Nutrition 57 (2019) 74–83

Contents lists available at ScienceDirect

Nutrition

journal homepage: www.nutritionjrnl.com

Applied nutritional investigation

Impact of anthropometric nutritional parameters on the university selection test in Chile: A multifactorial approach

Daniza M. Ivanovic M.Sc. [a,*], Rodrigo B. Valenzuela Ph.D. [b], Atilio F. Almagià B.Sc. [c], Cynthia R. Barrera M.Sc. [b], Violeta C. Arancibia Ph.D. [d,e], Cristián G. Larraín M.D. [f], Claudio F.A. Silva M.D. [f], Pablo B. Billeke Ph.D. [g], Francisco M. Zamorano Ph.D. [g,h], Francisca S. Villagrán M.Sc. [a], Yasna Z. Orellana Ph.D. [a], Víctor C. Martínez M.Sc. [i]

[a] Institute of Nutrition and Food Technology, Dr. Fernando Monckeberg Barros, University of Chile, Santiago, Chile
[b] Department of Nutrition, Faculty of Medicine, University of Chile, Santiago, Chile
[c] Institute of Biology, Laboratory of Physical Anthropology and Human Anatomy, Faculty of Sciences, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile
[d] Faculty of Social Sciences, School of Psychology, Pontifical University of Chile, Santiago, Chile
[e] Facultad de Educación, Universidad de Los Andes, Institute of Nutrition and Food Technology Dr. Fernando Monckeberg Barros (INTA), University of Chile, Santiago, Chile
[f] Radiology Department, Facultad de Medicina-Clínica Alemana, Universidad del Desarrollo, Santiago, Chile
[g] División de Neurociencia, Centro de Investigación en Complejidad Social, Facultad de Gobierno, Universidad del Desarrollo, Santiago, Chile
[h] Unidad de Imágenes Cuantitativas Avanzadas, Departamento de Imágenes, Clínica Alemana de Santiago, Santiago, Chile
[i] Department of Commercial Engineering, Faculty of Economics and Business, University of Chile, Santiago, Chile

ARTICLE INFO

Article History:
Received 30 November 2017
Received in revised form 8 March 2018
Accepted 13 May 2018
Available online xxx

Keywords:
Nutritional status
Head circumference
Brain development
Intelligence
Maternal educational status
School age population
School health

ABSTRACT

Objectives: Scholastic achievement (SA) is a multifactorial problem that depends on factors related to the child, the child's family, and the educational system. The aim of this study was to quantify the relative impact of significant variables at the beginning of high school during 2010 (first grade of high school [1 HSG]) on 2013 university selection test (Prueba de Seleccion Universitaria [PSU]) outcomes, both in language scholastic achievement (LSA) and mathematics scholastic achievement (MSA), when students graduated from high school (4 HSG). This was done at the time of university admission with a multicausal approach. The purpose was to confirm the hypothesis that the level of educational establishment SA, intellectual ability, sex, parental schooling levels, and head circumference for age Z-score at the onset of high school are the most relevant parameters associated with 2013 PSU outcomes, both in LSA and MSA.

Methods: A representative, proportional, and stratified sample of 671 children of both sexes who enrolled in 1 HSG in 2010 (mean age: 14.8 ± 0.6 y) participated in the study. Nutritional, intellectual, brain developmental, cardiovascular risk, socio-to-economic, demographic, and educational variables were quantitated. SA was assessed at 4 HSG with the 2013 PSU tests. Data were analyzed with SAS software.

Results: Educational establishment SA, intellectual ability, maternal schooling, and age Z-score were the most relevant parameters to explain LSA ($R^2 = 0.493$; $P < 0.0001$) and MSA variance in addition to sex (male), but only in MSA ($R^2 = 0.600$; $P < 0.0001$).

Conclusions: These findings confirm the hypothesis and can be useful to support nutritional, health, and educational planning.

Introduction

Education is a crucial social determinant of health and is viewed as the change lever for the improvement of quality of life. Food insecurity can be detrimental to children's scholastic achievement (SA) and potentially perpetuate a cycle of poverty [1].

Worldwide, nearly 900 million people live in poverty; approximately half are children. Many families make huge efforts to

Sources of support: This work was supported by Grants 1100431 and 1150524 from the National Fund for Scientific and Technologic Development (PI: Daniza M. Ivanovic).

Conflicts of interest: None.

* Corresponding author. Tel.: +56229781459; fax: +56222214030.
E-mail address: Daniza@inta.uchile.cl (D.M. Ivanovic).

https://doi.org/10.1016/j.nut.2018.05.035
0899-9007/

provide their children with basic health and nutritional care that could guarantee a good start in life. Adverse conditions could have irreversible consequences, such as growth failure, psychiatric comorbidities, cognitive development, and school dropout without learning to read and write and without a basic notion of arithmetic [2].

Nutrition is one of many factors that affect children's cognitive development. Poor cognitive performance of school-aged children is significantly associated with pre- and postnatal nutritional history, such as birth weight (W), head circumference (HC), and height (H), as well as the environment and maternal-infant interaction [3–10].

Figure 1 illustrates the theoretical framework of the multicausal conception of the learning process [11]. The flow chart shows some of the most relevant factors that affect SA and dropout rates. The full expression of the genetic potential of school-aged children can be verified but depends on multiple environmental factors. In this context, SA is the result of the interaction between 1) the child and dependent factors (e.g., prenatal, postnatal, and current nutritional status; brain development; psychological variables; healthy lifestyle; health conditions; dietary intake; physical activity; food habits; cardiovascular risk factors; drug consumption; and demographic characteristics); 2) family factors (socioeconomic status [SES] and sociocultural conditions such as parental schooling, parental occupation, housing characteristics, and other variables related to family [e.g., number of family members and siblings, order of place among siblings, crowding, promiscuity, alcoholism, smoking, drug consumption, concern for the education of children, economic and health support, and stimulation at home, especially maternal attachment]; and 3) factors of the educational system (e.g., type of school, teachers' academic backgrounds, teaching methodologies, school infrastructure, number of students per course, attendance rate).

These factors significantly affect educational system productivity, measured as SA and dropout rate, and thus the environmental conditions and quality of life. The purpose of the present investigation is to contribute to and increase the existing evidence for the formulation of a theory about SA, which is difficult to establish because its determinants vary from child to child [1,2,4–12]. Thus, the educational process presents itself as a multicausal problem.

