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Association between infant feeding and ADHD development in childhood: a birth cohort study in Taiwan

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Background: Infant feeding plays a vital role in neurodevelopment, and a lack of breastfeeding and complementary feeding may increase the risk of developing attention-deficit/hyperactivity disorder (ADHD). However, empirical evidence on this relationship remains uncertain, as most studies are based on cross-sectional designs. Therefore, this study aimed to examine this temporal relationship using longitudinal data from a birth cohort. **Methods:** A retrospective cohort study was conducted using data from Wave I (starting at 6 months old, 2005–2006) to Wave IV (up to 5 years old, 2010–2011) of the Taiwan Birth Cohort Study. A total of 19,721 pairs completed the four-wave interviews and provided information on infant feeding, medical history, ADHD occurrence, and sociodemographic characteristics. An extended Cox model with time-dependent covariates was used to examine this association. **Results:** In total, 207 infants developed ADHD during the 54-month observational period, with an estimated cumulative incidence of 5.56 per 1,000 person-years. The average breastfeeding duration was approximately 2 months. With complementary feeding, rice solid food (HR = 0.73) was found to be a protective factor against developing ADHD. Significantly associated factors for increasing ADHD risk included males, lower family income, low birth weight, maternal weight, advanced maternal age, child gastrointestinal disease, child seizures, maternal heart disease, and paternal diabetes mellitus. **Conclusions:** Complementary feeding within 6 months is important to protect infants from developing ADHD. The beneficial effect of breastfeeding within 6 months was not observed while controlling for other risk factors. However, owing to the limitation of a smaller number of ADHD cases, further studies should rely on larger observational periods. **Keywords:** Infant feeding; breastfeeding; complementary feeding; attention-deficit/hyperactivity disorder; birth cohort.

Introduction

Attention deficit/hyperactivity disorder (ADHD) is characterized by pervasive and impairing symptoms of inattention, hyperactivity, and impulsivity. It is one of the most common childhood neurodevelopmental disorders. In recent years, the increasing prevalence of ADHD has drawn great public concern, with the estimated global prevalence of ADHD in children ranging from 2.2% to 7.2% (Pérez-Crespo, Canals-Sans, Suades-González, & Guxens, 2020; Sayal, Prasad, Daley, Ford, & Coghill, 2018). Taiwan experienced a similar trend, in which the reported prevalence in community survey data increased from 3.3% to 7.5% during 1995–1997 (Gau, Chong, Chen, & Cheng, 2005) and to 10.1% during 2015–2017 (Chen, Chen, Lin, Shen, & Gau, 2020). While the exact cause of ADHD is still unknown, a variety of risk factors – genetic factors, brain structure, prenatal smoking, prematurity, low birth weight, adverse family environmental factors, and nutritional factors including sufficient nutrition from infant feeding – breastfeeding in particular, have been identified (Antshel et al., 2011; Biederman, 2005; El Marroun et al., 2012; Feldman & Reiff, 2014; Lee, Chang, & Lung, 2006; Núñez-Jaramillo, Herrera-Solís, & Herrera-Morales, 2021; Shamberger, 2012).

Sufficient nutrition during infant feeding is fundamental to infant health and their later development. The World Health Organization (WHO, 2001a) recommends exclusive breastfeeding for the first 6 months of life, followed by adequate complementary feeding and continued breastfeeding up to the age of 2 years and beyond to ensure that infants and young children obtain the nutrients required for healthy growth and development. Existing evidence supporting neurodevelopmental benefits in this respect has

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linked breastfeeding to a reduced risk of ADHD; specifically, breastfeeding duration is considered a protective factor against ADHD development (Soled, Keim, Rapoport, Rosen, & Adesman, 2021; Tseng et al., 2019; Zeng et al., 2020). This beneficial effect was reflected in a recent systematic review and meta-analysis study (Zeng et al., 2020), but the conclusions remain uncertain as the meta-analysis was limited to several weaknesses across the studies, including small sample sizes, inadequate adjustment for clinical and sociodemographic confounding factors, a lack of longitudinal study designs, and variations in measuring breastfeeding duration possibly because of the difficulty in distinguishing exclusive from non-exclusive breastfeeding. In addition, although a nationwide cross-sectional survey in the United States presented a promising result that exclusive breastfeeding (yes/no) for at least 6 months was associated with a reduced risk of ADHD, the influence of exclusive breastfeeding duration (months) was not identified (Soled et al., 2021). Thus, the temporal link between breastfeeding and the later onset of ADHD is still inconclusive.

While essential nutrients, such as proteins and many vitamins, for early development are provided via breastfeeding during infancy, mineral elements are found to be relatively low in human milk. Therefore, complementary feeding is recommended to supply the elements of iron, zinc, phosphorus, magnesium, sodium, and calcium from both plant- and animal-based solid or liquid foods (WHO, 2001b). Deficiencies in iron, magnesium, and zinc are associated with ADHD development (Dufault, 2018; Lange et al., 2017; Villagomez & Ramtekkar, 2014; Yang et al., 2019); however, empirical studies in this respect are still lacking. It seems that little attention has been paid to the role of complementary feeding in the later development of ADHD.

In light of the above considerations, the present study aimed to ascertain the relationship between infant feeding practices – breastfeeding and complementary feeding in particular – and the later onset of ADHD while taking other potential risk factors into account by using longitudinal data from a birth cohort in Taiwan.

Methods

Study design and sample

This study used data from the Taiwan Birth Cohort Study (TBCS), a nationally representative cohort study designed to establish national norms for children's development. The TBCS employed a multistage stratified systematic sampling design based on national birth registration data in Taiwan in 2005 and obtained 24,200 pairs of newborns and their mothers or caregivers as the study sample. Since then, the national longitudinal survey has completed six-wave surveys. After obtaining informed consent from infants' mothers or caregivers, the TBCS conducted home interviews using structured questionnaires to collect important information related to the development during infancy and childhood (Health Promotion Administration, 2021).

In this study, we used interview data from Waves I to IV obtained from 6-month-old, 18-month-old, 3-year-old, and 5-year-old infants in 2005–2006, 2006–2007, 2008–2009, and 2010–2011, respectively. Among these four-wave interviews, the initial sample size was 24,200 pairs, and excluding those lost to follow-up, the final sample sizes at Waves I to IV were 21,248, 20,172, 19,910, and 19,721 pairs, respectively. Approval for data use was obtained from the Health Promotion Administration of Taiwan. Ethical approval was obtained from the China Medical University and Hospital Research Ethics Committee (CMUH110-REC1-130).

