Journal of Medical and Health Studies
ISSN: 2710-1452
DOI: 10.32996/jmhs
Journal Homepage: www.al-kindipublisher.com/index.php/jmhs

JMHS
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Understanding the Relationship between Child Malnutrition and Cognitive Development: An Analysis of the Ecuadorian Case

Santiago Aguilar-Paredes[1] ✉ Andrea Ponce-Altamirano[2], Zoila Moreira-Moreira[3], Cassandra Garibay-Alonso[4], Paola Salazar-Vélez[5] and Verónica Guaya-Galindo[6]

[1]*Medical Nutritionist, Instituto Tecnológico Superior España, Ambato, Ecuador*
[2]*Medical Doctor, Hospital General IESS Santo Domingo, Santo Domingo de los Tsáchilas, Ecuador*
[3]*Medical Doctor, Ministry of Public Health, Miguel Hilario Alcivar General Hospital, Manabí, Ecuador*
[4]*Medical Doctor, Universidad Nacional Autónoma de México (UNAM), Mexico City, Mexico*
[5]*Family and Community Medicine Specialist. Dirección Distrital 13D11-Jama- Pedernales-Sucre-San Vicente-Salud, Bahía de Caráquez, Manabí, Ecuador*
[6]*Medical Doctor, Universidad Nacional de Loja, Loja, Ecuador*

Corresponding Author: Santiago Aguilar-Paredes, **E-mail**: scienceacrev@gmail.com

| ABSTRACT
The analysis of the relationship between childhood malnutrition and cognitive development in children contributes significantly to the literature, given that nutritional status is recognized as a determinant factor for health and cognitive and psychosocial development during early childhood. Malnutrition at these stages can lead to imbalances in nutritional needs, which, in turn, can influence cognitive development. Our research was based on a representative sample of 4,568 children under 5 years of age from the 2018 National Health and Nutrition Survey (ENSANUT). We used a linear regression model and quantile regressions to estimate heterogeneous relationships in the studied relationship. Our results show that child undernutrition decreases by 0.25 BMI points with respect to those children who did not report child undernutrition. In addition, we have evidence that an increase in BMI at the extremes of the cognitive development distribution (Q0.10 and Q0.90) has a greater effect on children with lower and higher cognitive development. Another important finding is that males are more likely to have high cognitive development. Likewise, a greater number of siblings at home reduces cognitive development by -0.1032 points. Our data also reveal that more hours in front of the TV could reduce the risk of high cognitive development, while the number of hours of play causes the opposite effect, as the coefficient reveals that children with more hours of play have 0.1034 points less cognitive development. From our findings, the importance of exploring the neurodevelopmental processes involved in malnutrition is highlighted. In this article, we examine the basic psychomotor process, which is characterized by the child's ability to carry out bodily movements and mental representations, as well as symbolic expressions that allow him or her to relate constructively to people and objects.

| KEYWORDS

Childhood malnutrition, Cognitive development, child development, child development, psychomotor development

| ARTICLE INFORMATION

ACCEPTED: 27 November 2023 **PUBLISHED:** 27 November 2023 **DOI:** 10.32996/jmhs.2023.4.6.7

1. Introduction
Child malnutrition, a persistent reality in various parts of the world, presents itself as a multifaceted challenge that goes beyond purely physical implications. This phenomenon significantly affects cognitive development in children under 5 years of age, a population that is especially vulnerable during this critical phase of life(Glewwe & King, 2001).. Other studies have also shown that health is an important determinant of human capital outcomes in developing countries.

Childhood undernutrition, defined by the World Health Organization (WHO) as the condition resulting from insufficient intake of essential nutrients, has been identified as a determinant factor in cognitive development during childhood (WHO, 2021). (Smith & Haddad, 2015) highlight that "undernutrition affects not only physical growth but also brain development in the first years of life". This perspective establishes a critical starting point for exploring the relationship between undernutrition and cognitive development. The identification of undernutrition is based on the relationships between weight, height and age, making it possible to distinguish between severe, acute-moderate or chronic undernutrition.

Child malnutrition in Ecuador has been a persistent concern, significantly affecting children under the age of five. According to the World Food Program report (2017), approximately 24% of children under 5 years of age in the country experienced stunting due to malnutrition, reflecting the magnitude of the challenge the nation faces in this regard. Not only does this situation have immediate implications for children's health, but according to data from the National Institute of Statistics and Census (INEC) (2018), malnutrition, along with nutritional anemia, was identified as one of the ten leading causes of death in children under one year of age in 2017. In addition, a study by Galler et al. (2021) highlights that if childhood malnutrition persists without being detected and treated in a timely manner, the adverse effects on brain development can negatively affect academic performance during the school years. These data underscore the critical need for effective strategies and public health policies to address childhood undernutrition in Ecuador and improve the long-term prospects for children's health and development.

