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ORIGINAL RESEARCH

Effects of Breastfeeding on Cognitive Abilities at 4 Years Old: Cohort Study

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Abstract

Human breast milk dynamically adapts to meet the needs of healthy neurodevelopment. While a great deal of research has examined the relationship between breastfeeding, infant cognitive development and IQ, findings are inconclusive when potential confounders are adjusted for. This raises questions about the various ways in which breastfeeding and other crucial factors can impact on infant IQ and cognitive abilities. The main aim of this study was to analyse the relationship between breastfeeding and child IQ and cognitive abilities after adjusting for sociodemographic, perinatal and postnatal variables. The participants were 613 boys and girls aged 4–5 years old from two cohort studies carried out in Tarragona, Spain**.** IQ and cognitive abilities were assessed using the Wechsler Preschool and Primary Scale of Intelligence-IV (WPPSI-IV). Sociodemographic, prenatal, perinatal, and postnatal factors were collected. Descriptive analyses compared mother and infant characteristics by breastfeeding categories using Chi-squared and ANOVA tests. Regression models explored associations between breastfeeding duration and WPPSI-IV indexes. Breastfeeding from 1 to 8 months was related to higher scores on the Full-Scale IQ (b = 3.909, p = 0.035) and Working Memory Index (b = 3.757, p = 0.044), Non-Verbal Index (b = 4.184, p = 0.029), Cognitive Proficiency Index (b = 4.015, p = 0.038) at 4–5 years old, even after adjusting for the mother's IQ and mother-infant attachment difficulties. Our study emphasizes the numerous advantages of breastfeeding and underscores the importance of infants being breastfed through healthcare and health policies. Advocating breastfeeding for the first six months of life is crucial for enhancing lifelong well-being and cognitive development in children.

Keywords Intelligence quotient · Breastfeeding · Cognitive abilities · Executive function

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Résumé

Le lait maternel humain s'adapte dynamiquement pour répondre aux besoins d'un neurodéveloppement sain. Bien qu'un grand nombre de recherches aient examiné la relation entre l'allaitement, le développement cognitif des nourrissons et le QI, les résultats sont peu concluants lorsque les potentiels facteurs de confusion sont pris en compte. Cela soulève des questions sur les différentes façons dont l'allaitement et d'autres facteurs cruciaux peuvent avoir un impact sur le QI et les capacités cognitives des nourrissons. L'objectif principal de cette étude était d'analyser la relation entre l'allaitement et le QI ainsi que les capacités cognitives des enfants après ajustement pour les variables sociodémographiques, périnatales et postnatales. Les participants étaient 613 garçons et filles âgés de 4 à 5 ans provenant de deux études de cohorte réalisées à Tarragone, Espagne. Le QI et les capacités cognitives ont été évalués à l'aide de l'Échelle d'intelligence de Wechsler pour la période préscolaire et primaire-IV (WPPSI-IV). Les facteurs sociodémographiques, prénatals, périnatals et postnataux ont été collectés. Des analyses descriptives ont comparé les caractéristiques des mères et des nourrissons selon les catégories d'allaitement en utilisant des tests du Chi carré et des tests ANOVA. Des modèles de régression ont exploré les associations entre la durée de l'allaitement et les indices WPPSI-IV. L'allaitement de 1 à 8 mois était lié à des scores plus élevés sur le QI global ($b = 3.909$, $P = 0.035$) et l'Indice de Mémoire de Travail ($b = 3.757$, $P = 0.044$), l'Indice Non-Verbal ($b = 4.184$, $P = 0.029$), l'Indice de Compétence Cognitive ($b = 4.015$, $P = 0.038$) à 4–5 ans, même après ajustement pour le QI de la mère et les difficultés d'attachement mère-enfant. Notre étude met en évidence les nombreux avantages de l'allaitement et souligne l'importance des politiques de santé promouvant l'allaitement maternel. Promouvoir l'allaitement pendant les six premiers mois de la vie est crucial pour améliorer le bien-être tout au long de la vie et le développement cognitif des enfants.

Resumen

La leche materna humana se adapta dinámicamente para satisfacer las necesidades de un neurodesarrollo saludable. Aunque se ha investigado extensamente la relación entre la lactancia materna, el desarrollo cognitive infantil y el coeficiente intelectual (CI), los resultados son inconclusos cuando se ajustan por posibles factores de confusión. Esto plantea interrogantes sobre las diversas maneras en que la lactancia materna y otros factores cruciales pueden influir en el CI y las habilidades cognitivas de los lactantes. El objetivo principal de este studio fue analizar la relación entre la lactancia materna y el CI infantil y las habilidades cognitivas, después de ajustar por variables sociodemográficas, perinatales y postnatales. Los participantes fueron 613 niños y niñas de 4 a 5 años de edad, provenientes de dos estudios de cohorte realizados en Tarragona, España. El CI y las habilidades cognitivas se evaluaron utilizando la Escala de Inteligencia de Wechsler para Preescolar y Primaria-IV (WPPSI-IV). Se obtuvo información sobre factores sociodemográficos e información del periodo prenatal, perinatal y postnatal. Las características descriptivas de la madre y del infante según las categorías de lactancia materna se compararon mediante pruebas de Chi-cuadrado y ANOVA. Las asociaciones entre la duración de la lactancia materna y los índices de la WPPSI-IV se exploraron mediante modelos de regresión. La lactancia materna de 1 a 8 meses se relacionó con puntuaciones más altas en el CI Total (b = 3.909, P = 0.035) y el Índice de Memoria de Trabajo (b = 3.757, P = 0.044), el Índice No Verbal (b = 4.184, P = 0.029), el Índice de Competencia Cognitiva (b = 4.015, P = 0.038) a los 4-5 años de edad, incluso después de ajustar por el CI de la madre y las dificultades de apego madre-infante. Nuestro estudio enfatiza las numerosas ventajas de la lactancia materna y subraya la importancia de promover la lactancia materna a través de políticas de salud. Promover la lactancia maternal durante los primeros seis meses de vida es crucial para mejorar el bienestar y el desarrollo cognitivo a lo largo de la vida en los niños.

Introduction

Human breast milk is an optimal food for infants, not only because it has a variety of constituents but also because it is dynamic and adapts to the evolving requirements of the growing infant. The variety of nutrients and bioactive molecules in breast milk makes it an ideal source of nourishment for infants and contributes positively to healthy growth and neurodevelopment (Gabbianelli et al., 2020; Kramer et al., 2008).

