Comparison of Executive Functions in School Children Aged 7 to 12 Years in a State of Malnutrition Due to Thinness, Risk of Thinness and a Control Group of an Educational Institution of the Locality of Ciudad Bolívar- Bogotá, D.C.

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Abstract: The aim of this research was to compare the neuropsychological performance of executive functions of school children in a state of malnutrition caused by thinness and risk of thinness and a control group of a District educational institution of the locality of *Ciudad Bolívar* in Bogotá, Colombia. The research used a descriptive cross-sectional comparative design, where children aged between 7 and 12 years were selected based on the diagnosis of malnutrition. The executive functions assessed were fluency, working memory, problem solving, inhibitory control and cognitive flexibility, through the Neuropsychological Battery for Children [ENI, for its Spanish acronym] and the original version of Stroop and Wisconsin tests. Results showed statistically significant differences in executive functioning between the children with thinness, thinness risk and the control group. The students with thinness showed a low performance in verbal fluency, visual fluency, working memory, cognitive flexibility and inhibitory control compared with students in a state of malnutrition due to thinness risk and those with normal weight (control group). In conclusion, a strong association was found between the effect of child malnutrition and poor performance in executive tasks where there is evidence that executive functioning is more affected in children with malnutrition due to thinness (severe malnutrition) than in children with malnutrition due to thinness risk and in those of the control group.

Keywords: Executive functions, malnutrition, child neuropsychology, inhibitory control, working memory.

INTRODUCTION

Malnutrition is a multifactorial problem that includes genetic, environmental, cultural, social, economic and psychological factors, among others [1,2]. It describes a pathological condition resulting from an imbalance in the nutritional status and refers to a deficit in nutrients intake, or to a state of overnutrition that causes significant damage to brain development both at a morphological and functional level and becomes evident in the later stages of pregnancy and the first years of life [3,4].

In Latin America and the Caribbean, a figure of about 4.1 million children with low birth weight has been recorded [5]. In Colombia, the National Survey of Nutritional Status (2010) [ENSIN, for its Spanish acronym] revealed that 2.1% of children and young people aged between 5 and 17 years showed thinness (severe deficit of weight for height) [6]. These findings are relevant considering the relationship between nutrition and intellectual development since nutrients like vitamin B6, folic acid, vitamin B12 and omega-3 fatty acids have been specifically related to brain development. There are also associations with iron and blood glucose. The effects of these particular nutrients on the brain are intrinsically related to their physicochemical characteristics and, therefore, the nutritional effects can be very specific. For example, iron deficiency can affect neurotransmitter synthesis and DHA [Docosahexaenoic acid] deficiency affects its release [7-9].

Prenatal malnutrition and during the early years of life can affect brain growth and the production of neurotransmitters, having an impact on nerve myelination process, which causes reduced nerve conduction velocity. The cells primarily affected by nutritional deficits are the myelin-producing cells, thus promoting axonal degeneration. As a result of these alterations, children are often described as lethargic, possibly because they reduce their activity as a protection strategy for the conservation of energy, which in turn limits the practice and acquisition of new or more complex skills. Likewise, these children often present anxiety disorders, reduced physical activity and social interactions, deficits in attention, memory, self-

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control and executive functions, as well as chronic fatigue syndrome and depression, among other symptoms [10, 11].

During the school years the child should display the ability to regulate their behavior according to school activities and maintain adequate motivational and attentional levels that can favour their optimal performance in the classroom. Similarly, the child should be prepared to inhibit their response before any external stimulus that can distract them from their school process. These tasks lie within the executive functions (EF) which broadly refer to a set of cognitive skills involved in solving novel, unforeseen, or changing situations [12,13].

The EF are part of the more complex human functions and are in charge of associating simple ideas to gear them towards solving highly complex behaviors [14,15]. A great variety of skills are included within EF such as the ability to set goals, develop action plans, flexibility of thinking, automatic response inhibition, self-regulation of behavior and verbal fluency [15-17].

The EF starts developing between 6 and 12 months of age and continues to mature into adulthood [18, 19]. The structural brain changes related to their maturity are manifested in a linear growth in the volume of the white matter and in non-linear changes in the density of the gray matter, increasing during childhood and pre-puberty and decreasing in early adulthood [20-22]. Also, changes in myelination, synaptic processes, brain metabolism and interhemispheric connections have been reported [23, 24].

It has been suggested that the various EF units follow a particular development. For example, the basic modular structure of the working memory is present from six years of age and each component of the module increases its ability until adolescence [25]. However, other authors point out that the development of working memory continues into adulthood [26]. On the other hand, cognitive flexibility develops gradually during childhood and adolescence while the ability to plan and solve complex problems is reached in adolescence [27]. Verbal fluency tasks are also associated with age, so that there is an improvement in performance on these tasks, achieving its highest level around 11-12 years [28, 29]. The inhibitory control increases with age during childhood and adolescence [29, 30].

In practice, it can be seen that the emergence and development of EF is accompanied by structural and functional changes in the brain that last until adulthood, in such a way that it is possible to infer how the EF performance should improve over time as a result of the maturation of the brain structures that support them.

The EF analysis and its relationship with nutritional status has been reported in the literature in different studies [31-36] and these show that children with nutritional problems have a lower neuropsychological performance in relation to normal weight controls in processes such as language comprehension, short-term memory and visuospatial skills, thus leading to the conclusion that malnutrition significantly affects the development of higher cognitive processes in children during each developmental stage and is associated with a widespread cognitive impairment in this population.