Cognitive development during the first five years of life represents a critical phase in the formation of children's intellectual capacities. During this period, the fundamental foundations are laid that will shape their ability to learn, reason and process information throughout their lives. The scientific literature has highlighted the importance of understanding and nurturing this early cognitive development, as it is intrinsically linked to health and well-being throughout the life cycle.

According to Piaget (1952), a pioneer in the theory of cognitive development, the first years of life are a unique window of opportunity where children absorb information from the environment in an exceptional way, thus building their mental structures. This perspective highlights the critical importance of addressing cognitive development from infancy itself. Furthermore, current research argues that access to adequate nutrition during the first years of life is essential for optimal cognitive development. Thus, "poor nutrition in early childhood can have long-lasting effects on brain function, affecting areas related to attention, memory and problem-solving ability."

Most of the recent research on factors influencing cognitive development has focused on developed nations, where data availability has been more accessible. For a detailed exploration of this topic, please refer to the comprehensive study by. The relevance of this topic in the context of child health is evident in epidemiological studies that have identified undernutrition as a significant risk factor for inadequate cognitive development in children under 5 years of age (Black et al., 2013). This introductory discussion highlights the interconnection between nutrition, health, and cognitive development in the early years of life, underscoring the need to address this complex relationship to promote the comprehensive well-being of children from an early age.

The connection between childhood undernutrition and cognitive development is not limited to a mere correlation; rather, it involves a complex set of factors that comprehensively impact children's intellectual potential. Grantham-McGregor et al. (2007) indicate that "early malnutrition can have long-lasting effects on brain function, affecting areas related to attention, memory, and problem-solving ability." This multidimensional approach highlights the need for a comprehensive analysis that encompasses not only the physical dimensions, but also the cognitive aspects of childhood undernutrition.

This cross-sectional study aims to analyze the intricate relationship between childhood undernutrition and cognitive development, exploring the dimensions of this connection and its possible implications for long-term child health. The choice of a cross-sectional design for this study allows us to capture meaningful snapshots of the relationship between undernutrition and cognitive development in children under 5 years of age. However, it is critical to recognize and address the methodological challenges inherent in this approach. Black et al. (2018) note that "cross-sectional studies provide a snapshot view, but causality and direction of the relationship can be difficult to establish." Despite these challenges, this design provides a valuable platform to explore patterns and trends in the relationship between these two complex phenomena. This study not only seeks to contribute to the theoretical understanding of the relationship between childhood undernutrition and cognitive development, but also aims to generate knowledge applicable to public health interventions and policies. Understanding this connection can inform preventive and therapeutic strategies, thus improving the quality of life of affected children and laying the groundwork for future research.

In summary, this cross-sectional study embarks on the task of unraveling the complex relationship between childhood undernutrition and cognitive development in children under 5 years of age, guided by the premise that a deeper understanding of this connection can pave the way for more effective interventions and more informed public health policies.

2. Methodology

2.1 Survey and Population

A cross-sectional analysis was conducted using information collected from the National Health and Nutrition Survey of Ecuador (ENSANUT) corresponding to the year 2018, which was compiled and provided by the National Institute of Statistics and Census (INEC). After cleaning the database, we were able to obtain information from a group of 5243 Ecuadorian children under 5 years of age.

2.2 Source of Information

The 2018 ENSANUT is part of the National Statistical Program and is conducted through probability sampling every 5 years. Its scope covers all inhabitants of households in Ecuador's 24 provinces. In particular, the ENSANUT 2018 Household questionnaire covers section 1 of the survey, which focuses on measuring anthropometry for all persons in the household.

2.3 Study Variables

Our dependent variable of interest is the cognitive development of the children. The information for this variable was obtained through 11 questions detailed in Table 1: Did you ever attend a CIBV/ CDI Child Development Center or day care center? Did you ever receive assistance from CNH educators in your home? With whom do you spend most of your time Monday through Friday, Can you identify or name at least ten letters of the alphabet, Can you read at least four simple, common words, Can you recognize the symbol for numbers from 1 to 10 and know their names, Can you pick up a simple, common object, and can you read at least four simple, common words, ¿Puede leer al menos cuatro palabras sencillas, comunes?, ¿Reconoce el símbolo de los números del 1 al 10 y sabe sus nombres?, ¿Puede recoger un objeto pequeño con dos dedos, como un palo o una piedra del piso?, ¿A veces se siente cansado/ desanimado sin ganas de jugar?, ¿Puede seguir instrucciones sencilla sobre cómo hacer algo correctamente?, Cuando se le da algo para hacer, ¿puede hacerlo por sí solo/a?, ¿Se distrae fácilmente?.