Research has shown that breastfeeding has numerous physical and psychological benefits for children and their mothers in both the short and the long term. Since 1929, numerous studies on infant cognitive development have suggested that there is a relationship between breastfeeding and intelligence but, as yet, the results are by no means definitive (King & Barger, 2021); (Guxens et al., 2011). In this regard, numerous studies have examined the relationship between breastfeeding and children's cognitive development and intelligence. While most of them have demonstrated a positive association, some have not. For instance, after controlling for several confounders, (Jardí et al., 2017) found that infants who had been breastfed for at least four months presented better psychomotor development at 6 and 12 months of age. Another longitudinal prospective study showed that a higher frequency of breastfed meals and the duration of exclusive breastfeeding during the first year of life was associated with greater memory retention, improved language and motor skills at 14 and 18 months of age (Krol & Grossmann, 2018). Similar results were reported by Leventakou et al., (2015). In children, breastfeeding was associated with better intelligence quotient (IQ) scores at 4 years old (Guxens et al., 2011), 5 years old (Plunkett et al., 2021; Strøm et al., 2019) and 7 years old (Belfort et al., 2013), as well as better language abilities at 10 years old (Jedrychowski et al., 2012). Even, in a 30-year follow-up study in Brazil, Victora et al., (2015) found a relationship between breastfeeding and intelligence, educational attainment during infancy and better status and incomes in adulthood (Victora et al., 2015). However, other studies found no significant relationship between breastfeeding and children's cognitive abilities (Rochat et al., 2016; Zhou et al., 2007) or evidence of this relationship disappearing after controlling for confounders (Clark et al., 2006; Der et al., 2006b; Holme et al., 2010). The debate surrounding these inconclusive results has focused on the various ways in which breastfeeding—along with other factors such as socioeconomic status, attachment, and maternal intelligence—contributes to child development. In this regard, numerous studies have shown that women with higher socioeconomic status, higher education levels, and greater intellectual capacity tend to choose breastfeeding (Der et al., 2006; Ip et al., 2007; Walfisch et al., 2013), and these factors have also been shown to have an impact on cognitive development and intellectual capacity in childhood (Ronfani et al., 2015). Walfish et al., (2013) conducted a systematic review of studies on the effect of confounding variables that find a positive relationship between breastfeeding and intellectual capacity. They reported that the initial positive effect of breastfeeding on IQ in many studies disappeared or diminished after multivariate analysis controlled for significant confounders and that the leading confounders were maternal cognition and socioeconomic status (Walfish et al., 2013). Another meta-analysis of 17 studies controlling for maternal IQ revealed a slightly reduced advantage of breastfeeding. Nevertheless, the analysis reported that breastfeeding was still associated with improved performance in intelligence tests by children and adolescents, who had an average score that was 3.5 points higher than other test takers (Horta et al., 2015). Drawing conclusions is challenging because of the considerable variability of the studies and the confounding variables used to adjust the associations. The development of a child's cognitive and intellectual abilities is an intricate and multifaceted process, influenced by a myriad of genetic and environmental factors that often interact in complex ways. Therefore, any study of how breastfeeding affects child intelligence and cognition needs to consider numerous factors of the context in which the child develops. Taking all this into account, the main aim of this study was to analyse the relationship between breastfeeding and infant IQ and cognitive abilities at 4–5 years of age, adjusting for important sociodemographic, prenatal, perinatal, and postnatal factors.

Methods

Design, Participants, and Procedure

The sample (n = 613) consisted of participants from the ECLIPSES study (Arija et al., 2014; Iglesias-Vázquez et al., 2023) (n = 318) and the EPINED study (Canals et al., 2021; Morales-Hidalgo et al., 2018) (n = 295) conducted in the region of Tarragona, a province of the north of Spain.

The ECLIPSES study was a community randomised controlled trial (RCT) carried out between 2013 and 2017 that aimed to determine the levels of iron supplementation that would be most effective at increasing haemoglobin (Hb) in early pregnancy and be optimum for mother–child health. Infants born during the ECLIPSES study were followed for 4–5 years to determine which nutritional, environmental and sociodemographic factors during pregnancy and early infancy are related to cognitive abilities at 4–5 years old. The ECLIPSES study consisted of three visits during pregnancy (in the 12th, 24th, and 36th weeks), a visit 40 days after delivery and a follow-up visit 4–5 years after delivery when blood samples, sociodemographic, clinical and psychosocial information were collected and an individual infant cognitive assessment was performed. A total of 793 pregnant women were included in the study at week 12 of pregnancy. At 4 years old, a total of 318 infants came to the follow-up visit with their mothers. Participants dropped out for various reasons: voluntary drop out, emergence of exclusion criteria during pregnancy, miscarriage, and lost to follow-up.

The EPINED study was a two-phase cross-sectional study performed between 2014 and 2019 conducted in the region of Tarragona, Spain. Its aim was to estimate the epidemiology of autism spectrum disorders (ASD), and attention deficit hyperactivity disorder (ADHD) in a community school population by analysing the influence of prenatal, perinatal and postnatal factors. The study included a screening procedure (first phase) carried out by 2764 parents and teachers, and an individual clinical and cognitive assessment, which included an interview with parents (second phase), of the sample of 781 children, 295 of whom were 4–5 years old.

Instruments and Data Collection

Measurements

The information about breastfeeding was provided by the parents when the children were 4 years old. The parents were asked about the months their children were breastfed. Children were considered to have been breastfed when breastfeeding was exclusive or combined with formula feeding. For data analysis, the sample was divided into three categories according to the number of months a child was breastfed. The first category consisted of infants who were not breastfed at any time; the second category consisted of infants who were breastfed for 1 to 8 months; and the third category consisted of infants who were breastfed for more than 8 months.