Measurement

The outcome variable was the occurrence of ADHD, which was first assessed in children aged 3 years in the TBCS. Therefore, from Waves III to IV data, we used information on the answer to the survey question: 'Was your child ever diagnosed with ADHD by a physician or professional of child development?'

Maternal breastfeeding and complementary feeding (also called solid food feeding) were assessed from responses to a set of questions on infant feeding methods within 6 months of the Wave I survey. Information related to breastfeeding practices included ever being breastfed (ever/never) and duration of being breastfed (days). Based on answers regarding the days of being breastfed, maternal breastfeeding lasting at least 3 months (yes/no) and at least 6 months (yes/no) were obtained. Information on complementary feeding practices was obtained from responses to questions about solid foods that the infant received – fruit/vegetable juice or mash, rice porridge, other rice products, and wheat products. Exclusive breastfeeding was assessed by asking whether the infant ever received only breast milk after birth (ever/never). The duration of exclusive breastfeeding (in days) was also determined.

Data on other risk factors for ADHD development were also obtained in this study, such as birth number (singleton or multiple pregnancy), low birth weight, prematurity, disease and sleeping conditions of the infant, maternal weight and body mass index (BMI), maternal conditions in pregnancy and during delivery, maternal age when giving birth, parental medical conditions within 6 months after birth, maternal exposure to smoke and alcohol in pregnancy and after birth within 6 months, and infant exposure to secondhand smoke. In addition, we also used information on sociodemographic characteristics, including infant sex, urbanization level of living area, presence of siblings, family income, maternal employment status, maternal working time (only daytime, only nighttime, shifts work between daytime and nighttime, both daytime and nighttime), and maternal education level.

Statistical analysis

Considering that some risk factors can vary over the follow-up period, we applied an extended Cox model with time-dependent covariates to examine the relative influence of the studied factors on the occurrence of ADHD over time. This model is an extension of the conventional Cox proportional hazards model. Unlike the conventional model, which is limited by the assumption that explanatory variables should be constant over time, the extended model allows for time-dependent explanatory variables (Kleinbaum & Klein, 2012). Two types of factors were identified: time-independent and time-dependent. Time-independent factors included the sociodemographic characteristics of infant sex, urbanization level of living area, maternal employment status, maternal working time, and maternal education level; parents' medical conditions during delivery including maternal weight, maternal BMI,

advanced maternal age, and presence of chronic diseases such as hypertension, heart disease, diabetes, asthma, and nasal allergy; parents' drinking and smoking behaviors during the pregnancy and breastfeeding periods; and the infants' health, including premature birth, low birth weight, singleton or multiple births, and presence of asthma and nasal allergy at the age of 3 years (as this information was only available from the Wave III survey results). Time-dependent factors included family income (at 6 months, 18 months, 3 years, and 5 years), presence of siblings (at 18 months, 3 years, and 5 years), presence of gastrointestinal diseases, seizures (at 6 months, 18 months, 3 years, and 5 years), skin allergy (at 6 months, 18 months, and 3 years), and exposure to secondhand smoke (at 18 months, 3 years, and 5 years).

Results

During the follow-up period, ADHD was reported among 38 children aged 3 years (the observed period was 30,033 person-years) and 169 children aged 5 years (the observed period was 39,386 person-years) (Table not shown). The incidence rates were 1.27‰ and 4.29‰, respectively. A cumulative incidence rate of 5.56‰ indicated the likelihood of developing ADHD from birth to the age of 5 years (see Figure 1).

Table 1 shows the distributions of infant feeding practices within 6 months of the birth among the total of 21,248 infants at Wave I, the rate of the later ADHD onset by the feeding practice, and the results of the univariate analyses for the causal relationship between infant feeding and the subsequent development of ADHD. Of the mothers, 82.1% ever breastfed after delivery, but their breastfeeding duration days were, on average, not over 2 months (the duration mean [*SD*] was 58.51 [84.98] days). Approximately 26% of the mothers breastfed for 3 months, and few (9.8%) breastfed for 6 months. Among the mothers, only 21.9% ever exclusively breastfed their infants (their breastfeeding duration mean [*SD*] was 125.32 [74.63] days), and even fewer (only 3.8%) adhered to the WHO's recommendation to exclusively breastfeed for up to 6 months. The insignificant hazard ratio of 0.93 (95% CI: 0.67–1.31, $p = .685$) indicates that there is no association between exclusive breastfeeding and the later onset of ADHD (see Table 1).

Regarding complementary feeding to infants within 6 months, 64.4% of mothers provided a variety of rice solid foods but no traditional rice porridge; 44.1% provided traditional rice porridge. Approximately half of the mothers provided fruit or vegetable juice or mash, and only one-third provided wheat solid foods (see Table 1). The crude hazard ratios in Table 1 indicate that, among the methods of infant feeding within 6 months, only those who had received maternal breastfeeding and complementary feeding with rice solid foods had significant effects. The significant hazard ratios of 0.72 (95% CI: 0.52–1.00, $p = .049$) and 0.74 (95% CI: 0.56–0.98, $p = .034$) without adjusting for other risk factors indicated that maternal breastfeeding and complementary feeding with rice solid foods might play a protective role in the development of ADHD in childhood.

The cumulative incidence rates with and without breastfeeding (see Figure 1) and rice solid food feeding (see Figure 2) are noteworthy. Compared with infants with maternal feeding, the cumulative incidence rates of those without maternal feeding growing up to 3 and 5 years were 1.91‰ (vs. 1.13‰) and 7.30‰ (vs. 5.19‰), respectively; compared with infants who were fed rice solid food, the cumulative incidence rates of those who were not growing up to 3 and 5 years were 1.60‰ (vs. 1.08‰) and 6.71‰ (vs. 4.93‰), respectively. However, after conducting