Our independent variable of interest is child malnutrition as measured by body mass index. For this variable, we use two questions: What is the weight of ....? and What is the height of ...? We should emphasize that the body mass index (BMI) is measured as $BMI = \frac{Weigth}{Heigth^2}$

2.4 Inclusion and Exclusion Criteria

The working universe was considered to be children under 5 years of age whose anthropometric measurements were reported in the 2018 ENSANUT survey household form. We performed two types of analysis, first we used a dichotomous variable to identify children with malnutrition (that below the 3rd percentile), from those without malnutrition. Then, we excluded all children with normal and high weight, i.e. all children above the 3rd percentile.

2.5 Statistical Analysis

The ENSANUT 2018 survey database was analyzed with the statistical package Stata v15 (Stata Corporation, College Station, Texas, USA). A value of $p<0.05$ was considered to determine statistical significance between variables. The association was evaluated using prevalence ratios with their respective 95% confidence intervals, with an analysis for each of the variables included in the study, being the independent variable.

Taking into account the literature, we used an ordinary least squares (OLS) model to examine the relationship between the variables. The proposed model is given by the following equation:

$$CD_i = \beta_0 + \beta_1 X_i + \sum_{j=2}^{12} \beta_j Z_i + \varepsilon_i \qquad (1).$$

Where CD_i represents a development index, X_i represents the dichotomous variable for child malnutrition, and Z_i represents a set of control variables of the linear regression model. Finally, ε_i represents the stochastic error term.

Subsequently, we used a quantile regression (QR) approach. Since linear regression model techniques such as the OLS model assume a common slope for all individuals and, these can focus on modeling only the conditional mean of the covariates and the dependent variable. Then, they cannot consider the properties of the full conditional distribution of the latter. Therefore, QR is the appropriate methodology to test whether any determinant has a heterogeneous effect on the entire distribution of the cognitive development variable. The QR model for the τth quantile can be formulated as the following optimization problem:

$$\widehat{Q_Y}(\tau) = min_{\hat{\theta}\epsilon R^k} \sum_i \rho_\tau \left(y_i - X_i\hat{\theta}\right)$$
$$\widehat{Q_Y}(\tau) = min_{\hat{\theta}\epsilon R^k}(u_i) \quad (2).$$

where τ∈ [0, 1] and Q_τ(.) are defined as:

$$\rho_\tau\,(u_i) = \begin{cases} \tau u_i, \text{ y si } u_i \geq 0 \\ (1-\tau)u_i, \text{ y si } u_i < 0 \end{cases} \quad (3).$$

The QR method minimizes the weighted sum of the residuals, not the squared sum of these residuals that is often applied in the simple linear regression model.

By applying the QR approach equation (1) can be rewritten as:

$$CD_i = \beta_0 + \beta_{1q}X_i + \sum_{j=2}^{12} \beta_{jq}\, Z_i + \varepsilon_i \quad (4).$$

Where now the β_1 now varies by quantile, the commonly used quantiles are the 0.10; 0.25; 0.50; 0.75; 0.90 quantiles. This helps us to explore the heterogeneity within each quantile of the distribution of the dependent variable.

3. Results

To meet our research objective, we specifically used 11 items from the questionnaires and considered that cognitive development is a multidimensional concept, and used principal component factor analysis (PCA) to ensure that the items can be grouped into one-factor dimension. Through PCA with a varimax rotation, we obtained 1 eigenvalue greater than 1. Therefore, we confirmed that we can explain the index of cognitive development through a one-dimensional index, where the factor loadings of each variable have the greatest weight in their respective dimension and these explain 78% of the variance. The questionnaire questions and their initial coding in the questionnaires are presented in **Table A1** in **Appendix A**. Our index of cognitive development was standardized in such a way that we obtained a number between 0-1 where a number closer to 1 means greater cognitive development.

In **Table A2** of **Appendix A** we observe the results of the validity and reliability tests. Here we observe that the total number of items is 11. Moreover, the average inter-item correlation is 0.621. That is to say, we observe that there is a high correlation between the 11 items, in such a way that we evidence that the items are highly correlated and explain in a good way our index of cognitive development. Crombach's alpha also shows an acceptable level, since it presents a value of 0.712. The Kayser Meyer Olin (KMO) statistic shows a high level. The KMO takes values between 0 and 1, and small values indicate that, in general, the variables have too little in common to justify a PCA analysis. In our case, we observed that our 11 items considered for analysis have a lot in common. We also note that Barlet's test is significant, indicating that the items are good measures for constructing the index of cognitive development.