Infant IQ and cognitive abilities were assessed by the Wechsler Preschool and Primary Scale of Intelligence—fourth edition (WPPSI-IV) (Wechsler, 2014) at 4 years old. The WPPSI-IV is a battery designed to measure intelligence with 15 subtests. The Spanish version has been shown to have good psychometric properties. From these 15 subtests, 4 main indexes, 4 secondary indexes and a full-scale IQ (FSIQ) score can be obtained. The main indexes are: *1)* the Verbal Comprehension Index (VCI—the child's verbal reasoning ability, which is influenced by semantic knowledge) with a Cronbach's alpha of 0.89; *2)* the Fluid Reasoning Index (FRI –the child's ability to think logically, determined by identifying abstract relationships between pairs of words or images) with a Cronbach's alpha of 0.91; *3)* the Working Memory Index (WMI—the child's ability to hold information in the short-term memory and then process it) with a Cronbach's alpha of 0.82; and *4)* the Processing Speed Index (PSI—the speed at which children understand information and begin to respond) with a Cronbach's alpha of 0.88. The secondary indexes are: *1)* the General Ability Index (GAI—an estimate of intellectual functioning without working memory or processing speed) with a Cronbach's alpha of 0.91; *2)* the Cognitive Proficiency Index (CPI—a measure of general ability derived with less influence of working memory and processing speed tasks) with a Cronbach's alpha of 0.87; *3)* the Vocabulary Acquisition Index (VAI—the child's ability to acquire new vocabulary skills) with a Cronbach's alpha of 0.87; and *4)* the Non-Verbal Index (NVI—a measure of general intelligence that reduces expressive language) with a Cronbach's alpha of 0.92. Also used was the Full-Scale IQ (FSIQ—a general measure of cognitive and intellectual functioning) with a Cronbach's alpha of 0.93. For data analysis, the total scores of the primary and secondary indexes were used. These scores have a theoretical mean of 100 and a standard deviation of 15 (Wechsler, 2014).

Obstetric and neonatal variables were obtained from the obstetric medical records of each pregnant woman (in the ECLIPSES study), and from the parents' interview (in the EPINED study). These variables were: mother's age at the beginning of pregnancy, family's socioeconomic level, mother's smoking during pregnancy, infant sex, gestational age at birth, birth weight and mode of delivery.

The Socioeconomic Status (SES) was estimated using the Hollingshead index (Hollingshead, 2011) with data of the parents' level of education and their jobs classified according to the Catalan classification of jobs (Institut Nacional d'Estadística, 2011).

Smoking during pregnancy was assessed by the Fagerström Questionnaire (Fagerström_Q) (Heatherton et al., 1991) in the ECLIPSES study, and by the parents' interview in the EPINED study. Using this information, women were classified as smokers or non-smokers.

The type of family the infants belonged to was coded as nuclear (when father, mother and child live together in the same house whether the parents are married or not) or others.

The quality of the infants' diet was determined at 4 years old by the Standardized Diet Quality Index (Norte Navarro & Ortiz Moncada, 2011), which considers the variety, frequency, quantity and nutritional adequacy of the foods consumed, and provides an overall score of diet quality.

The emotional symptoms of the parents were assessed at 4 years old using the Goldberg Anxiety and Depression Scale (GADS) (Goldberg et al., 1988; Montón et al., 1993) a self-reported tool for adults that contains questions about symptoms, duration, frequency, and impact on daily life. It gives separate anxiety and depression scores.

The mother's IQ approximation was assessed by the Matrix subtest of the Wechsler Adult Intelligence Scale—IV (Wechsler, 2012) which had been extensively validated, and was considered to be sufficiently reliable and valid to be a measure of overall intellectual functioning (Wechsler, 2012).

Mother-infant attachment difficulties were assessed at 4 years after birth by the Parent Stress Index-Short Form (Abidin, 1995), a 36-item questionnaire that measures stress directly associated with the role of parenting. It can provide a total score of parent–child dysfunctional interaction.

Statistical Analyses

Descriptive analyses of the general characteristics of mothers and infants were performed and differences between cohort and breastfeeding categories (not breastfeeding, breastfeeding up to 8 months and breastfeeding more than 8 months) were computed using the Student T-Test and ANOVA for continuous variables and the Chi-Square test for categorical variables.

To test whether breastfeeding is related to child cognitive performance, multiple linear regression models predicting the primary and secondary indexes of the WPPSI-IV and using the enter method were carried out with the total sample. The adjustment variables entered into the model were: mother's age at birth (years), family's socioeconomic level (low, medium, high), infant's gestational age at birth (weeks), infant's sex (boy, girl), type of family (nuclear, others), mother's smoking during pregnancy (yes, no), mother's emotional symptoms (yes, no), father's emotional symptoms (yes, no), quality of children's diet (total score) and cohort (EPINED, ECLIPSES). Previously, the hypothesis of collinearity between covariates was tested. To test whether breastfeeding protects against low IQ ($IQ < 85$) and low cognitive ability scores, logistic regression models were carried out also using the enter method and the same adjustment variables entered into the multiple linear regression models. Finally, to test whether breastfeeding is related to child cognitive performance after adjusting for mother's IQ approximation (total scalar score) and mother-infant attachment difficulties (total score), multiple linear and logistic regression models were performed with the ECLIPSES cohort data and the adjustment variables mentioned above.

The covariates and the interactions between the main variables were analysed, but the results are not shown because they were not significant.

Results

Descriptive Data of the Sample

The sociodemographic, perinatal, and cognitive data of the whole sample and of each cohort are displayed in Table 1.

The sociodemographic data show that the average age of mothers in the total sample was 28.92 years ($SD = 5.6$), most of the families have a medium socioeconomic status and 87.0% of families were nuclear when the child was assessed. In terms of gender, 44.5% of the infants from the whole sample were girls while in the EPINED cohort there was a significantly higher proportion ($X^2 = 6.256$, $p = 0.012$) of boys (60.7%) to girls (39.3%).

As far as the prenatal factors are concerned, 82.9% of the mothers reported not smoking during pregnancy and the mean gestational age at birth was 39.31 weeks ($SD = 2.1$).

A total of 54.2% of the mothers and 62.8% of the fathers did not report emotional symptoms 4 years after birth, and this ratio is significantly lower in the mothers ($X^2 = 61.771$, $p < 0.001$) and fathers ($X^2 = 35.934$, $p < 0.001$) from the EPINED cohort.