A child's intelligence, parental schooling (especially maternal), maternal intelligence, undernutrition in the first year of life, brain volume, and head circumference have been described as the most relevant parameters associated with SA [12–18]. Our previous studies have revealed that head circumference (and not W or H) is the most relevant physical growth index associated with SA, intellectual ability, and school dropout in Chilean school-aged children [14–18]. Head circumference in infants has been reported to predict brain size, and children aged 0 to 4 y are at the optimal time for brain growth [19]. In fact, head circumference has been described as the most sensitive anthropometric index of intrauterine malnutrition at an early age, especially during the first 2 y of life [20–24].

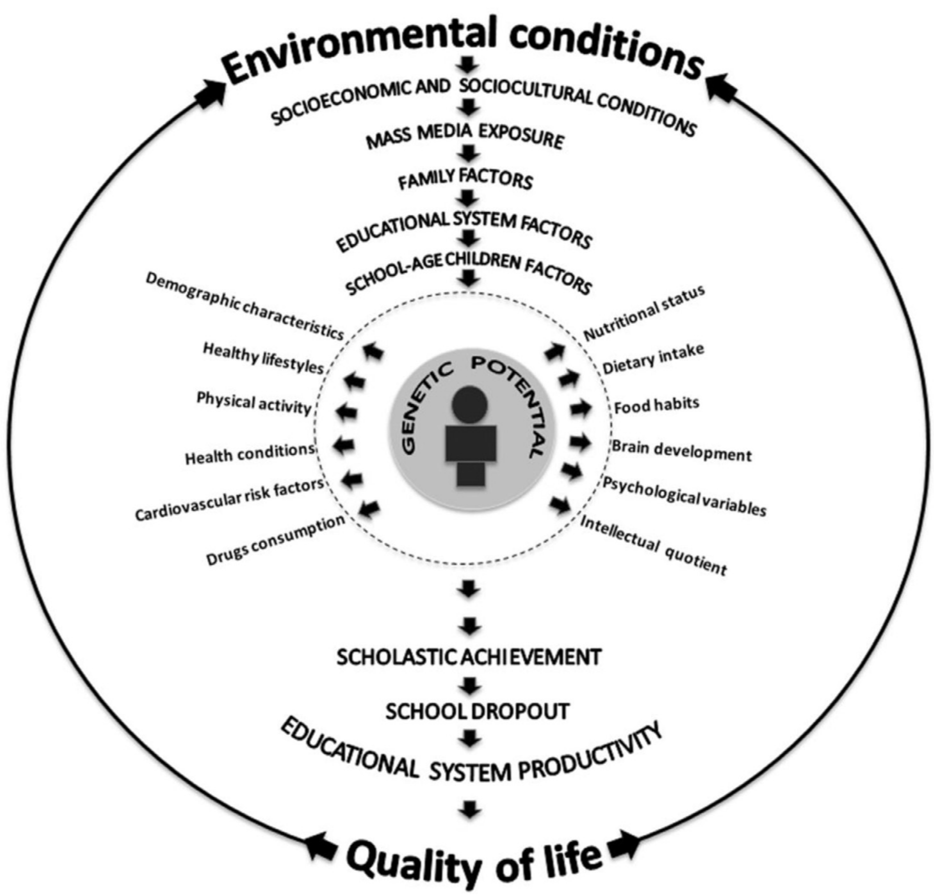

Fig. 1. Flow chart of the multicausal conception of the learning process. The full expression of the genetic potential of school-aged children depends on multiple environmental factors. In this context, the learning process is the result of the interaction among child, family, educational system factors, and others.

The aim of this study was to use a multicausal approach to quantify the relative impact of nutritional, intellectual, brain developmental, cardiovascular risk, socioeconomic, demographic, and educational variables among children beginning high school (first grade of high school [1 HSG]) during 2010 on 2013 university selection test outcomes (Prueba de Seleccion Universitaria [PSU]), both in language scholastic achievement (LSA) and mathematics scholastic achievement (MSA), at the time of university admission at the end of high school (4 HSG). The purpose was to confirm the hypothesis that the level of educational establishments SA (EESA), intellectual ability, sex, parental schooling levels, and head circumference for age Z-score at the beginning of high school in 2010 are the most relevant parameters associated with PSU outcomes, both in LSA and MSA, for university admission at the end of high school in 2013. Knowing the best predictors of PSU results at the beginning of high school would be very useful to serve the most disadvantaged children through comprehensive school care until the end of high school, which allows them to develop their talents and thus be in a better position to perform well on this important test for their future life.

Methods

Study population

The target population of 96 197 children (39% of the Chilean school population) included all school-aged children enrolled in 1 HSG in the Metropolitan Region of Chile in 2010. The children all took the quality education measurement system tests (Sistema de Medición de la Calidad de la Educación [SIMCE]) administered by the Agency for Education Quality at the end of 2009 in both language and mathematics. The children were part of public, privately subsidized, and private non-subsidized schools from urban areas [25].

Sample selection

The population sampling included all educational establishments from the urban areas in the Metropolitan Region of Chile. The sampling was carried out in two stages. First, 33 educational establishments (2.61% of the total population of urban schools; n = 1262) were randomly selected by proportional allocation according to their stratification by type of school and level of EESA in the 2009 SIMCE tests, which was classified as high, medium, or low by the Ministry of Education [25]. In the second stage, at each of these 33 schools, all students enrolled in 1 HSG and their parents, the principals of the establishments, and the language and mathematics teachers were invited to participate.

A total of 671 school-aged children of the 2010 1 HSG and their parents, school principals, and teachers agreed to participate and signed the informed consent form. Students' age ranged from 12.7 y to 17.6 y (mean age: 14.8 $\pm$ 0.6 y). At the end of 2013, the school-aged children of 2010 1 HSG graduated from 4 HSG and took the PSU, which is the baccalaureate examination with national coverage for admission to universities [26]. From the total sample (n = 671), 550 and 548 school-aged children took the language and mathematics PSU tests, respectively.

Ethical considerations

This study was approved by the Committee on Ethics in Studies in Humans of the Institute of Nutrition and Food Technology, Dr. Fernando Monckeberg Barros, University of Chile, and ratified by the Committee on Bioethics of the National Fund for Scientific and Technological Development in Chile. During 2010 and 2015, consent was obtained from participants in accordance with the norms for Human Experimentation, Code of Ethics of the World Medical Association (Declaration of Helsinki) [27].