Table A3 in **Appendix A** shows the results of the factor loadings from principal component analysis. Here, we can observe each of the items used to construct our index of cognitive development. We observe that the factor loadings are high, meaning that each item contributes significantly to the constructed index. Furthermore, we observe that all our 11 items explain 78% of the variance, suggesting that our index has a large variance explained through each item used to construct it.

Table 1 presents the descriptive statistics of the variables used in this study. Here we observe that the average index of cognitive development is 0.72 on a scale of 0 to 1. As for child malnutrition, 16.48% (CI=14.48%-19.48%) of the children are malnourished. Likewise, when we observe the BMI variable we can analyze that the average BMI is 14.31. Our data also reveal that 53.33% (CI=50.33%-55.33%) of the children are male. The number of siblings at home is 4 and our data show that the number of hours the child is exposed to TV is 4 and the average number of hours spent playing is 3. On the other hand, 75.61% of the mothers are of mestizo ethnicity, while the average number of prenatal controls is 7 and 55.61% (CI=52.51%-57.51%) of the mothers reported having had a normal delivery.

Table N°1: Descriptive statistics of the variables used in this study

Variable	Mean-Percent	SD	Min	Max	95% CI		
Cognitive development							
Cognitive development index	0.72	0.13	0	1	0.66	-	0.79
Child malnutrition							
No	83.52%	0.67	0	1	79,52%	-	84,52%
Yes	16.48%	0.89	0	1	14,48%	-	19,48%
BMI	14.31	0.10	3.02	12.33	11.24	-	17.53
Child's age							
Age	3.41	0.12	3	5	3.13	-	4.22
Sex of child							
Woman	46.76%	0.14	0	1	43,67%	-	48,67%
Man	53.33%	0.33	0	1	50,33%	-	55,33%
Siblings at home							
Number of siblings at home	4.12	0.25	0	8	4.01	-	4.98
Hours of TV watched by the child							
Number of hours watching TV	4.01	0.67	0	5	3.68	-	4.49
Child's hours of play							
Number of hours of play	3.08	0.54	1	6	2.97	-	3.96
Do you think a child should be punished?							
No	69.45%	0.66	0	1	66,45%	-	71,45%
Yes	30.55%	0.26	0	1	27,55%	-	32,55%
Mother's age							
Age	34.78	0.55			31.54	-	36.86
Mother's ethnicity							
Indigenous	14.73%	0.35	0	1	14.26%	-	15.20%
Afro-Ecuadorian	4.03%	0.20	0	1	3.77%	-	4.29%
Mongrel	75.61%	0.43	0	1	75.04%	-	76.18%
White	1.32%	0.11	0	1	1.17%	-	1.47%
Montubio	4.31%	0.20	0	1	4.04%	-	4.58%
Prenatal checkups							
Number of prenatal checkups	7.01	0.25	1	28	4,01%	-	9,01%
Exclusive breastfeeding							
No	7.48	0.89	0	1	5,48%	-	9,48%
Yes	92.52%	0.67	0	1	87,52%	-	94,52%
Type of delivery							
Normal delivery	55.51%	0.54	0	1	52,51%	-	57,51%
Cesaria	44.49%	0.36	0	1	41,49%	-	46,49%

Next, we conducted a formal test to rule out the presence of multicollinearity among our independent variables. A multicollinearity analysis using the Variance Inflator Factor (VIF) is presented in **Table 2.** According to previous literature, a VIF greater than 5 could indicate the existence of multicollinearity in our data. However, we can observe that none of the variables shows a VIF higher than 5, which allows us to rule out multicollinearity problems in our independent variables. This analysis is important since the presence of multicollinearity can lead to instability of the regression parameters, incorrect signs and larger standard errors, which in turn results in a lack of statistical significance in the parameters.

Table N° 2: Multicollinearity test of the variables.

Variable	**VIF**	**SQRT VIF**	**Tolerance**	**R-Squared**
Child malnutrition	1.25	1.55	0.9433	0.3305
BMI	1.32	1.11	0.9966	0.0004
Child's age	1.01	1.54	0.9918	0.0082
Sex of child	1.77	1.28	0.6101	0.3899
N. of siblings at home	1.88	1.28	0.6145	0.3855
N. of hours watching TV	1.97	1.01	0.9764	0.0236
N. hours of play	1.45	1.06	0.8821	0.1179
Should a child be punished?	1.66	1.05	0.8812	0.1188
Mother's age	1.58	1.45	0.6310	0.3690
Mother's ethnicity	1.29	1.14	0.7746	0.2254
N. of prenatal checkups	1.17	1.08	0.8583	0.1417
Exclusive breastfeeding	1.11	1.34	0.7981	0.1254
Type of delivery	1.05	1.05	0.9537	0.0463
Mean VIF	1.49			

In addition to multicollinearity tests, we performed heteroscedasticity tests (White test and Breush-Pagan heteroscedasticity test) and autocorrelation tests to rule out modeling problems. The heteroscedasticity tests rule out the existence of heteroscedasticity in the models and the correlation graph test rules out the existence of autocorrelation in the model. The results of these tests are shown in the Annexes in **Figure 1** and **Figure 2**.