Regarding the quality of the children's diet at 4 years, infants in the EPINED cohort had significantly higher scores ($t = 4.570$, $p = 0.033$) than infants in the ECLIPSES cohort. A total of 27.3% of the sample reported no breastfeeding. Those women who did breastfeed did so for a mean of 12.75 months ($SD = 12.2$) although this duration was significantly lower in the EPINED cohort sample

Table 1 Descriptive characteristics of the sample and differences by cohort

		Total Sample Mean (SD)*n (%)#	EPINED Cohort Mean (SD)*n (%)#	ECLIPSES Cohort Mean (SD)*n (%)#	t (p)*X^2 (p)#
Mothers' age (years)*		28.92 (5.6)	30.82 (5.7)	27.21 (4.8)	−10.048 (<0.001)
Family socioeconomic status #	low	174 (28.4)	90 (30.5)	84 (26.4)	1.584 (0.453)
	medium	346 (56.4)	164 (55.6)	182 (57.2)	
	high	93 (15.2)	41 (13.9)	52 (16.4)	
Mother's smoking during pregnancy (no)#		470 (82.9)	211 (71.5)	259 (81.4)	0.010 (0.919)
Infant sex (girls) #		273 (44.5)	116 (39.3)	157 (49.4)	6.256 (0.012)
Gestational age (weeks)*		39.31 (2.1)	38.82 (2.57)	39.75 (1.4)	4.925 (<0.001)
Family type (nuclear)#		504 (87.0)	238 (80.7)	266 (83.6)	21.634 (<0.001)
Mother emotional symptoms (no)#		283(54.2)	198 (70)	85 (30.0)	61.771 (<0.001)
Father emotional symptoms (no)#		296 (62.8)	186 (62.8)	110 (37.2)	35.934 (<0.001)
Quality of children's diet*		61.70 (9.4)	62.54 (7.4)	60.93 (10.8)	4.570 (0.033)
Mother's IQ approximation (total score)*				9.02 (3.6)	
Mother-infant attachment difficulties (total score)*				51.68 (5.9)	
Breastfeeding (months)*		12.75 (12.2)	10.44 (11.1)	14.56 (12.7)	4.804 (<0.001)
Non-breastfeeding#		154 (27.3)	94 (31.9)	60 (18.9)	19.816 (<0.001)
Breastfeeding from 1 to 8 months#		212 (37.6)	107 (36.3)	105 (33.0)	
Breastfeeding more than 8 months#		198 (35.1)	74 (25.1)	124 (39.0)	
Verbal Comprehension Index (VCI)	total score*	99.98 (16.1)	94.83 (17.4)	104.86 (13.1)	7.803 (<0.001)
	<85 score#	100 (16.3)	78 (13.1)	22 (3.7)	43.591 (<0.001)
Fluid Reasoning Index (FRI)	total score*	102.74 (14.5)	102.65 (15.8)	102.83 (13.1)	0.147 (0.441)
	<85 score#	73 (11.9)	45 (7.8)	28 (4.8)	5.231 (0.022)
Working Memory Index (WMI)	total score*	97.94 (13.4)	97.92 (14.6)	97.97 (12.1)	0.041 (0.483)
	<85 score#	98 (16.0)	52 (9.1)	46 (8.0)	0.607 (0.436)

Table 1 (continued)

		Total Sample Mean (SD)*n (%)#	EPINED Cohort Mean (SD)*n (%)#	ECLIPSES Cohort Mean (SD)*n (%)#	t (p)*X^2 (p)#
Processing Speed Index (PSI)	total score*	95.25 (13.3)	94.92 (14.0)	95.57 (12.6)	0.576 (0.282)
	< 85 score#	157 (25.6)	77 (13.4)	80 (13.9)	0.001 (0.980)
Full Scale IQ (FSIQ)	total score*	99.66 (14.2)	96.96 (16.0)	102.25 (11.6)	4.521 (< 0.001)
	< 85 score#	79 (12.9)	60 (10.4)	19 (3.3)	26.529 (0.001)
Vocabulary Acquisition Index (VAI)	total score*	95.81 (15.7)	93.97 (17.2)	97.49 (13.9)	2.781 (0.003)
	< 85 score#	149 (24.3)	92 (15.6)	57 (9.6)	15.336 (< 0.001)
Non-Verbal Index (NVI)	total score*	100.79 (14.2)	100.38 (16.0)	101.19 (12.2)	0.684 (0.247)
	< 85 score#	75 (12.2)	49 (8.5)	26 (4.5)	9.056 (0.003)
General Ability Index (GAI)	total score*	101.98 (14.9)	97.85 (16.6)	105.91 (12.0)	6.682 (< 0.001)
	< 85 score#	69 (11.3)	56 (9.7)	13 (2.2)	32.836 (< 0.001)
Cognitive Proficiency Index (CPI)	total score*	96.06 (13.9)	95.89 (15.6)	96.24 (12.0)	0.301 (0.382)
	< 85 score#	136 (22.2)	73 (12.8)	63 (11.0)	1.367 (0.242)

*Results shown as mean and standard deviation (SD)

#Results shown as n and percentage (%)

(10.44 months, SD = 11.1) than in the ECLIPSES cohort sample (14.56 months, SD = 12.7) (t = 4.804; $p < 0.001$).

As far as cognitive performance is concerned, infants from the ECLIPSES cohort scored significantly higher than those from the EPINED cohort on the VCI (mean = 104.86, SD = 13.1 versus mean = 94.83, SD = 17.4; t = 7.803, $p < 0.001$), the FSIQ (mean = 102.25, SD = 11.6 versus mean = 96.96, SD = 16.0; t = 4.521; $p < 0.001$), the VAI (mean = 97.49, SD = 13.9 versus mean = 93.97, SD = 17.2); t = 2.781; $p = 0.003$), and the GAI (mean = 105.91, SD = 12.0 versus mean = 97.85, SD = 16.6; t = 6.682; $p < 0.001$). Infants in the EPINED cohort obtained more scores below 85 on the VCI (n = 22, 3.7% versus n = 78, 13.1% from the total; $x^2 = 43.591$; $p < 0.001$), the FRI (n = 28, 4.8% versus n = 45, 7.8% from the total; $x^2 = 5.231$; $p = 0.022$), the FSIQ (n = 19, 3.3% versus n = 60, 10.4% from the total; $x^2 = 26.529$; $p = 0.001$); the VAI (n = 57, 9.6% versus n = 92, 15.6% from the total; $x^2 = 15.336$; $p < 0.001$); the NVI (n = 26, 4.5% versus n = 48, 8.5% from the total; $x^2 = 9.056$; $p = 0.003$); and the GAI (n = 13, 2.2% versus n = 56, 9.7% from the total; $x^2 = 32.836$; $p < 0.001$).