The field study was carried out during 2010 and 2015. During 2015, consent was obtained to register the PSU outcomes of the school-aged children of the 2010 1 HSG who graduated from 4 HSG at the end of 2013.

Data collection conducted during 2010

Anthropometric nutritional parameters

Prenatal nutritional background and early nutritional measurements such as birth weight, birth length, and duration of breastfeeding were registered. Measurements of W, H, and HC were carried out at school using standardized procedures. All instruments were verified before each subject was measured [28]. The postnatal nutritional background was expressed as H for age Z-score (Z-H) according to National Center for Health Statistics-Centers for Disease Control and Prevention tables [29,30] and HC for age Z-score (Z-HC), which was assessed using the tables by Ivanovic et al. [31], Nellhaus [32,33], Roche et al. [34], and Tanner [35]. The Z-HC values were similar when applying these four tables (correlation coefficient between these patterns was 0.98) [31]. The current nutritional status was expressed as body mass index (BMI; weight/height^2), compared with the National Center for Health Statistics-Centers for Disease Control and Prevention tables, and expressed as BMI Z-score (Z-BMI) [29,30]. BMI was calculated using biological age, as derived from the Tanner stages [35]. Birth weight and length were used as indices of prenatal nutrition, Z-H and Z-HC served as indicators of postnatal nutritional background, and Z-BMI was used as an index of current nutritional status. The anthropometric parameters were considered independent variables.

Intellectual ability

Intellectual ability (IA) was assessed with the standard version of the Raven's Progressive Matrices Test in book form with a general scale for children aged $\geq$12 y, which had been standardized for Chilean school-aged children [36,37]. The test was administered collectively in the classroom and was assessed by an educational psychologist. The scores were recorded in a percentile scale in accordance with age and were classified according to the Raven's grades [36]. IA was considered an independent variable.

Brain development

Brain development was assessed through the measurement of HC and expressed as Z-HC. HC measurement is a simple method to assess brain growth and has been defined as an anthropometric indicator of both nutritional background and brain development [23,24,28,38]. Our previous studies on Chilean school-aged children who graduated from high school confirmed a high degree of correlation between absolute HC and brain volume, as measured by magnetic resonance imaging [22,39]. Brain development was considered an independent variable.

Cardiovascular risk factors

In addition to BMI expressed as overnutrition (obesity risk and obese, Z-BMI >25), waist circumference was measured using standard procedures, and abdominal obesity was calculated using a percentile scale [40]. Systolic and diastolic blood pressures were classified as normal or high in a percentile scale [41]. Diabetes, smoking, and alcohol consumption were also registered. The cardiovascular risk index was expressed as number of risk factors. The cardiovascular risk factors were considered independent variables.

Socioeconomic status

SES was measured by applying the Graffar's modified scale, which considers schooling and occupation of the household head as well as characteristics of the housing (i.e., building materials, ownership, water supply, and ownership of durable goods) [42]. The Graffar's modified scale has been adapted for Chilean urban and rural populations and classified the sample into five socio-economic strata: 1 = high (0.3%); 2 = medium-high (14.3%); 3 = medium (39.8%); 4 = medium-low (44.5%); and 5 = low (1.1%). SES and their indicators were considered independent variables.

Demographic variables

Demographic characteristics such as student age, sex, age of menarche, number of siblings, order of place among siblings, number of family members, crowding (persons per bedroom), and promiscuity (persons per bed) were registered and considered as independent variables.

Variables dependent on educational system

Data of the 2009 SIMCE tests, which have national coverage and are administered by the Agency for Education Quality, were registered and considered an independent variable. The aim of this testing was to evaluate changes in the quality and equitableness of the educational process in the different areas covered by the national curriculum both in language and mathematics in some grades of elementary and high school. Data are also categorized in three ranges of achievements, high, medium, and low, in both school-aged children and EESA, as defined by the Ministry of Education. Scores were also expressed as mean $\pm$ standard deviation [25].

Teachers were invited to answer a questionnaire to evaluate their academic background and teaching methodologies, and the principals of the schools were interviewed to assess the infrastructure of their school. An index was calculated in each of these variables, which was expressed as scores categorized as adequate, fair, and not adequate. Other educational variables were the type of school and EESA in the 2009 SIMCE tests. Four years later, the LSA and MSA scores from the 2013 PSU taken by 4 HSG students were also registered to determine the extent to which SA in the 2009 SIMCE would predict PSU outcomes 4 y later.

Data collection during 2015

University selection test

Results from the 2013 PSU outcomes in both LSA and MSA tests were registered for the 2010 1 HSG school-aged children when they graduated from 4 HSG in 2013. The PSU has a maximum total score of 850 and a minimum score of 150 for each test (LSA and MSA tests with 80 items each), expressed as mean ± standard deviation [26]. PSU scores were provided by the Studies Centre of the Ministry of Education during 2015 and graded in both LSA and MSA tests as low SA (<p25; score <450), medium SA (≥p25 and ≤*P* 75; 450–620), and high SA (>p75; >620). Scores <450 bar students from applying to higher education [26]. PSU was considered a dependent variable.

Statistical analysis

Data were analyzed by means of variance tests and the Bonferroni's test for comparison of means. Pearson and Spearman correlation coefficients were used for continuous and ordinal variables, respectively. The stepwise procedure was used to establish the most important independent variables that affect PSU outcomes in both LSA and MSA (dependent variables), and multiple regression analysis was used to determine the explanatory power of the independent variables on LSA and MSA variances. Chi squared test was applied for categorical variables [43].

Data were processed using the Statistical Analysis System package (SAS version 9.3; SAS Institute Inc., Cary, NC). This study represents one of the greatest research carried out in Chile focused on the assessment of the impact of nutritional status on PSU outcomes with a multicausal approach. The study is unique in terms of the extensive number of variables that were analyzed and the combination of nutritional, behavioral, anthropologic, and indirect brain measures from our previous studies [14–18,22,24,39,44].