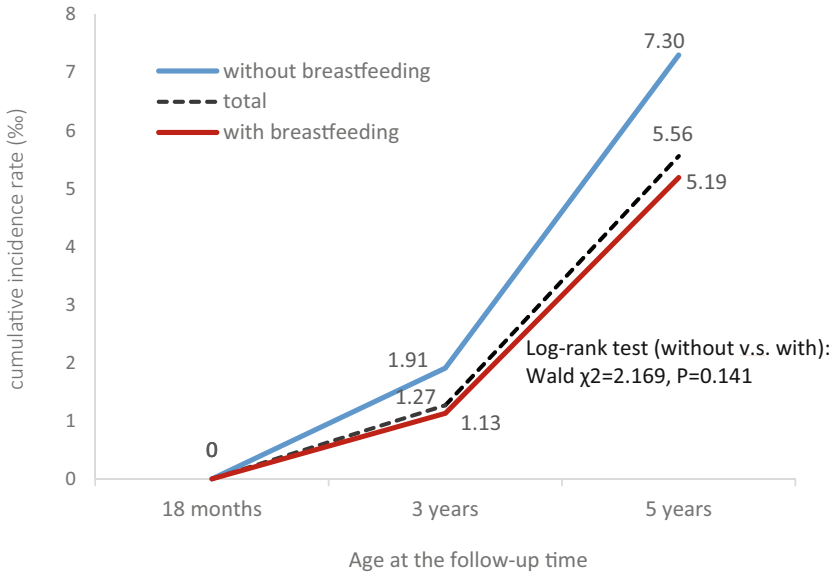

Figure 1 Comparison of cumulative incidence rate curves of ADHD between infants with and without breastfeeding and the curve in total

Table 1 Distributions of breastfeeding and complementary feeding within 6 months of birth, ADHD occurrence rate and crude hazard ratio for ADHD

Variables	*N* (%)/mean (*SD*)	ADHD (%)/ mean (*SD*)	Crude HR (95% CI)	*p* Value
Breastfeeding within 6 months				
Ever fed with breast milk				
Never	3,797 (17.9)	47 (1.24)	1	
Ever	17,451 (82.1)	160 (0.92)	0.72 (0.52–1.00)	.049
Breastfeeding ≥3 months				
No	15,768 (74.2)	154 (0.98)	1	
Yes	5,480 (25.8)	53 (0.97)	0.98 (0.72–1.34)	.907
Breastfeeding ≥6 months				
No	19,160 (90.2)	188 (0.98)	1	
Yes	2,088 (9.8)	19 (0.91)	0.92 (0.58–1.48)	.742
Breastfeeding duration (days)	58.51 (84.98)	55.65 (64.77)[b]		
Exclusive breastfeeding (only breast milk)				
Never	16,600 (78.1)	164 (0.99)	1	
Ever	4,648 (21.9)	43 (0.93)	0.93 (0.67–1.31)	.685
Exclusive breastfeeding ≥3 months				
No	17,947 (84.5)	177 (0.99)	1	
Yes	3,301 (15.5)	30 (0.91)	0.92 (0.63–1.36)	.685
Exclusive breastfeeding ≥6 months				
No	20,444 (96.2)	199 (0.97)	1	
Yes	804 (3.8)	8 (1.00)	1.15 (0.57–2.34)	.696
Exclusive breastfeeding duration (days)	125.32 (74.63)	41.19 (61.98)[b]		
Complementary feeding within 6 months				
Ever fed with solid foods				
Never	2,677 (12.6)	30 (1.12)	1	
Ever	18,571 (87.4)	177 (0.95)	0.72 (0.49–1.08)	.109
Fruit/vegetable juice				
No	10,090 (47.5)	101 (1.00)	1	
Yes	11,158 (52.5)	106 (0.95)	0.94 (0.72–1.24)	.672
Fruit/vegetable mash				
No	11,215 (52.8)	117 (1.04)	1	
Yes	10,033 (47.2)	90 (0.90)	0.86 (0.65–1.13)	.27
Traditional rice porridge				
No	11,883 (55.9)	126 (1.06)	1	
Yes	9,365 (44.1)	81 (0.86)	0.81 (0.62–1.08)	.149
Rice solid food[a]				
No	7,558 (35.6)	88 (1.16)	1	
Yes	13,690 (64.4)	119 (0.87)	0.74 (0.56–0.98)	.034
Wheat solid food				
No	14,797 (69.6)	141 (0.95)	1	.592
Yes	6,451 (30.4)	66 (1.02)	1.08 (0.81–1.45)	

[a]Rice solid food here did not include traditional rice porridge.
[b]Denotes the value obtained from those with ADHD.

log-rank tests for the cumulative incidence rate curves between the two groups, no differences existed in the cumulative incidence rates between infants with and without maternal breastfeeding (Wald $\chi^2 = 2.169$, $p = .141$); however, two curves between with and without rice solid food appeared significant (Wald $\chi^2 = 4.971$, $p = 0.026$). This suggests the importance of complementary feeding within 6 months, particularly rice solid food feeding. However, this protective effect should be adjusted by considering other risk factors in future analyses. Table 2 also shows the crude hazard ratios of other risk factors associated with the later onset of ADHD.

To examine the net effect of infant feeding by adjusting for the possible influential effects of other risk factors, which varied by time, on the subsequent development of ADHD, an extended Cox model with time-dependent covariates was adopted for the multivariate analysis. Table 2 shows the final analysis results, in which the significant hazard ratio of 0.73 (95% CI: 0.55–0.96, $p = .029$) demonstrates that infant complementary feeding within 6 months, particularly rice solid food feeding, could exert a protective effect on ADHD development in childhood. Compared with females, male infants were 3.16 times (aHR = 3.16, 95% CI: 2.25–4.43, $p < .001$) more likely to develop ADHD. Maternal employment status affected infants' risk of developing ADHD; infants with unemployed mothers had a 1.48 times higher risk of developing ADHD than those with employed mothers who worked only in the daytime. Infants with a low birth weight had a 2.39