Descriptive Data of the Sample According to Breastfeeding Groups

Table 2 shows the sociodemographic and perinatal descriptive variables according to breastfeeding groups. The results showed that the mothers who breastfed their babies smoked less during pregnancy ($X^2 = 10.678$; $p < 0.001$) and had longer pregnancies ($F = 3.811$; $p = 0.023$) than the mothers of infants who were not breastfed. No significant differences were found in the other variables: family socioeconomic status (high, medium, low), infant sex (girl, boy) and family type (nuclear, others), mother's IQ approximation (total score), mother-infant attachment (total score).

Table 3 shows the continuous scores and the proportion of scores lower than 85 on the WPPSI-IV at 4–5 years old for each of the breastfeeding groups. In general, infants who were breastfed from 1 to 8 months tended to obtain higher scores on the WPPSI-IV scales than infants who were not breastfed or infants who were breastfed for more than 8 months. In this regard, infants who were breastfed from 1 to 8 months obtained significantly higher scores on the FRI (mean = 104.63, SD = 14.4) and the WMI (mean = 99.63, SD = 13.6) than infants who were not breastfed (mean = 100.17, SD = 14.17 and mean = 96.08, SD = 13.6, respectively). For the FSIQ, infants in the non-breastfeeding group obtained lower scores (mean = 97.12, SD = 14.2) than the infants in other groups (F = 3.533, $p = 0.030$). Also, on the secondary indexes, infants in the 1 to 8 months breastfeeding group obtained significantly higher scores on NVI (mean = 102.52, SD = 14.4) (F = 4.377, $p = 0.013$) and GAI (mean = 103.54, SD = 14.9) (F = 3.839, $p = 0.022$) than infants in the non-breastfeeding group (mean = 98.00, SD = 14.6; mean = 99.12, SD = 15.6, respectively).

Table 2 Descriptive characteristics of the sample and differences by cohort according to breastfeeding groups

	Non-breastfeeding	Breastfeeding from 1 to 8 months	Breastfeeding more than 8 months	
	Mean (SD)* n (%)#	Mean (SD)* n (%)#	Mean (SD)* n (%)#	F(p) X^2 (p)
Mothers' age (years)*	31.03 (6.7)	30.80 (5.0)	30.58 (5.1)	0.128 (0.880)
Family socioeconomic status #				
Low	43 (26.5)	52 (32.1)	67 (41.4)	0.990 (0.372)
Medium	94 (30.0)	125 (39.9)	94 (30.0)	
High	17 (19.1)	35 (39.3)	37 (41.6)	
Mother's smoking during pregnancy (no)#	99 (22.7)	171 (39.1)	167 (38.2)	10.678 (<0.001)
Infant sex (girls)#	69 (27.1)	92 (36.1)	94 (36.9)	0.702 (0.705)
Gestational age (weeks)*	38.91 (2.4)	39.30 (2.1)	39.59 (1.8)	3.811 (0.023)
Family type (nuclear)#	123 (25.3)	188 (38.6)	176 (63.1)	2.422 (0.090)
Mother emotional symptoms (no)#	70 (26.3)	107 (40.2)	89 (33.5)	0.904 (0.636)
Father emotional symptoms (no)#	80 (28.6)	108 (38.6)	92 (32.9)	1.423 (0.491)
Quality of children's diet*	61.15 (8.6)	61.89 (8.4)	63.01 (10.02)	1.903 (0.150)
Mother's IQ approximation (total score)*	8.72 (3.6)	8.96 (3.6)	9.7 (3.7)	0.290 (0.749)
Mother-infant attachment difficulty (total score)*	51.96 (4.9)	51.75 (6.3)	51.54 (5.9)	0.082 (0.921)

*Results shown as mean and standard deviation (SD)

#Results shown as n and percentage (%)

Table 3 WPPSI-IV general and secondary indexes scores according to breastfeeding groups

		Non-breastfeeding [a]	Breastfeeding from 1 to 8 months [b]	Breastfeeding more than 8 months [c]		
		Mean (SD)* n (%)#	Mean (SD)* n (%)#	Mean (SD)*n (%)#	F (p)* X^2 (p)#	Bonferroni*
Verbal Comprehension Index (VCI)	Total score*	98.00 (15.5)	100.88 (16.2)	101.06 (16.5)	1.771 (0.171)	
	Score > 85#	28 (18.9)	33 (15.9)	28 (14.5)	1.2299 (0.549)	
Fluid Reasoning Index (FRI)	Total score*	100.17 (14.7)	104.63 (14.4)	102.47 (13.8)	4.139 (0.016)	a-b (0.013)
	Score > 85#	25 (17.0)	21 (10.1)	22 (11.4)	4.064 (0.131)	
Working Memory Index (WMI)	Total score*	96.08 (13.6)	99.63 (13.6)	97.77 (13.4)	2.971 (0.052)	a-b (0.048)
	Score > 85#	30 (20.5)	33 (15.9)	30 (15.5)	1.782 (0.410)	
Processing Speed Index (PSI)	Total score*	64.65 (13.8)	96.00 (13.3)	95.18 (13.3)	0.446 (0.641)	
	Score > 85#	46 (31.7)	50 (24.0)	53 (27.6)	2.551 (0.279)	
Full Scale IQ (FSQI)	Total score*	97.12 (14.2)	101.12 (14.3)	100.19 (13.6)	3.533 (0.030)	a-b (0.029)
	Score > 85#	25 (17.2)	27 (13.0)	19 (9.9)	3.928 (0.140)	
Vocabulary Acquisition Index (VAI)	Total score*	95.63 (15.4)	96.92 (15.4)	95.40 (15.9)	0.536 (0.585)	
	Score > 85#	37 (25.3)	48 (23.1)	48 (25.0)	0.305 (0.859)	
Non-Verbal Index (NVI)	Total score*	98.00 (14.6)	102.52 (14.4)	100.82 (13.1)	4.377 (0.013)	a-b (0.010)
	Score > 85#	28 (19.2)	22 (10.6)	21 (10.9)	6.727 (0.035)	
General Ability Index (GAI)	Total score*	99.12 (15.6)	103.54 (14.9)	102.48 (14.3)	3.839 (0.022)	a-b (0.021)
	Score > 85#	19 (13.3)	24 (11.6)	20 (10.4)	0.548 (0.761)	
Cognitive Proficiency Index (CPI)	Total score*	94.43 (15.1)	97.45 (13.9)	96.12 (13.3)	1.960 (0.142)	
	Score > 85#	35 (24.1)	50 (24.0)	42 (21.9)	0.339 (0.844)	

*Results shown as mean and standard deviation (SD)

#Results shown as n and percentage (%)

As far as the proportion of scores lower than 85 was concerned, there were no significant differences between groups except for the NVI, in which the proportion was higher in the non-breastfeeding group ($X^2 = 6.727$, $p = 0.035$).

