at 6 months in Korea was 61%, which is consistent with the present findings [22]. The prevalence of breastfeeding in Korea is reported to have increased remarkably since the lowest prevalence in 2000, which is encouraging news for the health of children [22]. Moreover, the infant mortality rate decreased markedly from 9.9 children per 1,000 live births in 1993 to 3.2 in 2009, despite the lack of direct association between increased prevalence of breastfeeding and decreased infant mortality rate [23].

Early development

Early development of infants at T1 (5.5 months), T2 (14.1 months), and T3 (26.2 months) assessed by Denver II showed no significant differences in odds ratios for developmental delay between the groups of breastfeeding duration. These are inconsistent findings with previous studies. Barros et al. reported significantly higher suspected developmental delay at the age of 1-year assessment in children breastfed for ≤1 month (42.4%) compared to those breastfed for ≥9 months (25.5%) [24]. Wang and Wu [25] also reported significantly higher developmental delay in the personal–social domain of Denver II assessed at 1 year of age in non-exclusively breastfed children (36%) compared to exclusively breastfed children (21%). The results of the early development assessment with K-ASQ presented different aspects than Denver II assessment. The odds ratios to have atypical scores in at least one subdomain of K-ASQ at T1 (5.5 months) and T3 (26.2 months). In the comparison of the K-ASQ score as a continuous variable among breastfeeding groups, scores on communication and problem-solving subdomains at T2 (14.1 months) and T3 (26.2 months) in children breastfed for ≥3 months were significantly higher than the children breastfed for ≤3 months. These are consistent with the findings of previous studies on early development using the ASQ, which have reported the benefits of breastfeeding on early development. An Irish study of 11,134 children that assessed early development with the ASQ at 9 months old reported the positive effect of breastfeeding on gross motor, fine motor, problem-solving and personal–social skills [26]. A French study with 1,999 3-year-old children also reported that ever-breastfed children scored 6.2 points higher on the ASQ than never-breastfed children [27]. The study also reported a significant positive association between exclusively breastfed infants and higher scores on the problem-solving domain of the ASQ. An Australian cohort study with 2,868 children reported that infants breastfed for ≥4 months had higher scores in fine motor skills and communication assessed at ages of 1 and 3 years. Infants who were breastfed for <4 months were also more likely to have at least one atypical score across the subdomains compared to children breastfed for ≥4 months [28].

Cognitive function in middle childhood and at school age

There were significant differences in cognitive function assessed using the vocabulary test (REV) among the groups of breastfeeding duration. There was no difference in receptive language score among the six groups of breastfeeding duration. However, when grouped by children who were breastfed for ≥3 months or ≤3 months, those breastfed for ≥3 months scored significantly higher on the vocabulary test. This is consistent with previous findings for language development in middle childhood based on breastfeeding duration. An Australian cohort study with 1,195 children assessed language ability with the Peabody Picture Vocabulary Test (mean=100; SD=15) and reported that children who were breastfed for ≥6 months presented higher mean scores (3.56 points at 5 years and 4.04 points at 10 years, respectively) than children who were never-breastfed [29].

Our results indicate an advantageous association between breastfeeding and cognitive function during school days. Scores on the M-FIT subscales of vocabulary and language inference in children breastfed for ≥3 months were significantly higher than children breastfed for ≤3 months. These findings are consistent with previous studies on the cognitive function of school-age children based on breastfeeding duration [30-32]. For instance, children born preterm who were breastfed had higher IQ scores by 7.6 points (about half a standard deviation) at eight years than never-breastfed children [25]. An Irish study with 8,226 9-year-old school children also reported that ever-breastfed children scored significantly higher percentage points on reading and mathematics than never-breastfed children [32]. Huang et al. also reported that breastfeeding had a significant association with higher intelligence and that the association remained significant during the schooling and adolescent period [33].

Limitations

The present study has some limitations to note. First, due to the characteristics of longitudinal cohort studies, a substantial number of subjects did not participate in the follow-up assessments. Notably, some participants were excluded from the adjusted model analysis due to missing covariate data. The missing data may bias the relationship between breastfeeding and children's cognitive function. Thus, future study of a more complete
dataset with covariate analysis is warranted. Second, although we tried to include important sociodemographic covariates, all covariates could not be included. For instance, previous studies indicated that maternal IQ is a major moderating factor for the association between breastfeeding and children's intelligence, which was not included in our study [6, 34]. In addition, previous studies included two extents of breastfeeding in their analysis: "any" or "exclusive." However, we did not collect such information on the extent of breastfeeding. Thus, future studies are warranted to include more detailed information on the related demographic variables and extent of breastfeeding to confirm our findings. Third, our study included many multiple comparisons due to various outcome assessments. Moreover, some significant findings were insignificant after multiple comparison adjustments. Despite these insignificant levels, associations contradictory to our main findings between the prevalence of breastfeeding and delayed development were observed in some development assessments (e.g., lower odds ratio in children breastfed for a lesser period with development delay in Denver II assessment at T1 and T3). The significance level may be influenced by sample number or size of the differences in outcome variables. Thus, although the sample size of our study is not small, a future study with a larger sample size would provide further information to confirm our findings. Despite these limitations, the present study has the strength of using multiple tools at multiple time points to assess children's cognitive development using a prospective design.

Conclusion

The findings of our study present a generally positive association between breastfeeding and cognitive function from early childhood through to school age. In contrast, development assessed with some tools (i.e., Denver II) and at some points (T1-5.5 months) revealed null findings for the association. Many previous studies support the finding that there are positive associations between breastfeeding and cognitive development. However, the mean difference (effect size) in cognitive development due to breastfeeding was only 3.44 points (about one-third of a standard deviation), which is reduced again by the adjustment for maternal IQ [6]. Considering these findings comprehensively, breastfeeding is not considered a critical factor in the cognitive development of children. Other studies have also reported that the observed advantage of breastfeeding on IQ score is actually due to genetic and socioenvironmental factors. When the results are adjusted for covariates such as maternal IQ, the effect of breastfeeding on cognitive function was insignificant [35, 36]. Thus, breastfeeding should not be interpreted to have medical benefits for cognitive development. Another study on 12-year-old twins stratified by maternal education level reported a significant effect of breastfeeding on cognition in all strata of maternal education level, although much of the individual difference in cognition scores was accounted for by genetic factors (80%) [34]. Although the reported effects are not significant, it is worthwhile to continue breastfeeding for the possible beneficial effect on children's cognitive development. In addition, more research to investigate the underlying mechanism for the association between breastfeeding and cognitive development is warranted.

List Of Abbreviations

ANCOVA, analysis of variance and analysis of covariance
ASQ, Ages and Stages Questionnaire
K-ASQ, Korean Ages and Stages Questionnaire
M-FIT, Multifactorial intelligence test
PSKC, Panel Study on Korean Children
REVT, Receptive and Expressive Vocabulary Test

Declarations

Ethics approval and consent to participate

We provided parents with information on the purpose and procedure of the study and collected written informed consent from them before enrollment. This study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The study protocol was approved by the Institutional Review Board of the Korean Institute of Child Care of Education (KICCEIRB-2016-07).

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

Conception and design of the study: KM Kim and JW Choi. Acquisition and analysis of data: KM Kim. Original draft and tables: KM Kim. Final editing of manuscript: JW Choi.

Acknowledgments

The authors wish to thank the Korea Institute of Child Care and Education, which provided the raw data.

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**Additional File 1**

Title of data: Table S1. Comparison of scores on intellectual function tests among the six groups of breastfeeding duration.

**Supplementary Files**

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