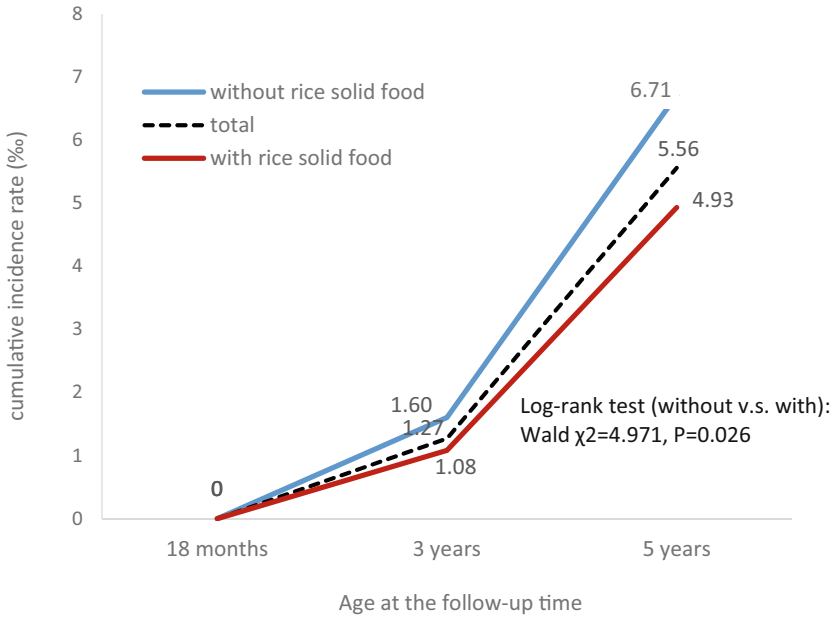

Figure 2 Comparison of cumulative incidence rate curves of ADHD between infants with and without rice solid food complementary feeding and the curve in total

times (aHR = 2.39, 95% CI: 1.03–5.59, $p = .044$) increased likelihood of developing ADHD. Parental health conditions at birth affected the development of ADHD during childhood. Furthermore, the higher the maternal weight, the greater was the risk for her infant to develop ADHD; herein, the risk increased 1.02 times by a 1-unit increase in the mother's weight (aHR = 1.02, 95% CI: 1.00–1.03, $p = .025$). Delivering the newborn at an advanced maternal age could increase the newborn's risk of developing ADHD by 1.55 times (aHR = 1.55, 95% CI: 1.01–2.36, $p = .043$). Mothers with a heart disease (aHR = 2.89, 95% CI: 1.25–6.67, $p = .013$) and fathers with diabetes (aHR = 3.86, 95% CI: 1.69–8.79, $p = .001$) significantly increased infants' risk for developing ADHD. Interestingly, compared with those without any siblings, children with siblings were less likely to develop ADHD (aHR = 0.65, 95% CI: 0.47–0.88, $p = .006$). Any occurrences of gastrointestinal diseases (aHR = 1.81, 95% CI: 1.37–2.41, $p < .001$) and seizures (aHR = 2.32, 95% CI: 1.01–5.30, $p = .046$) during infancy and childhood could significantly increase the risk of developing ADHD.

Discussion

Following a nationally representative cohort of newborns, which was randomly selected from the 2005 Taiwan birth registry, from the age of 6 months (initial sample size was 21,248) to 5 years (final sample size was 19,721), we found a cumulative incidence of ADHD of 5.56 ‰ person-years. This finding is similar to the incidence of 4.3056 ‰ person-years for children aged 0 to 6 years reported in a previous study in Taiwan, in which a nationally representative sample of one million beneficiaries was randomly selected from the 2005 Taiwan National Health Insurance System, and their medical claims from 1999 to 2005 were used to identify new cases of ADHD (Huang, Chu, Cheng, & Weng, 2014). However, the ADHD cases identified in our study were based on mothers' or caregivers' answers to the survey question on whether their children had obtained professional reports or clinical diagnoses for ADHD. The slightly higher incidence in this study may partly reflect a self-reported bias or that a few mothers did not visit medical doctors to seek healthcare for their children. Nevertheless, this slim gap of about 1.0‰ should be considered acceptable and would not bias the estimated hazard ratios while examining the risk factors associated with the subsequent development of ADHD.

Maternal breastfeeding has been demonstrated to affect growth and neurodevelopment in infancy and childhood (Eidelman et al., 2012), and exclusive breastfeeding (with no other foods or liquids being provided, including water) for the first 6 months of life appears crucial in this respect and is highly recommended by the WHO (2001a) and the United Nations Children's Fund (UNICEF). In addition, the recommendation notes that infants should be breastfed on demand (i.e., as often as the child wants, day and night). From the age of 6 months, children should begin eating safe and adequate complementary foods while continuing to be breastfed for up to 2 years (WHO, 2022). Despite Taiwan's health government having promoted the WHO's recommendation via a variety of hospitals and community health centers since 2002, the results of this study showed that although over 80% of mothers breastfed their newborns, only

Table 2 Distributions of antecedent factors and their associations with ADHD incidence