Association Between Breastfeeding and Child Cognitive Performance

To test whether breastfeeding is related to child cognitive performance, multiple linear and logistic regressions were performed in the whole sample with other covariables related to cognitive functioning.

Table 4 shows the results of multiple linear regression models testing the association between breastfeeding and infant performance on the WPPSI-IV indexes. In comparison with the non-breastfeeding group, the results showed that breastfeeding up to 8 months was related to a significant increase in WMI (b = 3.757, C.I. 95% = 0.107–7.406, $p = 0.044$), FSIQ *(b = 3.909,* C.I. 95% = 0.270–7.549 $p = 0.035$), NVI (b = 4.184, C.I. 95% = 0.433–7.936 $p = 0.029$), and CPI (b = 4.015, C.I. 95% = 0.222–7.809, $p = 0.038$).

Table 5 shows the results of logistic regression models testing the association between breastfeeding and the risk of having scores lower than 85 on the WPPSI-IV indexes. In comparison with the non-breastfeeding group, breastfeeding from 1 to 8 months (OR = 0.440, $p = 0.053$) and more than 8 months (OR = 0.342, $p = 0.023$) were both related to a lower risk of having a score lower than 85 on NVI.

Table 6 shows the results of multiple linear regression analyses testing the association between breastfeeding and infant performance on the WPPSI-IV indexes after adjusting for maternal IQ approximation and mother-infant attachment difficulties. The results showed that breastfeeding up to 8 months was related to a significant increase in NVI (b = 6.362, $p = 0.012$) in comparison to non-breastfeeding. Finally, in comparison to non-breastfeeding, breastfeeding up to 8 months and more than 8 months was related to a significant increase in PSI (b = 6.300, $p = 0.015$ and b=7.568, $p = 0.002$ respectively), FSIQ (b = 5.165, $p = 0.024$ and b = 5.148, $p = 0.019$ respectively) and CPI (b = 5.086, $p = 0.047$ and b = 5.153, $p = 0.036$ respectively).

Discussion

The present study aimed to explore the impact of breastfeeding on child intelligence and cognitive abilities in a community sample of 4- and 5-year-old children. Our findings indicate that breastfeeding was significantly associated with infant IQ and cognitive abilities, even after controlling for major sociodemographic, prenatal, perinatal and postnatal confounders considered to be important for intellectual performance (Walfisch et al., 2013).

Our results align with previous research (Boucher et al., 2017; Horta et al., 2015; Jedrychowski et al., 2012; Lenehan et al., 2020; Plunkett et al., 2021; Strøm et al., 2019) that demonstrates the long-term cognitive benefits of breastfeeding. In particular, we found that breastfeeding from 1 to 8 months is associated with higher overall child IQ and (Boucher et al., 2017; Horta et al., 2015; Jedrychowski et al.,

Table 4 Linear regression models to estimate child WPPSI-IV scores based on breastfeeding duration

	Non-breastfeeding vs breastfeeding from 1 to 8 months		Non-breastfeeding vs breastfeeding more than 8 months		
	B (95% CI)	*p*	B (95% CI)	p	Model parameters
Verbal Comprehension Index (VCI)	2.664 (− 1.520;6.847)	0.211	1.562 (− 2.747;5.872)	0.476	$r^2_{*100} = 24.4$; $F_{12,357} = 9.279$ $p < 0.001$
Fluid Reasoning Index (FRI)	3.454 (0.511;7.416)	0.088	2.255 (− 1.831;6.341)	0.279	$r^2_{*100} = 9.7$; $F_{12,358} = 3.093$ $p < 0.001$
Working Memory Index (WMI)	3.757 (0.107;7.406)	0.044	1.882 (− 1.880;5.645)	0.326	$r^2_{*100} = 12.4$; $F_{12,358} = 4.098 p < 0.001$
Processing Speed Index (PSI)	2.413 (− 1.166;5.992)	0.186	1.543 − 2.152;5.237))	0.412	$r^2_{*100} = 14.4$; $F_{12,358} = 4.28$ $p < 0.001$
Full Scale IQ (FSQI)	3.909 (0.270;7.549)	0.035	2.231 (− 1.519;5.981)	0.243	$r^2_{*100} = 20.2$; $F_{12,358} = 7.285 p < 0.001$
Vocabulary Acquisition Index (VAI)	1.731 (− 2.409;5.872)	0.411	− 0.675(− 4.940;3.590)	0.756	$r^2_{*100} = 15.8$; $F_{12,357} = 5.394 p < 0.001$
Non-Verbal Index (NVI)	4.184 (0.433;7.936)	0.029	3.562 (− 0.315;7.438)	0.072	$r^2_{*100} = 12.6$; $F_{12,357} = 4.150$ $p < 0.001$
General Ability Index (GAI)	3.384 (− 0.420;7.187)	0.081	1.446 (− 2.476;5.364)	0.469	$r^2_{*100} = 23.0$; $F_{12,357} = 8.601 p < 0.001$
Cognitive Proficiency Index (CPI)	4.015 (0.222;7.809)	0.038	3.169 (− 0.747;7.085)	0.112	$r^2_{*100} = 13.7$; $F_{12,356} = 4.542 p < 0.001$

Models adjusted for: mother's age (years), family socioeconomic status (low; medium; high), mother's smoking during pregnancy (no; yes), infant sex (boy; girl), gestational age at birth (weeks), family type (nuclear; others), cohort (EPINED; ECLIPSES)

Table 5 Logistic regression models to estimate the risk of WPPSI-IV scores lower than 85 based on breastfeeding duration