Figure 1. Heteroscedasticity tests

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(8)      =   2603.27
         Prob > chi2  =    0.2000

Cameron & Trivedi's decomposition of IM-test

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of ingrl

         chi2(1)      =  3494.42
         Prob > chi2  =   0.3000
```

Figure 2. Autocorrelation test

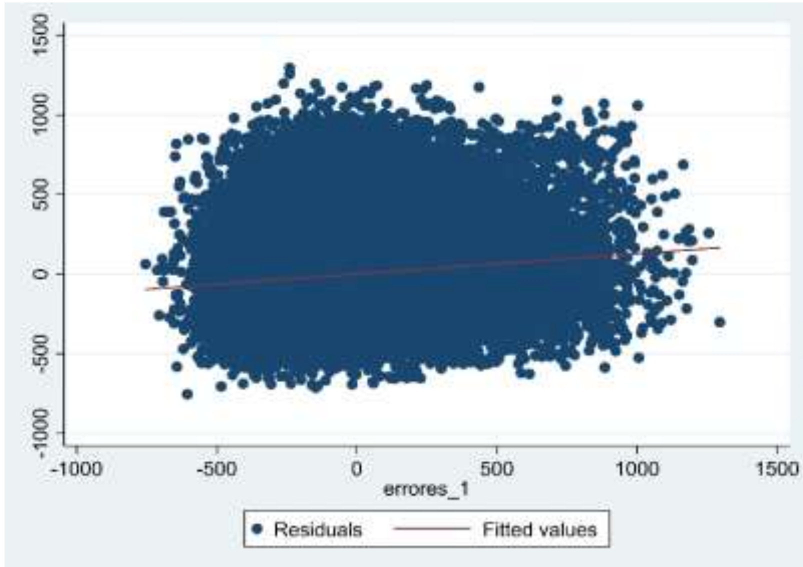

Table 3 below shows a multivariate linear regression analysis to analyze the factors influencing cognitive development. Our logistic regression involves 5243 children under 5 years of age. Here, we observe that the dependent variable is the index of cognitive development constructed weighted across 11 variables described above. Our results show that child malnutrition decreases by 0.25 BMI points with respect to those children who did not report child malnutrition. Another significant coefficient is the one associated with the child's sex variables, with a coefficient of -0.1001, showing that males are more likely to have high cognitive development. Likewise, a greater number of siblings at home reduces cognitive development by -0.1032 points. Our data also reveal that a greater number of hours in front of the TV could reduce the risk of high cognitive development, while the number of hours of play causes an opposite effect since the coefficient reveals that children with a greater number of hours of play have 0.1034 points less cognitive development. We also evidenced that parents who answered that they believe that children should be punished show that they have -0.1455 points of cognitive development. These results are in line with findings showing that more prenatal checkups increase children's cognitive development. In addition, exclusive breastfeeding increases by 0.1423 cognitive development points.

Table N° 3: Regression analysis between the cognitive development index and the dichotomous variable of child malnutrition.

Variable		**Coef.**		**Std. Err.**		**P>t**		**95% CI**		
Child malnutrition										
No		Ref.								
Yes		-0.2567*		0.535		0.045		-0.235	-	-0.285
Child's age										
Age		-0.1001		0.863		0.057		-0.087	-	-0.132
Sex of child										
Woman		Ref.								
Man		0.1592**		00.765		0.003		0.134	-	0.197
Siblings at home										
Number of siblings at home		-0.1032**		0.0054		0.004		-0.101	-	-0.145
Hours of TV watched by the child										
Number of hours watching TV		-0.1034		0.0987		0.0872		-0.100	-	-0.132
Child's hours of play										
Number of hours of play		0.1686***		0.0542		0.0001		0.1543	-	0.1754
Do you think a child should be punished?										
No		Ref.								
Yes		-0.1455*		00216		0.0032		-0.132	-	-0.176
Mother's age										
Age		-0.1653		0.0654		0.0035		-0.134	-	-0.189
Mother's ethnicity										
Indigenous		Ref.								
Afro-Ecuadorian		-0.1043		0.0312		0.0067		-0.101	-	-0.123
Mongrel		0.1065		0.0432		0.0655		0.100	-	0.119
White		-0.1986		0.0563		0.0192		-0.1.4	-	-0.200
Montubio		0.1654		0.0643		0.0431		0.1594	-	0.1865
Prenatal checkups										
Number of prenatal checkups		0.1654**		0543		0.0031		0.1493	-	0.1985
Exclusive breastfeeding										
No		Ref.								
Yes		0.1423		0.0754		0.0356		0.1653	-	0.1765
Type of delivery										
Normal delivery		Ref.								
Cesaria		-0.1456		0.0753		0.0912		-0.132	-	-0.176
Observations		5243								
R^2		0.8067								
Prob>F		0.000***								

Notes: Asterisks mean: *p < 0.10,**p < 0.05, ***p < 0.01

Subsequently, we eliminated from the base all those children who did not present child malnutrition. We applied the quantile regression approach to explore the heterogeneity in the relationship studied. **Table 4** shows a positive correlation between BMI and cognitive development. That is, when BMI increases in malnourished children, cognitive development increases. It should be emphasized that the first 5 years are crucial for the cognitive development of children. A more important finding is that there is a heterogeneous impact of BMI on cognitive development. That is, we observed that an increase in BMI at the extremes of the cognitive development distribution (Q0.10 and Q0.90) has a greater effect on children with lower and higher cognitive development. This fact shows us that programs focused on increasing the BMI of children with malnutrition have a positive influence on their cognitive development, specifically on children with less cognitive development.