	Descriptive analysis		Bivariate analysis		Multivariate analysis	
Variables	*N* (%)	ADHD (%)	Crude HR (95% CI)	*p* Value	Adjusted HR (95% CI)	*p* Value
Time-independent variables						
Infant feeding within 6 months						
Maternal breastfeeding						
Never	3,797 (17.9)	47 (1.24)	1		1	
Ever	17,451 (82.1)	160 (0.92)	0.72 (0.52–1.00)	.049*	0.88 (0.62–1.24)	.458
Rice solid food						
No	7,558 (35.6)	88 (1.16)	1		1	
Yes	13,690 (64.4)	119 (0.87)	0.74 (0.56–0.98)	.034*	0.73 (0.55–0.97)	.029*
Sociodemographic characteristics						
Sex						
Female	10,103 (47.5)	48 (0.48)	1		1	
Male	11,145 (52.5)	159 (1.43)	3.01 (2.18–4.16)	<.001***	3.16 (2.25–4.43)	<.001***
Maternal employment status						
Employed	12,287 (57.8)	93 (0.76)	1			
Unemployed	8,961 (42.2)	114 (1.27)	1.71 (1.30–2.25)	<.001***		
Maternal working time						
Daytime only	8,641 (40.7)	58 (0.67)	1		1	
Nighttime only	488 (2.3)	7 (1.43)	2.22 (1.01–4.86)	.046*	1.73 (0.74–4.07)	.209
Shifting between both times	999 (4.7)	11 (1.10)	1.61 (0.85–3.07)	.147	1.84 (0.96–3.53)	.065
Involving both times	2,159 (10.2)	17 (0.79)	1.18 (0.68–2.02)	.559	1.12 (0.64–1.93)	.698
Unemployed	8,961 (42.2)	114 (1.27)	1.91 (1.39–2.61)	<.001***	1.48 (1.04–2.10)	.028*
Maternal education						
Graduate school	739 (3.5)	3 (0.41)	1		1	
College	8,883 (41.8)	72 (0.81)	1.97 (0.62–6.24)	.252	1.72 (0.53–5.60)	.368
Senior high school	8,483 (39.9)	90 (1.06)	2.58 (0.82–8.15)	.106	1.50 (0.45–5.04)	.508
Junior high school	2,297 (10.8)	34 (1.48)	3.71 (1.14–12.06)	.029*	1.94 (0.55–6.83)	.301
Elementary school	846 (4.0)	8 (0.95)	2.37 (0.63–8.91)	.204	1.29 (0.32–5.24)	.722
Infant birth status						
Premature birth						
No	18,843 (88.7)	174 (0.92)	1		1	
Yes	2,405 (11.3)	33 (1.37)	1.50 (1.04–2.18)	.032*	0.74 (0.35–1.58)	.437
Low birth weight						
No	19,789 (93.1)	182 (0.92)	1		1	
Yes	1,459 (6.9)	25 (1.71)	1.89 (1.24–2.87)	.003**	2.39 (1.03–5.59)	.044*
Parental health behaviors						
Maternal alcohol use in pregnancy						
No	20,903 (98.4)	199 (0.95)	1		1	
Yes	345 (1.6)	8 (2.32)	2.57 (1.27–5.21)	.009**	1.71 (0.79–3.69)	.17
Paternal cigarette use in pregnancy						
No	10,062 (47.4)	83 (0.82)	1		1	
<20 cigarette	10,074 (47.4)	107 (1.06)	1.30 (0.98–1.73)	.074	1.87 (0.62–5.65)	.268
≥20 cigarette	1,112 (5.2)	17 (1.53)	1.91 (1.14–3.22)	.015*	1.70 (0.21–13.95)	.622
Paternal cigarette use in breastfeeding period						
No	10,070 (47.4)	85 (0.84)	1		1	
<20 cigarette	10,044 (47.3)	105 (1.05)	1.25 (0.94–1.66)	.129	0.56 (0.18–1.68)	.297
≥20 cigarette	1,134 (5.3)	17 (1.50)	1.84 (1.09–3.10)	.022*	0.69 (0.08–5.60)	.724
Parent medical history at the birth						
Maternal weight	53.2 (8.7)	54.97 (10.82)	1.02 (1.01–1.03)	.004**	1.02 (1.00–1.03)	.025*
Advanced age at birth						
No	19,432 (91.5)	179 (0.92)	1		1	
Yes	1,816 (8.5)	28 (1.54)	1.71 (1.15–2.55)	.008**	1.55 (1.01–2.36)	.043*
Maternal hypertension						
No	21,141 (99.5)	203 (0.96)	1		1	
Yes	107 (0.5)	4 (3.74)	3.98 (1.48–10.70)	.006**	2.33 (0.83–6.58)	.109
Maternal heart disease						
No	21,053 (99.1)	201 (0.95)	1		1	
Yes	195 (0.9)	6 (3.08)	3.33 (1.48–7.50)	.004**	2.89 (1.25–6.67)	.013*
Paternal diabetes						
No	21,096 (99.3)	200 (0.95)	1		1	
Yes	152 (0.7)	7 (4.61)	4.91 (2.31–10.43)	<.001***	3.86 (1.69–8.79)	.001**
Maternal asthma						

(continues)

Table 2 (continued)

Variables	Descriptive analysis		Bivariate analysis		Multivariate analysis	
	N (%)	ADHD (%)	Crude HR (95% CI)	*p* Value	Adjusted HR (95% CI)	*p* Value
No	20,928 (98.5)	200 (0.96)	1		1	
Yes	320 (1.5)	7 (2.19)	2.35 (1.10–4.98)	.027*	1.46 (0.63–3.37)	.381
Maternal nasal allergy						
No	18,027 (84.8)	165 (0.92)	1		1	
Yes	3,221 (15.2)	42 (1.30)	1.41 (1.01–1.98)	.046*	1.41 (0.99–2.01)	.059
Infant medical history						
Asthma at 3 years						
No	19,285 (96.9)	191 (0.99)	1		1	
Yes	625 (3.1)	13 (2.08)	2.19 (1.25–3.85)	.006**	1.52 (0.85–2.72)	.156
Nasal allergy at 3 years						
No	15,939 (80.1)	147 (0.92)	1		1	
Yes	3,971 (19.9)	57 (1.44)	1.54 (1.14–2.10)	.006**	1.37 (0.99–1.90)	.055
Time-dependent variables						
Sociodemographic characteristics						
Siblings						
Without	4,019 (20.4)	57 (1.42)	1		1	
With	15,702 (79.6)	149 (0.95)	0.58 (0.43–0.78)	<.001***	0.65 (0.47–0.88)	.006*
Family income (Taiwan dollar)						
≥100,000	3,065 (15.5)	17 (0.55)	1		1	
50,000–99,999	8,913 (45.2)	64 (0.72)	1.19 (0.72–1.95)	.502	1.08 (0.64–1.81)	.777
20,000–49,999	6,713 (34.0)	103 (1.53)	2.21 (1.36–3.57)	.001**	1.67 (0.97–2.89)	.066
<20,000	1,030 (5.2)	22 (2.14)	3.03 (1.63–5.64)	<.001***	1.95 (0.96–3.98)	.065
Infant medical history						
Gastrointestinal disease						
No	13,410 (68.0)	112 (0.84)	1		1	
Yes	6,311 (32.0)	94 (1.49)	1.93 (1.47–2.53)	<.001***	1.81 (1.37–2.41)	<.0001***
Seizures						
No	19,564 (99.2)	200 (1.02)	1		1	
Yes	157 (0.8)	6 (3.82)	3.54 (1.57–7.98)	.002**	2.32 (1.01–5.30)	.046*
Infant health behavior						
Exposure to secondhand smoke						
Never	9,012 (45.7)	85 (0.94)	1		1	
Occasionally	8,853 (44.9)	96 (1.08)	1.19 (0.89–1.60)	.246	1.15 (0.84–1.56)	.385
Often	1,014 (5.1)	13 (1.28)	1.37 (0.76–2.46)	.293	1.19 (0.65–2.18)	.573
Daily	842 (4.3)	12 (1.43)	2.06 (1.20–3.52)	.008**	1.50 (0.83–2.72)	.183

Note: ** $.01 \leq p < .05$; ** $.001 \leq p < .01$; *** $p < .001$.

21.9% exclusively breastfed, and a mere 3.8% fully adhered to the recommendation of extending exclusive breastfeeding up to 6 months. Additionally, up to 18% of mothers fed their infants only formula. These findings suggest a need for increased advocacy for exclusive breastfeeding and the avoidance of infant formula.