	Non-breastfeeding vs breastfeeding from 1 to 8 months		Non-breastfeeding vs breastfeeding more than 8 months		
	Odds ratio (95% CI)	*p*	Odds ratio (95% CI)	p	Model parameters
Verbal Comprehension Index (VCI)	0.785 (0.345;1.782)	0.562	1.052(0.456;2.428)	0.906	r^2Nagelkerke*100 = 25.6; X^2 = 58.380; $p < 0.001$
Fluid Reasoning Index (FRI)	0.605 (0.264;1.388)	0.235	0.564(0.235;1.357)	0.201	r^2Nagelkerke*100 = 12.0; X^2 = 22.824; $p = 0.029$
Working Memory Index (WMI)	0.884 (0.412;1.897)	0.752	0.970 (0.442;2.128)	0.940	r^2Nagelkerke*100 = 9.7; X^2 = 21.014; *p* "<"?>=0.050
Processing Speed Index (PSI)	0.677 (0.351;1.304)	0.244	0.798 (0.411;1.548)	0.505	r^2Nagelkerke*100 = 14.0; X^2 = 35.881; $p < 0.001$
Full Scale IQ (FSQI)	0.613 (0.255;1.474)	0.275	0.514(0.200;1.324)	0.168	r^2Nagelkerke*100 = 24.6; X^2 = 49.070; $p < 0.001$
Vocabulary Acquisition Index (VAI)	1.076 (0.531;2.180))	0.838	1.295(0.630;2.662)	0.482	r^2Nagelkerke*100 = 18.2; X^2 = 45.941; $p < 0.001$
Non-Verbal Index (NVI)	0.440 (0.191;1.012)	0.053	0.342 (0.136;0.860)	0.023	r^2Nagelkerke*100 = 18.8; X^2 = 36.491; $p < 0.001$
General Ability Index (GAI)	0.958 (0.473;1.938)	0.904	0.732(0.348;1.537)	0.409	r^2Nagelkerke*100 = 18.9; X^2 = 46.652; $p < 0.001$
Cognitive Proficiency Index (CPI)	1.153 (0.438;3.040)	0.773	1.360 (0.490;3.770)	0.555	r^2Nagelkerke*100 = 32.5; X^2 = 66.393; $p < 0.001$

Models adjusted for: mother's age (years), family socioeconomic status (low; medium; high), mother's smoking during pregnancy (no; yes), infant sex (boy; girl), gestational age at birth (weeks), family type (nuclear, others), cohort (EPINED cohort; ECLIPSES cohort)

Table 6 Linear regression models to estimate child WPPSI-IV scores based on breastfeeding duration and adjusting for mother's IQ approximation and mother-infant attachment difficulties

	Non-breastfeeding vs breastfeeding from 1 to 8 months		Non-breastfeeding vs breastfeeding more than 8 months		
	B (95% CI)	p	B (95% CI)	p	Model parameters
Verbal Comprehension Index (VCI)	2.332 (− 2.982; 7.645)	0.387	4.862 (−0.236;9.960)	0.061	r^2*100 = 24.5; $F_{13, 169}$ = 3.886; $p < 0.001$
Fluid Reasoning Index (FRI)	2.750 (− 2.571;8.071)	0.309	1.009 (-4.096;6.115)	0.697	r^2*100 = 11.1; $F_{13, 169}$ = 1.497; $p = 0.124$
Working Memory Index (WMI)	3.653 (− 1.631;8.938)	0.174	1.956 (−3.114;7.026)	0.447	r^2*100 = 10.6; $F_{13, 169}$ = 1.430; $p = 0.151$
Processing Speed Index (PSI)	6.300 (1.237;11.362)	0.015	7.568 (2.711;12.426)	0.002	r^2*100 = 20.8; $F_{13, 169}$ = 3.143; $p < 0.001$
Full Scale IQ (FSQI)	5.165 (0.701;9.630)	0.024	5.148 (0.864;9.430)	0.019	r^2*100 = 20.8; $F_{13, 169}$ = 3.160; $p < 0.001$
Vocabulary Acquisition Index (VAI)	2.594 (− 2.829;8.017)	0.346	2.541 (−2.662;7.744)	0.336	r^2*100 = 26.5; $F_{13, 169}$ = 4.318; $p < 0.001$
Non-Verbal Index (NVI)	6.362 (1.392;11.332)	0.012	4.724 (−0.044;9.492)	0.052	r^2*100 = 12.5; $F_{13, 169}$ = 1.712; $p = 0.063$
General Ability Index (GAI)	3.363 (− 1.138;7.864)	0.142	3.538 (−0.781;7.857)	0.108	r^2*100 = 21.4; $F_{13, 169}$ = 3.270; $p < 0.001$
Cognitive Proficiency Index (CPI)	5.086 (0.072;10.099)	0.047	5.153 (0.342;9.963)	0.036	r^2*100 = 16.9; $F_{13, 169}$ = 2.439; $p < 0.005$

Models adjusted for: mother's age (years), family socioeconomic status (low; medium; high), mother's smoking during pregnancy (no; yes), infant sex (boy; girl), gestational age at birth (weeks), family type (nuclear; others), mother's IQ approximation (total score), mother-infant attachment difficulty (total score)

2012; Lenehan et al., 2020; Plunkett et al., 2021; Strøm et al., 2019)that cognitive domains other than IQ were also enhanced in breastfed children. These children proved to have improved working memory, non-verbal abilities, cognitive proficiency, spatial awareness, problem-solving abilities, and a broader spectrum of intellectual abilities, which corroborates findings from previous research. For example, using the K-BIT (The Kaufman Brief Intelligence Test), Lenehan et al., (2020) found better scores on non-verbal abilities. These outcomes collectively highlight the intricate interplay between early nutrition and cognitive functioning, and reinforce the significance of breastfeeding as a potentially pivotal factor in shaping a child's cognitive trajectory.

As far as the duration of breastfeeding is concerned, most studies have found a positive effect of even short periods (Jardí et al., 2017; Lenehan et al., 2020; Strøm et al., 2019), but have not been able to identify a clear dose–response relationship. However, other studies have managed to establish a correlation between the duration of breastfeeding and positive effects on cognitive abilities (Girard et al., 2017; Hou et al., 2021; Kramer et al., 2008). In our case, we examined the protective effect of breastfeeding on the risk of significantly low scores in cognitive assessments and our observations indicate that breastfeeding for more than 8 months acts as a protective factor for non-verbal abilities. Thus, children with lower baseline cognitive scores appear to derive greater benefits from an extended duration of breastfeeding. Moreover, breastfeeding for more than 8 months is also related to higher processing speed, and better cognitive proficiency and total IQ after adjusting for mother-infant attachment difficulties and mother's IQ approximation.