Results

2013. PSU outcomes at the end of high school by sex

PSU scores were significantly higher in male compared with female students both for LSA (556.0 ± 116.5; n = 262 and 525.1 ± 119.8; n = 288, respectively; Student's *t* test: 3.30, 548 df; $P < 0.001$) and MSA (580.6 ± 131.2; n = 261 and 508.2 ± 106.6; n = 287, respectively; Student's *t* test: 7.11, 546 df; $P < 0.0001$).

Pre- and postnatal nutritional background and current nutritional status at the beginning of high school in 2010 by PSU outcomes at the end of high school in 2013

Prenatal nutritional background and early nutritional measurements were not found to be significantly associated with PSU outcomes for either LSA or MSA in the total sample or by sex (Table 1). By contrast, Z-HC values were significantly higher in school-aged children from the high LSA or MSA groups compared with their peers from the medium and low SA groups in the total sample ($P < 0.0001$ and $P < 0.0001$, respectively) and in male ($P < 0.05$ and $P < 0.05$, respectively) and female ($P < 0.05$ and $P < 0.01$, respectively) students.

Similarly, Z-H values were significantly higher in school-aged children from the high LSA or MSA groups compared with their peers from the medium and low SA groups in the total sample ($P < 0.01$ and $P < 0.001$, respectively) and in male students ($P < 0.05$

Table 1

Pre- and postnatal nutritional background and current nutritional status at the onset of high school in 2010 by university selection test scores obtained in language and mathematics scholastic achievements at the end of high school in 2013 (in categories, in the total sample and by sex)

Nutritional parameters	2013 university selection test							
	Language scholastic achievement (n = 550)				Mathematics scholastic achievement (n = 548)			
	Low (<450) (n = 115)	Medium (450–620) (n = 302)	High (>620) (n = 133)	F	Low (<450) (n = 126)	Medium (450–620) (n = 278)	High (>620) (n = 144)	F
Prenatal nutritional background and early nutritional measurements								
Birth weight (g)								
Total sample	3359 ± 625	3324 ± 680	3418 ± 532	0.27 NS	3350 ± 591	3412 ± 533	3464 ± 793	0.64 NS
Male	3368 ± 780	3577 ± 835	3500 ± 526	0.85 NS	3351 ± 799	3524 ± 577	3575 ± 847	0.70 NS
Female	3352 ± 499	3301 ± 488	3273 ± 518	0.24 NS	3349 ± 494	3327± 483	3167 ± 538	1.24 NS
Birth length (cm)								
Total sample	49.9 ± 2.6	49.9 ± 3.6	50.4 ± 3.0	1.45 NS	49.8 ± 2.8	49.7 ± 3.6	50.3 ± 2.9	0.97 NS
Male	50.5 ± 3.3	49.8 ± 3.7	50.9 ± 2.8	1.69 NS	50.1 ± 3.3	50.2 ± 3.9	50.5 ± 2.6	0.15 NS
Female	49.5 ± 1.8	49.5 ± 3.5	49.5 ± 3.2	0.00 NS	49.7 ± 2.5	49.3 ± 3.3	49.8 ± 3.7	0.30 NS
Breastfeeding duration								
Total sample	5.3 ± 3.3	5.9 ± 4.7	5.7 ± 6.1	0.30 NS	6.1 ± 6.5	5.3 ± 3.3	6.0 ± 5.9	0.91 NS
Male	4.7 ± 3.5	5.6 ± 3.5	6.4 ± 7.3	0.93 NS	4.2 ± 3.2	5.3 ± 3.3	6.4 ± 6.7	1.50 NS
Female	5.8 ± 3.1	6.1 ± 5.4	4.4 ± 2.8	1.37 NS	7.0 ± 7.4	5.3 ± 3.2	5.1 ± 2.4	2.04 NS
Postnatal nutritional background and brain development measurement								
2010 head circumference for age Z-score								
Total sample	−0.18 a ± 1.09	0.14 b ± 1.24	0.53 c ± 1.09	10.35*	−0.26 a ± 1.17	0.08 b ± 1.19	0.71 c ± 1.03	23.78*
Male	0.35 a ± 1.00	0.86 b ± 1.20	0.91 b ± 0.99	4.52†	0.39 a ± 1.28	0.76 ab ± 1.16	0.95 b ± 0.97	3.25†
Female	−0.58 a ± 1.00	−0.40 ab ± 0.95	−0.07 b ± 0.97	3.67†	−0.54 a ± 1.00	−0.42 a ± 0.93	0.12 b ± 0.95	6.35‡
2010 height for age Z-score								
Total sample	−0.28 a ± 0.83	−0.23 a ± 0.88	0.03 b ± 0.85	4.67‡	−0.36 a ± 0.89	−0.23 a ± 0.85	−0.07 b ± 0.84	8.44§
Male	−0.10 a ± 0.79	0.06 ab ± 0.86	0.26 b ± 0.73	3.04†	−0.23 a ± 0.86	−0.07 ab ± 0.82	−0.26 b ± 0.77	4.99‡
Female	−0.42 ± 0.85	−0.46 ± 0.84	−0.33 ± 0.90	0.39 NS	−0.41 ± 0.90	−0.40 ± 0.85	−0.40 ± 0.85	0.02 NS
Current nutritional status								
2010 Body mass index Z-score								
Total sample	1.00 ± 1.04	0.85 ± 0.94	0.90 ± 0.93	0.98 NS	0.98 ± 1.05	0.83 ± 0.95	0.90 ± 0.87	0.97 NS
Male	1.00 ± 0.98	0.98 ± 0.98	1.03 ± 0.91	0.07 NS	0.93 ± 1.15	1.03 ± 0.99	0.96 ± 0.89	0.19 NS
Female	1.00 ± 1.03	0.75 ± 0.90	0.70 ± 0.93	1.95 NS	1.00 a± 1.02	0.69 b ± 0.90	0.75 ab ± 0.81	3.12†

NS, not significantly different

a, b and c, same letter are not significantly different at the 0.05 level based on Bonferroni's test.

Values expressed as mean ± standard deviation.