Table N° 4: Quantile regression analysis between the cognitive development index and the BMI of children suffering from child malnutrition

	Q(0.10)	**Q(0.25)**	**Q(0.50)**	**Q(0.75)**	**Q(0.90)**
Variable	**Coef./SE**	**Coef./SE**	**Coef./SE**	**Coef./SE**	**Coef./SE**
BMI	0.3358*	0.2744*	0.2567*	0.2291*	0.3089*
Child's age					
Age	-0.1001	-0.2032	-0.1001	-0.6006	-0.141
Sex of child					
Woman	Ref.	Ref.	Ref.	Ref.	Ref.
Man	0.1371**	0.2542**	0.1592**	0.6553**	0.1144**
Siblings at home					
Number of siblings at home	-0.1031**	-0.202**	-0.1032**	-0.603**	-0.101**
Hours of TV watched by the child					
Number of hours watching TV	-0.1034	-0.2054	-0.1034	-0.6036	-0.1014
Child's hours of play					
Number of hours of play	0.1686***	0.2585***	0.1686***	0.6686***	0.1686***
Do you think a child should be punished?					
No	Ref.	Ref.	Ref.	Ref.	Ref.
Yes	-0.1433*	-0.2455*	-0.1455*	-0.6655*	-0.1411*
Mother's age					
Age	-0.1633	-0.2555	-0.1653	-0.6653	-0.1611
Mother's ethnicity					
Indigenous	Ref.	Ref.	Ref.	Ref.	Ref.
Afro-Ecuadorian	-0.1043	-0.2045	-0.1043	-0.6063	-0.1041
Mongrel	0.1063	0.2055	0.1065	0.6065	0.1061
White	-0.1786	-0.2485	-0.1986	-0.6586	-0.1486
Montubio	0.1634	0.2554	0.1654	0.6656	0.1614
Prenatal checkups					
Number of prenatal checkups	0.1634**	0.2554**	0.1654**	0.6656**	0.1614**
Exclusive breastfeeding					
No	Ref.	Ref.	Ref.	Ref.	Ref.
Yes	0.1413	0.2425	0.1423	0.6633	0.1441
Type of delivery					
Normal delivery	Ref.	Ref.	Ref.	Ref.	Ref.
Cesaria	-0.1436	-0.2455	-0.1456	-0.6656	-0.1416
Observations	864	864	864	864	864
Pesudo R^2	0.670	0.790	0.8067	0.760	0.880
Prob>F	0.000***	0.000***	0.000***	0.000***	0.000***

Notes: Asterisks mean: *p < 0.10,**p < 0.05, ***p < 0.01

5. Conclusion

In the exploration of child undernutrition and its impact on cognitive development in children under 5 years of age, compelling evidence emerges that highlights the intimate relationship between nutrition and mental abilities in childhood. Malnutrition, whether chronic, acute or severe, is revealed as a determining factor that negatively affects the cognitive development of children, laying the groundwork for long-term consequences on their well-being and academic performance.

In our results, it was observed that 16.48% (CI=14.48%-19.48%) of the children were malnourished. Likewise, when we observe the BMI variable, we can analyze that the average BMI is 14.31. Our data also reveal that 53.33% (CI=50.33%-55.33%) of children are male. Our results show that child malnutrition decreases by 0.25 BMI points with respect to those children who did not report child malnutrition. Another significant coefficient is the one associated with the child's sex variables, with a coefficient of -0.1001, showing that males are more likely to have high cognitive development. Likewise, a greater number of siblings at home reduces cognitive development by -0.1032 points. Our data also reveal that a greater number of hours in front of the TV could reduce the risk of high cognitive development, while the number of hours of play causes an opposite effect, as the coefficient reveals that children with a greater number of hours of play have 0.1034 points less cognitive development. These results are in line with findings showing that a higher number of prenatal checkups increases children's cognitive development. In addition, exclusive breastfeeding increases by 0.1423 cognitive development points.

In light of the evidence presented, it is imperative to recognize child undernutrition as a significant obstacle to cognitive development, which has implications throughout children's lives. The implementation of preventive strategies, nutrition education and equitable access to nutritious foods are presented as crucial measures to address this complex challenge. This is why authors such as Ampaabeng & Tan (2013) found a direct, negative and significant impact of early childhood undernutrition on the cognitive development of famine survivors. These effects persist well into adolescence and adulthood. On the other hand, Suryawan et al. (2022) also concluded that undernutrition and overweight/obesity during the first 60 