This study showed that over 80% of the infants within 6 months were fed with a variety of complementary foods, among which rice solid foods, except for rice porridge, were the most common. The time to introduce solid foods tends to be earlier than that recommended by the Asia Pacific Academic Consortium for Public Health (Binns et al., 2020), which is exactly at the age of 6 months, reflecting a possible cultural influence on infant feeding in Taiwanese society. However, our findings indicated that, compared with those without breast milk and complementary rice solid foods (except for rice porridge) within 6 months, those with both had lower incidence rates of ADHD. Regarding whether appropriate infant feeding (breastfeeding and complementary feeding) could decrease the risk for later development of ADHD in childhood while considering other risk factors, our multivariate analyses results only demonstrated that infant feeding with rice solid food, except rice porridge, exerted a protective effect. Commercial rice solid foods contain more nutrients, like carbohydrates, sodium, calcium, protein, fat, iron, and zinc, than traditional rice porridge. Zinc and iron deficiencies have also been associated with ADHD. Zinc plays an important role in neurological functioning, and ADHD has been associated with lower levels of hair, plasma, serum, and urinary zinc. A zinc deficiency may contribute to metabolic loss by transporting lead and mercury outside the body, leading to ADHD development (Dufault, 2018). Iron is necessary for catecholamine synthesis, and

dopamine and ferritin are markers of peripheral iron stores. Some studies reported lower ferritin levels in children with ADHD (Cortese, Angriman, Lecendreux, & Konofal, 2012). Despite these associations, the exact mechanisms through which zinc and iron affect the development of ADHD remain unclear. However, as clinicians are encouraged to review the dietary history of children presenting with ADHD symptoms, they examine possible deficiencies by ordering RBC-magnesium, 25-OH vitamin D, ferritin, and serum zinc when appropriate (Villagomez & Ramtekkar, 2014). Rice solid foods with more micronutrients than rice porridge should be emphasized for infants' complementary feeding to prevent ADHD.

Being male presented a three times higher risk of ADHD, and the magnitude in this study (aHR = 3.18) was similar to that in a prospective study (aOR = 3.42) analyzing the Boston Birth Cohort (Ji, Hong, et al., 2018). This striking sex difference has been well documented; however, its underlying mechanism remains poorly understood. The finding of a significant antecedent factor of low birth weight in this study corresponds to that found in some cohort studies (Alamolhoda, Haghdoost, Shariatifar, Zare, & Ahmadi Doulabi, 2021) and a twin study in Sweden (N = 18,359 twins aged 9–12 years with complete information on birth weight and ADHD symptoms; Pettersson et al., 2015), which indicated an independent role of low birth weight in predicting the later onset of ADHD. The previous occurrence of gastrointestinal disorders increasing the risk of developing ADHD found in this study demonstrates the existence of empirical evidence in which the gut microbiome has been proposed to explain the relationship between GI symptoms and ADHD (Checa-Ros, Jeréz-Calero, Molina-Carballo, Campoy, & Muñoz-Hoyos, 2021). In addition, the finding that the previous occurrence of seizure symptoms was a significant predictor was consistent with the evidence found in some existing studies (Bertelsen, Larsen, Petersen, Christensen, & Dalsgaard, 2016).

Advanced maternal age significantly increased the offspring's risk of ADHD in this study (aHR = 1.55), although the existing evidence remains mixed (Chang et al., 2014; Janecka et al., 2019; Min, Li, & Yan, 2021). A U-shaped curve was found in a recent study, in which the peaks of the risk appeared in both the youngest (20 years or less) and oldest (41 years or more) groups (Kim, Choi, Lim, Ha, & Kwon, 2020), a finding that deserves further exploration in future studies. As pre-pregnancy weight gain or obesity has been found to be associated with ADHD in offspring (Grudzinski et al., 2019; Rodriguez et al., 2008) and a similar result was obtained in this study, the importance of weight control for pre-pregnant women should be emphasized in maternal- and child-health education. Parental health conditions are considered genetic and/or environmental determinants of offspring development. Parental diabetes mellitus, particularly type 1 diabetes, has been linked to an increased risk of offspring ADHD (Zeng et al., 2020); similarly, our study demonstrated the negative impact of the pre-existence of paternal diabetes mellitus (aHR = 3.88, 95% CI: 1.70–8.85). Unlike existing evidence indicating an association between maternal hypertension and an increased risk of ADHD, this study showed an insignificant link but found a significantly negative impact of the pre-existence of maternal heart disease. Little evidence supports this finding; nevertheless, a link between low maternal high-density lipoprotein levels and an increased risk of ADHD in offspring has previously been found (Ji, Riley, et al., 2018).

Regarding the family environment related to maternal work status and siblings, we found that unemployed mothers and not having siblings led to a significantly increased risk of developing ADHD. This could be because the more care the infant susceptible to ADHD symptoms needs, the less time is available for their mother to go out for a job, and similarly, the parental decision to have a second child could be withdrawn. However, this hypothesis must be explored in future studies.

This study had several limitations owing to the nature of the survey data used. The incidence of ADHD was not identified based on the medical records of the ICD-9-CM codes diagnosed by physicians. Limited by the confidentiality of personal information, the impossibility of merging the used TBCS data into National Health Insurance exists; information related to ADHD incidence in childhood could only be obtained from mothers' or primary caregivers' self-reports on ever being informed by pediatric physicians or specialized professionals about their children's potential ADHD. Nevertheless, the reliability of the self-reported answers is supported by the slim gap of about 1.0‰ person-years in the estimated cumulative ADHD incidence between this study and an existent Taiwan study that used medical claims data. The TBCS survey questions on breastfeeding and complementary feeding were only asked in Wave I, leading to a lack of opportunities to examine the effects of longer than 6-month feeding duration on ADHD incidence. The self-reported information obtained from the survey data in this study suffers from a recall bias, which can hardly be estimated unless individual-level data from different sources are allowed to be merged by law. In addition, a lack of information on some biological indicators such as maternal ADHD history and immune reactions limited this study from more comprehensively examining the studied association.