* $P < 0.0001$

† $P < 0.05$

‡ $P < 0.01$

§ $P < 0.001$

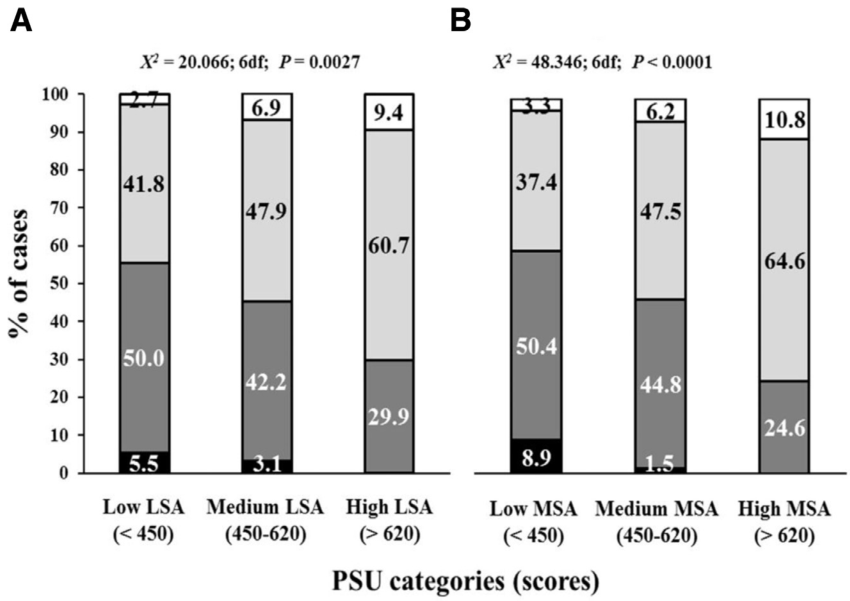

Fig. 2. Head circumference for age Z-score (Z-HC) values at the beginning of high school in 2010 by university selection test scores obtained both in language scholastic achievement (LSA) (A) and mathematics scholastic achievement (MSA) (B) at the end of high school in 2013, expressed in categories. A positive and significant association was observed between Z-HC and PSU outcomes in both tests because most school-aged children with high scores had Z-HC values above the mean and none had values <2. This was also observed in both sexes. Z-HC categories: ■ < −2; ■ −2 – <0 (mean); ■ 0 to 2; □ >2.

and $P < 0.01$, respectively). Current nutritional status expressed as Z-BMI values did not differ significantly by LSA or MSA in the total sample or in male students; however, in female students, Z-BMI values were significantly higher in those with low MSA scores compared with their peers with medium SA ($P < 0.05$).

Z-HC values expressed in categories by LSA and MSA outcomes in the PSU tests are shown in Figure 2. In the total sample, a positive and significant association was observed between Z-HC and LSA (Fig. 2A) and MSA (Fig. 2B) scores because most school-aged children who scored high in the LSA or MSA tests had Z-HC values above the mean and none had values <−2 (microcephaly). By contrast, students with low LSA or MSA mainly had Z-HC values below the mean (P = 0.0027 and $P < 0.0001$, respectively), which was observed in both sexes. According to Z-H (Fig. 3), in the total sample and in both sexes, high LSA (Fig. 3A) and MSA (Fig. 3B) scores were obtained mainly by tall school-aged children with normal H while most students with severe and moderate growth failure achieved

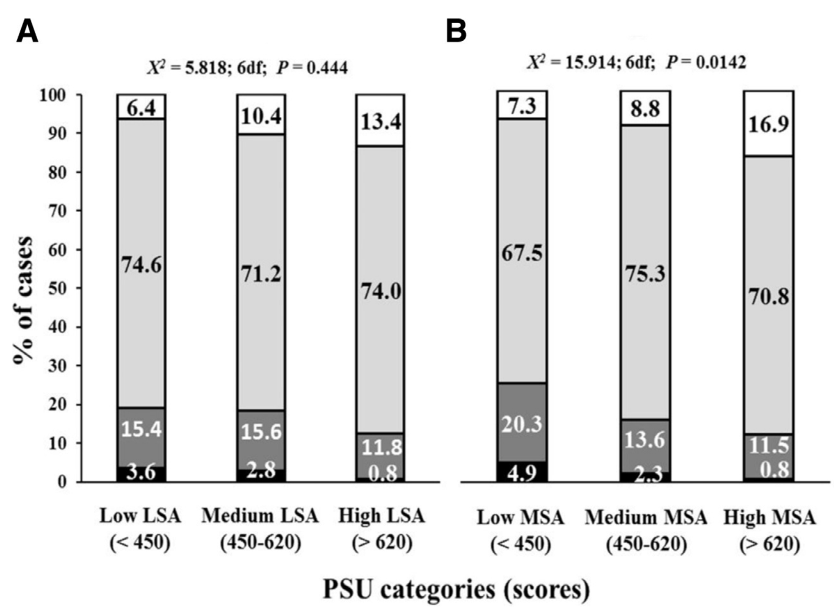

Fig. 3. Height for age Z-score values at the onset of high school in 2010 by the university selection tests scores obtained in language scholastic achievement (A) and mathematics scholastic achievement (B) at the end of high school in 2013 (in categories). High university selection test outcomes in both tests were obtained mainly from school-aged children who were normal height or tall, and most children with severe and moderate growth failure achieved low scores. However, these differences were significantly associated only with mathematics scholastic achievement. This was observed in both sexes. Height for age Z-score categories: ■ Severe growth failure (<−2); ■ moderate growth failure (−2 to <−1); ■ normal height (−1 to 1); □ tall (>1).