months of postnatal life affect children's cognitive neurodevelopmental trajectories later in life. Weight and length/height should be monitored even beyond 24 months of life to allow early recognition of growth retardation/deviations and enable appropriate and timely interventions to address their negative neurodevelopmental and cognitive impacts. (Ijarotimi, 2013) found similar results where they included 12 studies with 7,607 participants aged 1-12 years. Children with malnutrition had worse scores than controls on the Wechsler Intelligence Scale (SMD -0.40; 95% CI -0.60 to -0.20; $p < 0.0001$; I2 77.1%), Raven's Colored Progressive Matrices (SMD -3. 75; 95% CI -5.68 to -1.83; $p < 0.0001$; I2 99.2%), visual processing tests (SMD -0.85; 95% CI -1.23 to -0.46; p 0.009; I2 11.0%) and short memory (SMD 0.85; 95% CI -1.21 to -0.49; $p < 0.0001$; I2 0%).

The complexity of the relationship between childhood undernutrition and cognitive development underscores the need for continued research and multidisciplinary approaches that address not only the physical but also the cognitive and emotional aspects of this phenomenon. It is essential to expand the knowledge base on the precise mechanisms through which undernutrition affects the developing brain and how these influences can be mitigated or reversed.

In addition, research outreach should consider the socioeconomic and cultural disparities that contribute to undernutrition to ensure that interventions are culturally sensitive and address the root causes of the problem. Collaboration between governments, non-governmental organizations and local communities becomes essential to implement comprehensive programs that address child undernutrition from a variety of perspectives. In summary, child undernutrition significantly impacts cognitive development in the early years of life, marking a wake-up call for urgent action and investment in holistic strategies that address this critical challenge and contribute to the holistic flourishing of future generations.

Funding: This research did not receive external funding.
Conflicts of interest: The authors declare that they have no conflicts of interest.
Editor's note: All statements expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, nor those of the publisher, editors, and reviewers.
Ethical approval: The authors should indicate whether or not ethical approval has been requested for the present study, especially if it is a clinical trial or an animal experiment.
Informed consent: It was not necessary to apply informed consent to the participants since the data were obtained through a database available at the National Institute of Statistics and Census of Ecuador.

References

[1] Ampaabeng, S. K., & Tan, C. M. (2013). The long-term cognitive consequences of early childhood malnutrition: The case of famine in Ghana. *Journal of Health Economics*, *32*(6), 1013-1027. https://doi.org/10.1016/j.jhealeco.2013.08.001
[2] Bhutta, Z. A., Berkley, J. A., Bandsma, R. H. J., Kerac, M., Trehan, I., & Briend, A. (2017). Severe childhood malnutrition. *Nature Reviews Disease Primers*, *3*(1), Article 1. https://doi.org/10.1038/nrdp.2017.67.
[3] Black, K. E., Witard, O. C., Baker, D., Healey, P., Lewis, V., Tavares, F., Christensen, S., Pease, T., & Smith, B. (2018). Adding omega-3 fatty acids to a protein-based supplement during pre-season training results in reduced muscle soreness and the better maintenance of explosive

power in professional Rugby Union players. *European Journal of Sport Science*, *18*(10), 1357-1367. https://doi.org/10.1080/17461391.2018.1491626.
[4] Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., & Maternal and Child Nutrition Study Group (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet (London, England)*, *382*(9890), 427-451. https://doi.org/10.1016/S0140-6736(13)60937-X.
[5] Cunha, F., & Heckman, J. J. (2009). The Economics and Psychology of Inequality and Human Development. *Journal of the European Economic Association*, *7*(2), 320-364.
[6] Galler, J. R., Bringas-Vega, M. L., Tang, Q., Rabinowitz, A. G., Musa, K. I., Chai, W. J., Omar, H., Abdul Rahman, M. R., Abd Hamid, A. I., Abdullah, J. M., & Valdés-Sosa, P. A. (2021). Neurodevelopmental effects of childhood malnutrition: A neuroimaging perspective. *NeuroImage*, *231*, 117828. https://doi.org/10.1016/j.neuroimage.2021.117828.