However, this study also has several strengths that emphasize the significance and important implications of the results. First, it is a large-scale study that benefited from the multiple-wave surveys on a nationally representative birth cohort. Second, the

panel study design of the TBCS permitted the collection of offspring and parental information related to nurturing, medical conditions, and health behaviors. These are thought to be more comprehensive. Third, the loss of follow-up during the four-wave surveys was relatively small, showing that the evidence found in this study is sufficient to draw important conclusions regarding public health concerns. Fourth, despite mothers and primary caregivers reporting on the identification of offspring ADHD, answering yes or no to whether a health professional, either a specialized professional or a physician, had ever commented on their child exhibiting ADHD was based on professional judgments. Therefore, the likelihood of having a misclassification in the responses in recalling a professional's opinion might be slim. Finally, this study used an extended Cox model with time-dependent covariates to conduct multivariate analyses to better examine the association of infant feeding within 6 months with subsequent ADHD incidence in childhood, considering the effects of the repeated measures of other antecedent factors across multiple time points.

Conclusions

The estimated cumulative incidence of ADHD in children aged 5 years in Taiwan was 5.56 per 1,000 person-years. Although the time to introduce solid foods to infants was, on average, earlier than the time recommended by the WHO or UNICEF, sufficient complementary feeding to infants within 6 months, particularly rice solid foods but not traditional rice porridge, is important for protecting infants from developing ADHD. The beneficial effect of breastfeeding within 6 months on reducing ADHD risk was not found when other risk factors were considered. However, this effect remains inconclusive because of most mothers not breastfeeding for over 2 months and the possibly insufficient size of the observed ADHD cases during this short 5-year observation period. Further studies with longer observation periods are required.

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Author Contributions: CYC, PYS, MCL, and HYL conceptualized and designed the study. CTS, CFC contributed to the conceptualization and design. CTS and CFC assisted in performing the data management and statistical analyses. MCL and HYL provided professional support and interpretation of the results. CYC, PYS and CTS analyzed the data and interpreted the results. CYC and PYS drafted the initial manuscript; MCL and HYL revised the manuscript for important intellectual content and provided overall supervision of the study.

Ethical considerations

Approval for data use was obtained from the Health Promotion Administration of Taiwan. Ethical approval was obtained from the China Medical University and Hospital Research Ethics Committee (CMUH110-REC1-130). Informed consent was obtained.

Data availability

Data are not available because based on Taiwan Personal Data Protection Act and Human Subjects Research Act, the study participants were assured that their data would remain confidential and would not be shared.

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Key points

- Infant feeding plays a vital role in neurodevelopment, and the lack of breastfeeding and complementary feeding may potentially increase the risk of attention deficit/hyperactivity disorder (ADHD) development.
- This study found that complementary feeding of rice solid food (aHR = 0.73, p = .029) significantly protects infants from developing ADHD. The beneficial effect of breastfeeding within 6 months on reducing ADHD risk was not found while considering other risk factors.
- In clinical settings, nutrition education for ADHD prevention should emphasize infants' complementary feeding of rice solid food because some micronutrients, such as zinc and iron, in the food are beneficial for neurodevelopment in infancy and early childhood.

References

Alamolhoda, S.H., Haghdoost, S., Shariatifar, N., Zare, E., & Ahmadi Doulabi, M. (2021). Risk of child ADHD and low birth weight: A systematic review study. *International Journal Of Pediatrics*, *9*, 14421–14434.

Antshel, K.M., Hargrave, T.M., Simonescu, M., Kaul, P., Hendricks, K., & Faraone, S.V. (2011). Advances in understanding and treating ADHD. *BMC Medicine*, *10*, 72.

Bertelsen, E.N., Larsen, J.T., Petersen, L., Christensen, J., & Dalsgaard, S. (2016). Childhood epilepsy, febrile seizures, and subsequent risk of ADHD. *Pediatrics*, *38*, e20154654.

Biederman, J. (2005). Attention-deficit/hyperactivity disorder: A selective overview. *Biological Psychiatry*, *57*, 1215–1220.

Binns, C., Lee, M.K., Low, W.Y., Baker, P., Bulgiba, A., Dahlui, M., … & Tang, L. (2020). Guidelines for complementary feeding of infants in the Asia Pacific Region: APACPH public health nutrition group. *Asia-Pacific Journal of Public Health*, *32*, 179–187.

Chang, Z., Lichtenstein, P., D'Onofrio, B.M., Almqvist, C., Kuja-Halkola, R., Sjölander, A., & Larsson, H. (2014). Maternal age at childbirth and risk for ADHD in offspring: A population-based cohort study. *International Journal of Epidemiology*, *43*, 1815–1824.

Checa-Ros, A., Jeréz-Calero, A., Molina-Carballo, A., Campoy, C., & Muñoz-Hoyos, A. (2021). Current evidence on the role of the gut microbiome in ADHD pathophysiology and therapeutic implications. *Nutrients*, *13*, 249.

Chen, Y.L., Chen, W.J., Lin, K.C., Shen, L.J., & Gau, S.F. (2020). Prevalence of DSM-5 mental disorders in a nationally representative sample of children in Taiwan: Methodology and main findings. *Epidemiology and Psychiatric Sciences*, *29*, e15.

Cortese, S., Angriman, M., Lecendreux, M., & Konofal, E. (2012). Iron and attention deficit/hyperactivity disorder: What is the empirical evidence so far? A systematic review of the literature. *Expert Review of Neurotherapeutics*, *12*, 1227–1240.

Dufault, R.J. (2018). Food labeling requirements may explain lower autism and ADHD prevalence in the United Kingdom. *Integrative Food, Nutrition and Metabolism*, *5*, 2.

Eidelman, A.I., Schanler, R.J., Johnston, M., Landers, S., Noble, L., Szucs, K., & Viehmann, L. (2012). Breastfeeding and the use of human milk. *Pediatrics*, *129*, e827–e841.

El Marroun, H., Zeegers, M., Steegers, E.A., van der Ende, J., Schenk, J.J., Hofman, A., … & Tiemeier, H. (2012). Post-term birth and the risk of behavioural and emotional problems in early childhood. *International Journal of Epidemiology*, *41*, 773–781.

Feldman, H.M., & Reiff, M.I. (2014). Clinical practice. Attention deficit-hyperactivity disorder in children and adolescents. *The New England Journal of Medicine*, *370*, 838–846.

Gau, S.S., Chong, M.Y., Chen, H.H., & Cheng, A.T. (2005). A 3-year panel study of mental disorders among adolescents in Taiwan. *The American Journal of Psychiatry*, *162*, 1344–1350.