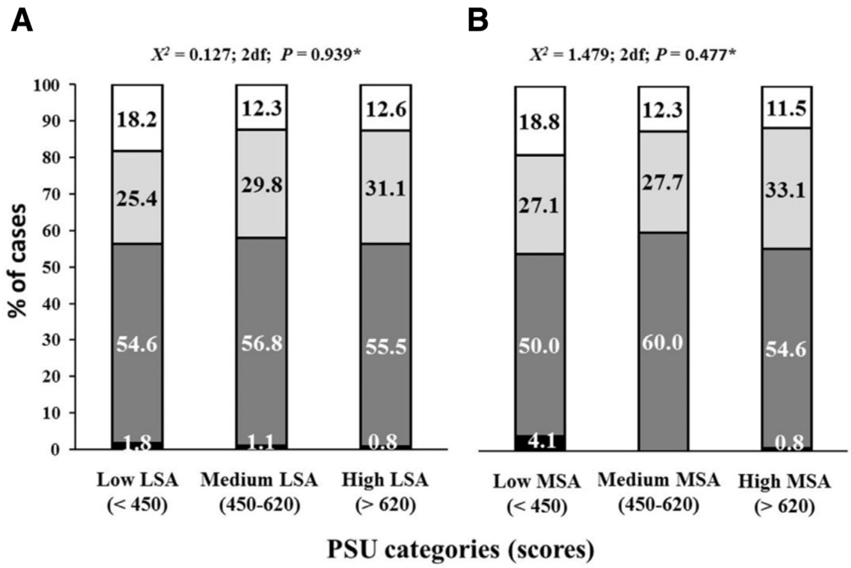

Fig. 4. Body mass index Z-score values at the beginning of high school in 2010 by the university selection test scores in language scholastic achievement (A) and mathematics scholastic achievement (B) at the end of high school in 2013 (in categories). University selection test score outcomes in both tests did not differ significantly by body mass index Z-score in the total sample and by sex. Body mass index Z-score categories: Underweight (<−1); Healthy weight (between −1 to 1); Overweight (between 1 to 2); Obesity (>2). * Calculated as underweight + healthy weight and overweight + obesity.

low scores. However, the differences were found to be significantly associated only with MSA in the total sample (P = 0.0142). Figure 4 shows that PSU outcomes for both LSA (Fig. 4A) and MSA (Fig. 4B) did not differ significantly according to Z-BMI in the total sample and by sex.

Correlation coefficients between PSU outcomes by LSA and MSA at the end of high school in 2013 (dependent variables) and independent variables evaluated at beginning of high school in 2010

The correlation coefficients between LSA and MSA scores and the variables considered in the present study in the total sample and by sex are indicated in Table 2. Positive and significant correlations were observed between postnatal nutritional background markers Z-HC and Z-H and PSU outcomes in both tests ($P < 0.0001$ and $P < 0.0001$, respectively). The correlations were higher for MSA than LSA, especially for Z-HC in the total sample, with the exception of the non-significant correlation between Z-H with both tests in female students.

A negative and significant correlation between Z-BMI was found only for LSA in female students ($P < 0.05$). IA positively and significantly correlated with PSU outcomes in LSA and MSA in the total sample and in both sexes ($P < 0.0001$). With regard to cardiovascular risk factors, in general, negative and significant correlations were found with both tests, with the exception of tobacco and alcohol consumption. Positive and significant correlations between PSU test outcomes and socioeconomic and sociocultural variables and negative correlations with demographic variables were observed. Maternal schooling was the only socioeconomic and sociocultural variable that contributed to both LSA and MSA. With regard to the variables related to the educational system, positive and significant correlations were mainly observed between PSU outcomes in both LSA and MSA with EESA level ($P < 0.0001$ and $P < 0.0001$, respectively) and LSA and MSA with the 2009 SIMCE ($P < 0.0001$ and $P < 0.0001$, respectively) in the total sample and by sex.

Multiple regression analysis between PSU outcomes for LSA and MSA at the end of high school in 2013 (dependent variables) and most relevant parameters at beginning of high school in 2010 (independent variables)

The multiple regression analysis (Proc Glm Error type III) between LSA (dependent variable) and the most relevant parameters (independent variables) revealed that EESA, IA, maternal schooling, and Z-HC at the beginning of high school in 2010 were the independent variables with the greatest explanatory power for LSA variance 4 y later ($R^2 = 0.493$; $P < 0.0001$; Table 3). On the other hand, EESA, IA, maternal schooling, Z-HC, and male sex were the independent variables with the greatest explanatory power for MSA variance 4 y later ($R^2 = 0.600$; $P < 0.0001$; Table 4).

Discussion

The findings of the present study reveal that PSU outcomes for both LSA and MSA are determined by many factors and confirm that learning is a multifactorial problem. However, EESA, IA, maternal schooling, and Z-HC at the beginning of high school are the main predictors of LSA and MSA; male sex is an additional predictor, but only for MSA outcomes.

EESA in the 2009 SIMCE tests significantly contributed to explain LSA and MSA. EESA was found to be significantly associated with the type of school and SES of the family and with the fact that school-aged children from high and medium SES levels studied mainly in schools with high levels of SA in the 2009 SIMCE tests. These schools probably create a more stimulating environment and provide a more adequate infrastructure that favors the learning process, and parents probably have higher levels of education and income. Students who attend these schools develop higher levels of intellectual ability, have higher Z-HC scores, and are trained by teachers with better academic backgrounds who apply more efficient teaching methodologies [45].

Intelligence is also one of the best predictors of PSU outcomes in both LSA and MSA. Intelligence is one of the best predictors of SA and is significantly associated with maternal schooling, maternal

Table 2
Correlation coefficients between university selection test scores in LSA and MSA (dependent variables) at the end of high school in 2013 and nutritional, psychological, cardiovascular risk, socioeconomic, sociocultural, family, demographic, and educational indicators (independent variables) at the onset of high school in 2010*