As mentioned above, several studies (Der et al., 2006; Jacobson et al., 1999; Wigg et al., 1998) have questioned the idea that breastfeeding improves cognitive development, and suggested that this association is confounded by the mother's IQ, mother's socioeconomic status or mother-infant attachment (Clark et al., 2006; Der et al., 2006; Holme et al., 2010; Jacobson et al., 1999). In a subsample of our study, when we adjusted for the mother's IQ approximation and mother-infant attachment difficulties, the association of breastfeeding with child IQ and cognitive abilities remained significant, as did the protective effect against low cognitive performance and low IQ scores. This supports the notion that breastfeeding has inherent beneficial effects (Horta et al., 2015; Strøm et al., 2019). It should be considered that these factors may not operate independently but interact in complex ways. Maternal intelligence and the quality of the mother–child attachment may serve as potential mediators of the effect of breastfeeding, and work in conjunction with the direct influence of breastfeeding. In this regard, breastfeeding may serve as an indicator of secure and nurturing maternal attachment, which has been shown to positively influence the psychological development of children as they grow older (Jedrychowski et al., 2012). This multifaceted relationship warrants further investigation, as it may provide insights into the nuanced mechanisms underlying the impact of breastfeeding on cognitive development. In this regard, the cognitive abilities of children who have been breastfed could be better due to the differences in the nutritional composition of human milk and formula milk (Mortensen et al., 2002). The special nutritional composition of breast milk played a crucial role in healthy physical growth, the development of the immune system development, and the maturation of the brain (Hoi & Mckerracher, 2015; Jacobi & Odle, 2012; Kramer et al., 2008; Rabet et al., 2008). Breast milk is rich in long-chain polyunsaturated fatty acids, which are necessary for the myelination process (Plunkett et al., 2021), neuronal growth and repair, and the formation of myelinated neural circuits (Krol & Grossmann, 2018) among other functions in the central nervous system. In this regard, some studies have shown that infants who have not been breastfed have a slower myelination profile in various brain regions, and a more pronounced decline in cognitive function during early childhood (Deoni et al., 2018) since the myelination process is associated with cognitive abilities and neural development (Deoni et al., 2018). Likewise, recent research has shown that breastfeeding plays an important role in establishing the neonatal gut microbiota (Edwards et al., 2022; Gabbianelli et al., 2020; O'Sullivan et al., 2015). Several studies have found that the composition of gut microbial colonization has short- and long-term effects on general health and contributes to good health status (Gabbianelli et al., 2020) and enhanced cognitive development in infants (Al-Khafaji et al., 2020). This association may be mediated through the intricate gut-brain axis, where the bioactive components in breast milk may have a significant influence on the development and functioning of the central nervous system (Edwards et al., 2022). Further research is warranted to elucidate the specific mechanisms underlying this relationship and to explore the potential role of breast milk in promoting optimal cognitive outcomes in early childhood.

Our results must be contextualized in terms of the limitations and strengths of the study. For instance, due to the inherent characteristics of follow-up cohort studies, a significant number of subjects did not take part in the follow-up assessments resulting in a high level of attrition and associated missing data. In relation to this aspect, there is a tendency for there to be more missing data among subjects of medium and high socioeconomic status. These missing data have been excluded from the analysis and the socioeconomic status have been added as adjustment variable. Likewise, the data we collected under the label "Breastfeeding" includes both exclusive and mixed breastfeeding and, unfortunately, there are no standardised criteria for collecting data about the duration of breastfeeding, which often makes it difficult to compare the results of different studies. As far as the sample is concerned, there is a bias in the EPINED cohort in comparison to the ECLIPSES cohort, mainly regarding sex and cognitive development. This is because the EPINED cohort is a community sample but contains participants with clinical and subclinical symptoms of ADHD and ASD. To address potential biases related to these differences, the information about which cohort the sample is drawn from has been included as a covariate in the regression models. In this respect, it should be pointed out that, although the design of the two studies is different, the main variables were collected in the same way.

One of the strengths of our study is the considerable effort made to adjust the analysis for several important confounders that have been related to cognitive development. For instance, Clark et al., (2006) pointed out that a family's socioeconomic level is an important factor in cognitive development and explained that their sample had a low socioeconomic status, so their findings could not be applied to people with a high or medium socioeconomic status. In this study no important associations have been found between family socioeconomic level and cognitive development. Nevertheless, socioeconomic level has been used as an adjustment variable, along with maternal and paternal emotional symptoms and family type, so that the family and sociocultural environment to which the child is exposed can be more fully understood. Additionally, although it would have been interesting to collect data on the child's diet throughout childhood, we have considered the quality of the child's diet at 4 years old (i.e. when the cognitive abilities were assessed). In this way, we can accurately determine whether breastfeeding continues to have a protective effect regardless of these factors. Another adjustment variable in this study was mother's smoking during pregnancy. Other studies have found an association between prenatal nicotine exposure and cognitive and behavioural problems during infancy (Hernández-Martínez et al., 2017; Roigé-Castellví et al., 2019). And our study has found significant differences in breastfeeding ratios between smokers and non-smokers so it is important to adjust for prenatal smoking. Finally, it should be pointed out that cognitive function in children has been assessed individually by the WPPSI-IV, a highly reliable international measure which makes it easier to compare study samples. As well as determining general IQ, the WPPSI-IV also provides a complete cognitive profile of the infant, which reveals the beneficial effect of breastfeeding on cognitive abilities in general and executive function. Other studies have applied the WPPSI scales to assess general IQ, but without considering any other indexes (Clark et al., 2006; Jedrychowski et al., 2012; Plunkett et al., 2021).

Conclusion

In conclusion, our findings underscored the importance of breastfeeding in promoting child cognitive development. In particular, in comparison to non-breastfeeding, breastfeeding from 1 to 8 months is associated with higher IQ and improved non-verbal abilities, and breastfeeding for more than 8 months decreases the risk of low non-verbal abilities. These results remain significant after adjusting for important confounders, which suggests that breastfeeding by itself has numerous benefits.

Our study contributes to the growing body of knowledge that supports the multifaceted advantages of breastfeeding and underscores the need to promote and facilitate breastfeeding as an important factor in infant health. By prioritizing breastfeeding support and education, particularly in the first six months of life, we can enhance the cognitive potential and lifelong well-being of future generations.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare.

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