Grudzinski, A., Campbell, L.A., Liu, L., Brown, M.M., Dodds, L., & Kuhle, S. (2019). Maternal pre-pregnancy weight status and health care use for mental health conditions in the offspring. *European Child & Adolescent Psychiatry*, *28*, 1499–1506.

Health Promotion Administration, Ministry of Health and Welfare, Taiwan. (2021). Taiwan birth cohort study (TBCS). Available from: https://www.hpa.gov.tw/Pages/Detail.aspx?nodeid=1077&pid=6199 [last accessed 10 January 2022].

Huang, C.L., Chu, C.C., Cheng, T.J., & Weng, S.F. (2014). Epidemiology of treated attention-deficit/hyperactivity disorder (ADHD) across the lifespan in Taiwan: A nationwide population-based longitudinal study. *PLoS One*, *9*, e95014.

Janecka, M., Hansen, S.N., Modabbernia, A., Browne, H.A., Buxbaum, J.D., Schendel, D.E., … & Grice, D.E. (2019). Parental age and differential estimates of risk for neuropsychiatric disorders: Findings from the Danish birth cohort. *Journal of the American Academy of Child and Adolescent Psychiatry*, *58*, 618–627.

Ji, Y., Hong, X., Wang, G., Chatterjee, N., Riley, A.W., Lee, L.C., … & Wang, X. (2018). A prospective birth cohort study on early childhood lead levels and attention deficit hyperactivity disorder: New insight on sex differences. *The Journal of Pediatrics*, *199*, 124–131.e8.

Ji, Y., Riley, A.W., Lee, L.C., Volk, H., Hong, X., Wang, G., … & Wang, X. (2018). A prospective birth cohort study on maternal cholesterol levels and offspring attention deficit hyperactivity disorder: New insight on sex differences. *Brain Sciences*, *8*, 3.

Kim, K.M., Choi, Y.J., Lim, M.H., Ha, M., & Kwon, H.J. (2020). Parental age at childbirth and risk for attention-deficit/hyperactivity disorder in offspring. *Journal of Psychiatric Research*, *131*, 180–186.

Kleinbaum, D.G., & Klein, M. (2012). Extension of the cox proportional hazards model for time-dependent variables. In *Survival analysis: A self-learning text* (3rd edn, pp. 241–288). New York: Springer.

Lange, K.W., Hauser, J., Lange, K.M., Makulska-Gertruda, E., Nakamura, Y., Reissmann, A., … & Takeuchi, Y. (2017). The role of nutritional supplements in the treatment of ADHD: What the evidence says. *Current Psychiatry Reports*, *19*, 8.

Lee, C.Y., Chang, Y.Y., & Lung, F.W. (2006). The marriage-related risk factors during maternal pregnancy in children with attention-deficit hyperactivity disorder. *Child: Care, Health and Development*, *32*, 205–211.

Min, X., Li, C., & Yan, Y. (2021). Parental age and the risk of ADHD in offspring: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *18*, 4939.

Núñez-Jaramillo, L., Herrera-Solís, A., & Herrera-Morales, W.V. (2021). ADHD: Reviewing the causes and evaluating solutions. *Journal of Personalized Medicine*, *11*, 166.

Pérez-Crespo, L., Canals-Sans, J., Suades-González, E., & Guxens, M. (2020). Temporal trends and geographical variability of the prevalence and incidence of attention deficit/hyperactivity disorder diagnoses among children in Catalonia, Spain. *Scientific Reports*, *10*, 6397.

Pettersson, E., Sjölander, A., Almqvist, C., Anckarsäter, H., D'Onofrio, B.M., Lichtenstein, P., & Larsson, H. (2015). Birth weight as an independent predictor of ADHD symptoms: A within-twin pair analysis. *Journal of Child Psychology and Psychiatry*, *56*, 453–459.

Rodriguez, A., Miettunen, J., Henriksen, T.B., Olsen, J., Obel, C., Taanila, A., … & Järvelin, M.-R. (2008). Maternal adiposity prior to pregnancy is associated with ADHD symptoms in offspring: Evidence from three prospective pregnancy cohorts. *International Journal of Obesity*, *32*, 550–557.

Sayal, K., Prasad, V., Daley, D., Ford, T., & Coghill, D. (2018). ADHD in children and young people: Prevalence, care pathways, and service provision. Lancet. *Psychiatry*, *5*, 175–186.

Shamberger, R. (2012). Attention-deficit disorder associated with breast-feeding: A brief report. *Journal of the American College of Nutrition*, *31*, 239–242.

Soled, D., Keim, S.A., Rapoport, E., Rosen, L., & Adesman, A. (2021). Breastfeeding is associated with a reduced risk of attention-deficit/hyperactivity disorder among preschool children. *Journal of Developmental and Behavioral Pediatrics*, *42*, 9–15.

Tseng, P.T., Yen, C.F., Chen, Y.W., Stubbs, B., Carvalho, A.F., Whiteley, P., … & Lin, P.Y. (2019). Maternal breastfeeding and attention-deficit/hyperactivity disorder in children: A meta-analysis. *European Child & Adolescent Psychiatry*, *28*, 19–30.

Villagomez, A., & Ramtekkar, U. (2014). Iron, magnesium, vitamin D, and zinc deficiencies in children presenting with

symptoms of attention-deficit/hyperactivity disorder. *Children*, *1*, 261–279.
World Health Organization. (2001a). Infant and young child feeding. Available from: https://www.who.int/en/news-room/fact-sheets/detail/infant-and-young-child-feeding [last accessed 10 March 2022].
World Health Organization. (2001b). *Guiding principles for complementary feeding of the breastfed child*. Geneva: WHO Press. Available from: http://www.who.int/nutrition/publications/guiding_principles_compfeeding_breastfed.pdf
World Health Organization. (2022). Breatfeeding. https://www.who.int/health-topics/breastfeeding#tab=tab_2 [last accessed 15 March 2022].
Yang, R., Zhang, Y., Gao, W., Lin, N., Li, R., & Zhao, Z. (2019). Blood levels of trace elements in children with attention-deficit hyperactivity disorder: Results from a case-control study. *Biological Trace Element Research*, *187*, 376–382.
Zeng, Y., Tang, Y., Tang, J., Shi, J., Zhang, L., Zhu, T., … & Mu, D. (2020). Association between the different duration of breastfeeding and attention deficit/hyperactivity disorder in children: A systematic review and meta-analysis. *Nutritional Neuroscience*, *23*, 811–823.

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