2010 Independent variables	2013 university selection test scores					
	Total sample		Male students		Female students n = 288	
	LSA (n = 550)	MSA (n = 548)	LSA (n = 262)	MSA (n = 261)	LSA (n = 288)	MSA (n = 287)
Prenatal nutritional background and early nutritional measurements						
Birth weight	0.038 NS	0.037 NS	0.059 NS	0.060 NS	0.049 NS	0.114 NS
Birth length	0.063 NS	0.091 NS	0.019 NS	0.045 NS	0.049 NS	0.010 NS
Breast-feeding duration	0.037 NS	0.030 NS	0.029 NS	0.077 NS	0.108 NS	0.033 NS
Postnatal nutritional background						
Head circumference-for-age Z-score	0.234†	0.322†	0.200‡	0.205‡	0.177‡	0.188‡
Height-for-age Z-score	0.134‡	0.193†	0.211§	0.265†	0.001 NS	0.004 NS
Current nutritional status						
Body mass index Z-score	−0.050 NS	−0.021 NS	0.013 NS	0.005 NS	−0.140‖	−0.117 NS
Psychological variables						
Intellectual ability	0.504†	0.588†	0.511†	0.550†	0.484†	0.563†
Cardiovascular risk factors‡						
Abdominal obesity	−0.079 NS	−0.127‡	−0.028 NS	−0.071 NS	−0.105 NS	−0.156‖
Obesity risk	−0.108‖	−0.153‡	−0.004 NS	−0.063 NS	−0.209‡	−0.240§
Systolic blood pressure	−0.191†	−0.180§	−0.162‖	−0.134‖	−0.234§	−0.255§
Diastolic blood pressure	−0.102‖	−0.098§	−0.135‖	−0.102 NS	−0.032 NS	−0.046 NS
Tobacco	−0.008 NS	−0.068 NS	−0.067 NS	−0.118 NS	0.019 NS	−0.050 NS
Alcohol consumption	−0.030 NS	−0.124 NS	−0.045 NS	−0.117 NS	0.032 NS	0.002 NS
Cardiovascular risk index	−0.125‖	−0.133‡	−0.035 NS	−0.072 NS	−0.243§	−0.246§
Socioeconomic, sociocultural and family variables						
Socioeconomic status	0.406†	0.428†	0.351†	0.413†	0.427§	0.409†
House-hold head	0.004 NS	0.024 NS	0.015 NS	0.019 NS	0.003 NS	0.006 NS
Paternal schooling	0.366†	0.405†	0.291†	0.365†	0.416§	0.410†
Maternal schooling	0.369†	0.371†	0.355†	0.385†	0.355§	0.327†
Household head schooling	0.361†	0.393†	0.275†	0.346†	0.423§	0.426†
Paternal occupation	0.400†	0.415†	0.373†	0.426†	0.401§	0.381†
Maternal occupation	0.238†	0.250†	0.237†	0.253†	0.223§	0.240†
Household head occupation	0.421†	0.426†	0.364†	0.402†	0.452§	0.426†
Quality of housing	0.364†	0.391†	0.305†	0.360†	0.411§	0.422†
Property of housing	0.048 NS	0.062 NS	0.033 NS	0.008 NS	0.040 NS	0.055 NS
Family stability (married)	0.014 NS	0.061 NS	0.011 NS	0.042 NS	0.011 NS	0.067 NS
Demographic variables						
Student age	−0.074 NS	−0.072 NS	−0.128‖	−0.215§	−0.056 NS	−0.000 NS
Menarche age					−0.041 NS	0.020 NS
Number of siblings	−0.139‡	−0.096‖	−0.198‡	−0.154‖	−0.068 NS	−0.024 NS
Place among siblings	−0.159§	−0.086 NS	−0.197‡	−0.185‡	−0.101 NS	−0.023 NS
Number of family members	−0.076 NS	−0.066 NS	−0.052 NS	−0.032 NS	−0.089 NS	−0.077 NS
Crowding (persons/bedroom)	−0.185†	−0.167†	−0.119 NS	−0.107 NS	−0.234†	−0.184‡
Promiscuity (persons/bed)	−0.152§	−0.167†	−0.128‖	−0.108 NS	−0.144‖	−0.156‖
Educational system variables						
Type of school (Private non-subsidized)	0.094‖	0.075 NS	0.222§	0.196‡	0.023 NS	0.005 NS
EESA	0.633†	0.661†	0.631†	0.664†	0.617†	0.650†
School infrastructure index	0.489†	0.512†	0.459†	0.471†	0.503†	0.550†
L teacher's academic background index	0.178‡	—	0.238‖	—	0.129 NS	—
M teacher's academic background index	—	0.133‖	—	0.166 NS	—	0.178‖
L teaching methodologies index	0.096 NS	—	0.168 NS	—	0.000 NS	—
M teaching methodologies index	—	0.097 NS	—	0.097 NS	—	0.044 NS
LSA SIMCE 2009	0.702†	—	0.732†	—	0.665†	—
MSA SIMCE 2009	—	0.784†	—	0.761†	—	0.746†

EESA, educational establishment scholastic achievement; LSA, language scholastic achievement; MSA, mathematics scholastic achievement; NS, not significantly different; SIMCE, Sistema de Medición de la Calidad de la Educación (quality education measurement system; L, language; M, mathematics)
Only four children had diabetes.
*Pearson and Spearman correlation coefficients were used for continuous and ordinal variables, respectively
† $P < 0.0001$
‡ $P < 0.01$
§ $P < 0.001$
‖ $P < 0.05$

intelligence, Z-HC, and brain development as well as the antecedent of undernutrition in the first year of life [14,16,18,22,24,44,46–50]. This has been observed independently of age, sex, and SES [46]; however, maternal schooling was the variable with the greatest explanatory power in IA variance [47].

The importance of maternal schooling as a significant predictor of PSU outcomes in LSA and MSA was also evident in the present study. Maternal schooling is the strongest predictor of long-term SA and cognitive neurodevelopment in children, even among disadvantaged groups, because mothers have a considerable effect on their child's intelligence as the main source of intellectual stimulation and enrichment of the psychosocial environment. In addition, mothers help their children study at home; this also affects SA because this parameter and intelligence are closely related [14,18,22,24,45,46,48–53].

Although PSU scores were significantly higher in male students in both LSA and MSA, sex differences contribute to the explanation

Table 3
Multiple regression analysis between the university selection test scores in language scholastic achievement (dependent variable) at the end of high school in 2013 and the most relevant parameters (independent variables) at the onset of high school in 2010 (n = 550)

Parameter	Estimate	Standard error of estimate	T for H0: Parameter = 0	$P > \|T\|$
Intercept	485.0719457	10.32758534	46.97	0.0001
EESA				
High	102.0272651	9.44164140	10.81	0.0001
Low	−4.6030541	11.69248524	−0.39	0.6940
Medium	0.0000000	.	.	.
Intellectual ability*				
Grade I–IV	−40.5688353	9.70932856	−4.18	0.0001
Grade I–V	−81.6052075	19.16420627	−4.26	0.0001
Grade I	62.6492123	16.18450050	3.87	0.0001
Grade I–II	43.4375343	9.31341491	4.66	0.0001
Grade I–III	0.0000000	.	.	.
Maternal schooling				
<12 y	−33.9027199	8.80810780	−3.85	0.0001
≥12 y	0.0000000	.	.	.
Head circumference for age Z-score				
<0	−17.5636426	8.18220757	−2.15	0.0323
≥0	0.0000000	.	.	.
Sex				
Female	10.0589813	8.16926915	1.23	0.2188
Male	0.0000000	.	.	.
Model R^2 = 0.493; Root MSE (Root mean squared error (standard deviation of the dependent variable mathematics scholastic achievement in the university selection test) = 80.84433; Model *F* Value = 53.80, $P < 0.0001$				