[7] Glewwe, P., & King, E. M. (2001). The Impact of Early Childhood Nutritional Status on Cognitive Development: Does the Timing of Malnutrition Matter? *The World Bank Economic Review*, *15*(1), 81-113. https://doi.org/10.1093/wber/15.1.81
[8] Grantham-McGregor, Yb, C., S, C., P, G., L, R., & B, S. (2007). Developmental potential in the first 5 years for children in developing countries. *Lancet (London, England)*, *369*(9555). https://doi.org/10.1016/S0140-6736(07)60032-4
[9] Ijarotimi, O. S. (2013). Determinants of Childhood Malnutrition and Consequences in Developing Countries. *Current Nutrition Reports*, *2*(3), 129-133. https://doi.org/10.1007/s13668-013-0051-5
[10] *National Institute of Statistics and Census (2018). National Health and Nutrition Survey. Available at https://www.ecuadorencifras.gob.ec/documentos/web-inec/Estadisticas_Sociales/ENSANUT/ENSANUT_2018/Principales%20resultados%20ENSANUT_2018.pdf*
[11] World Health Organization (2021). Malnutrition. Available at https://www.who.int/es/news-room/fact-sheets/detail/malnutrition
[12] Piaget, J. (1952). The fourth stage: The coordination of the secondary schemata and their application to new situations. In *The origins of intelligence in children* (pp. 210-262). W W Norton & Co. https://doi.org/10.1037/11494-005
[13] World Food Program in Ecuador (2017). Annual report. Available at https://docs.wfp.org/api/documents/WFP-0000074044/download/
[14] Smith, L. C., & Haddad, L. (2015). Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. *World Development*, *68*, 180-204. https://doi.org/10.1016/j.worlddev.2014.11.014.
[15] Suryawan, A., Jalaludin, M. Y., Poh, B. K., Sanusi, R., Tan, V. M. H., Geurts, J. M., & Muhardi, L. (2022). Malnutrition in early life and its neurodevelopmental and cognitive consequences: A scoping review. *Nutrition Research Reviews*, *35*(1), 136-149. https://doi.org/10.1017/S0954422421000159.

Annexes

Annex A

Table A1: ENSANUT questions and coding

ENSANUT question		**Codification**
(...) Did you ever attend a CIBV/ CDI Child Development Center or day care center?		0=No/1=Yes
(...) DID YOU EVER RECEIVE assistance from CNH educators in your home?		0=No/1=Yes
WITH WHOM do you stay (...) most of the time from Monday to Friday?		0=No/1=Yes
Can (...) identify or name at least ten letters of the alphabet?		0=No/1=Yes
Can you (...) read at least four simple, common words?		0=No/1=Yes
Do you recognize (...) the symbol for the numbers 1 to 10 and know their names?		0=No/1=Yes
Can (...) pick up a small object with two fingers, such as a stick or a stone from the floor?		0=No/1=Yes
Do you sometimes (...) feel tired/ discouraged and don't feel like playing?		0=No/1=Yes
Can (...) follow simple instructions on how to do something correctly?		0=No/1=Yes
When given something to do, can he/she (...) do it by him/herself?		0=No/1=Yes
Are you easily distracted (...)?		0=No/1=Yes

Table A2: Results of the sample reliability and validity test.

Test				**Cognitive development index**
Number of items				11
Average interitem correlation				0.621
Cronbach's alpha				0.714
Kayser Meyer Olin measure (KMO)				0.801
Bartlett's test		Chi square		3.47e+05
		df		20
		Sig.		0.000

Table A3: Results of the principal component analysis.

KMO= 0.801 **Variable**		**Cognitive Development Index**
(...) Did you ever attend a CIBV/ CDI Child Development Center or day care center?		0.723
(...) DID YOU EVER RECEIVE assistance from CNH educators in your home?		0.899
WITH WHOM do you stay (...) most of the time from Monday to Friday?		0.850
Can (...) identify or name at least ten letters of the alphabet?		0.825
Can you (...) read at least four simple, common words?		0.723
Do you recognize (...) the symbol for the numbers 1 to 10 and know their names?		0.899
Can (...) pick up a small object with two fingers, such as a stick or a stone from the floor?		0.850
Do you sometimes (...) feel tired/ discouraged and don't feel like playing?		0.825
Can (...) follow simple instructions on how to do something correctly?		0.745
When given something to do, can he/she (...) do it by him/herself?		0.882
Are you easily distracted (...)?		0.695
Variance explained		*78%*