EESA, educational establishment scholastic achievement
*Grade I: superior intellectual ability; Grade II: above average; Grade III: average; Grade IV: below average; Grade V: intellectually defective

Table 4
Multiple regression analysis between the university selection test scores in mathematics scholastic achievement (dependent variable) at the end of high school in 2013 and the most relevant parameters (independent variables) at the beginning of high school in 2010 (n = 548)

Parameter	Estimate	Standard error of Estimate	T for H0: Parameter = 0	$P > \|T\|$
Intercept	487.8626149	10.17955242	47.93	0.0001
EESA				
High	119.5657307	9.31408229	12.84	0.0001
Low	3.0185863	11.54101490	0.26	0.7938
Medium	0.0000000	.	.	.
Intellectual ability				
Grade I–IV	−53.9057044	9.56338304	−5.64	0.0001
Grade I–V	−86.0851754	19.24492106	−4.47	0.0001
Grade I	105.5765848	15.93840674	6.62	0.0001
Grade I–II	54.1529591	9.17814316	5.90	0.0001
Grade I–III	0.0000000	.	.	.
Maternal schooling				
<12 y	−18.2841789	8.72771405	−2.09	0.0367
≥12 y	0.0000000	.	.	.
Head circumference for age Z-score				
<0	−22.1593118	8.06348967	−2.75	0.0062
≥0	0.0000000	.	.	.
Sex				
Female	−21.0453260	8.05242361	−2.61	0.0092
Male	0.0000000	.	.	.
Model R^2 = 0.600; Root MSE (Root mean squared error (standard deviation of the dependent variable mathematics scholastic achievement in the university selection test) = 79.58726; Model *F* Value = 81.18, $P < 0.0001$				

EESA, educational establishment scholastic achievement
*Grade I: superior intellectual ability; Grade II: above average; Grade III: average; Grade IV: below average; Grade V: intellectually defective

of why PSU outcomes favor male students in MSA only. These findings are consistent with those from other investigators who explored the effect of sex differences in data obtained during 1 decade by the Program for International Student Assessment, including the mathematics and reading performance of nearly 1.5 million 15-y-olds in 75 countries. Across nations, male students scored higher than female students in mathematics but lower in reading [54].

HC, the anthropometric indicator of both nutritional background and brain development, was the only nutritional index that contributed to explain PSU outcomes in both LSA and MSA. Undernutrition at an early age, especially during the first year of postnatal life, decreases HC, which is the most sensitive physical index of alteration in malnutrition conditions [23,24,60]. Studies on Chilean school-aged children who graduate from high school have a confirmed high degree of correlation between absolute HC and brain volume as measured by magnetic resonance imaging ($r = 0.841$; $P < 0.0001$) [22]. This was also observed in both male ($r = 0.867$; $P < 0.0001$) and female ($r = 0.720$; $P < 0.0001$) children [39].

HC has been found to be the most important anthropometric parameter associated with SIMCE outcomes [20]. These findings are in agreement with results of several previous studies that concluded that HC is the most relevant anthropometric parameter significantly associated with SA, parental schooling levels, and—especially—with maternal schooling, intelligence, brain volume, and the antecedent of undernutrition in the first year of life, variables that are significantly interrelated [10,14,18,22–24,39,46,55–59]. Moreover, school dropout rates correlate with HC but not with W or H [15,17].

Long before a child enters the classroom, inequities create a lasting imprint on the architecture of the brain. Recent research on brain development casts new light on the formative influence of early childhood experience. In the first few years of life, a child's brain creates 700 to 1000 new neural connections every second, a pace that later diminishes; 70% of adult brain weight has been attained by the end of the first year [24,60]. Because the first year of a child's life affects brain development so significantly, early childhood offers a critical window of opportunity to break intergenerational cycles of inequity with risk factors that affect children's cognitive development, such as nutrition, environment, and maternal-child interaction [2,5,61].

The high school graduates who obtain the lowest 2013 PSU scores in both LSA and MSA have probably been exposed to unfavorable socioeconomic, sociocultural, and nutritional conditions starting from an early age, and their parents (especially their mothers) likely exhibited low schooling levels and intellectual stimulation of the child. As a consequence, in the long term, these children had suboptimal HC and brain development and lowered intelligence and SA; therefore, they attended school with low SA [2,5,10–24,39,44,46,53,55–61].

As previously indicated, knowing the best predictors of PSU outcomes at or before the beginning of high school is very useful because school-age children at risk of failing this test for their future life instead would be allowed to attend college.

Early interventions are essential on the basis of diagnoses made at an early age. Neuroplasticity begins to decline after early childhood, and the effects of early childhood deprivation on the brain become progressively harder to offset. Interventions are most effective during the period of the most dynamic growth and affect a child for life. The most effective interventions must be intersectoral and go beyond education to encompass health, nutrition, and protection. The healthy development of a child's brain depends on multiple positive experiences. Nutrition feeds the brain, stimulation sparks the mind, and love and protection buffer the negative impact of stress and adversity [61].

Conclusions

These findings confirmed our hypothesis that EESA level, IA, sex, parental schooling levels, and HC-Z-score at the beginning of high school in 2010 would be the most relevant parameters associated with PSU outcomes in both LSA and MSA for university admission at the end of high school in 2013. In the present study, PSU outcomes were focused on a multicausal or intersectoral context because the cognitive processes depend on many factors, as previously described [11,13–18,22,24,44,46,48]. These results could be useful for the implementation of nutritional, health, and educational policies in this and other countries. Studies carried out in the most diverse countries show that there are common factors that affect student learning in different socioeconomic conditions [1–24,39,44–53,55–59]. However, more applied research is needed in this area to contribute substantially to more significant positive changes in the learning process.

Acknowledgments

The authors thank the Ministry of Education of Chile and the Education Quality Agency for Agency, SIMCE General Coordination for their review, approval, and authorization of this study and for providing the 2009 and 2013 SIMCE results. The authors also thank the Studies Centre from the Ministry of Education of Chile for providing PSU scores and the principals, teachers, and school-aged children and their parents for generously participating in this study. Finally, the authors are grateful to Dr. Oscar Brunser for his review and valuable suggestions and to Mr. Luis Santander for his important collaboration in the field study.

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