In the face of the above mentioned, a study of a low-income community of Bogotá, Colombia, with high levels of malnutrition and high school dropout due to poor academic performance was proposed in order to assess the executive functions of school children with three different nutritional status: thinness, risk of thinness and adequate Body Mass Index (BMI), with the aim of generating future programs to address the locally identified relationship between these two variables and be able to project effective interventions.

METHOD

Type of Study

This research consisted of a descriptive comparative study. It was descriptive since it aimed to identify the neuropsychological characteristics of executive functions of students aged between 7 and 12 in a situation of malnutrition. It was comparative because it searched to establish the performance differences of these functions in the three targeted groups.

Participants

This study was conducted at a school of the Bogotá District, where 377 school children between 7 and 12, attending from second to fifth grade, all of them from a low socioeconomic status, were assessed. From the above sample, 65 children were diagnosed with thinness, 75 with risk of thinness and 193 with age-appropriate BMI.

Figures **1** and **2** present the description by gender and educational level of the three groups.

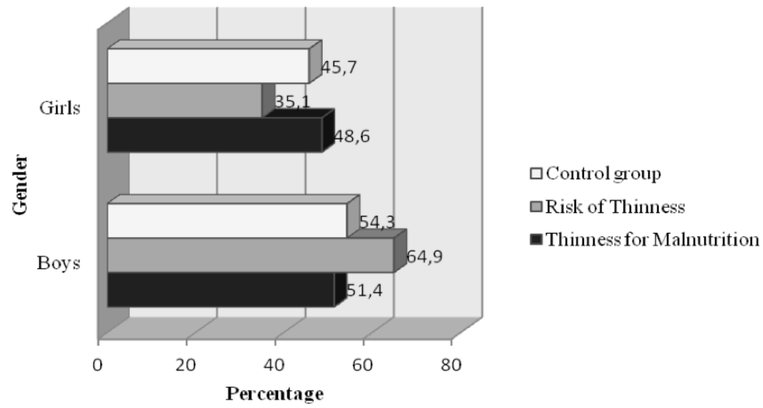

Figure 1: Percentage distribution by gender of school children in Condition of Malnutrition and Control Group.

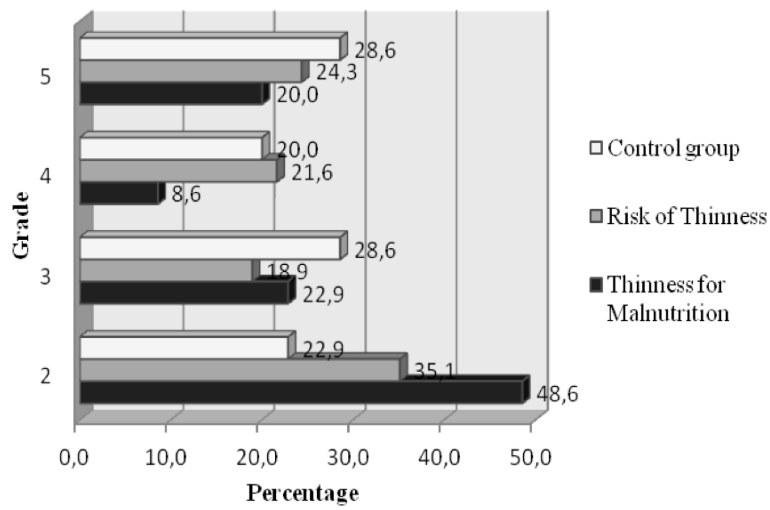

Figure 2: Percentage Distribution by schooling of the school children in Condition of Malnutrition and Control Group.

Subsequent to the nutritional diagnosis and after having applied the exclusion criteria, 50% of the children from each group were chosen by convenience: 35 children who represented the Thinness Condition, 37 children, the Risk of Thinness and 35 children, the age-appropriate BMI, or the Control Group. The total sample consisted of 107 children. The only exclusion criterion was intellectual impairment, defined as having obtained a Full Scale IQ score lower than 80 in the WISC-IV.

Table **1** shows the distribution of the school children involved in the study according to the variables age and nutritional diagnosis.

Instruments

Nutritional Assessment

For nutritional assessment, basic measures (weight and height) and body mass index (BMI) were determined. Anthropometric measurements of weight and height were taken based on the information set out in the report of an experts' committee of the World Health Organization- WHO (*Physical status: use and interpretation of anthropometry,* WHO, Geneva, 1995). Weight was determined with the least amount of clothing possible (shirt and shorts) and height in standing position. The BMI was calculated as weight (in kilograms) divided by the square of his or her height (in metres). Reference standards for BMI for age were the Growth Standards published by WHO in 2006 and 2007 for children and adolescents 0-18 years of age. For the diagnosis of nutritional status, designations were used as described in Resolution 2121 of 2010 whereby the growth patterns published in 2006 by WHO were adopted.

The indicator for assessing the nutritional status was Body Mass Index (BMI) for age. The students in the control group were those with adequate BMI for their age, that is, between +1 and -1 standard deviation in the instrument. In the -1 to -2 standard deviations,

Table 1: Total Sample Distributed by Age and Nutritional Diagnosis

Age	Nutritional Diagnosis					
	Thinness (n=35)		Risk (n=37)		Control group (n=35)	
	n	%	n	%	n	%
7	7	20,0%	11	29,7%	6	17,1%
8	9	25,7%	8	21,6%	12	34,3%
9	11	31,4%	7	18,9%	5	14,3%
10	4	11,4%	4	10,8%	5	14,3%
11	2	5,7%	3	8,1%	4	11,4%
12	2	5,7%	4	10,8%	3	8,6%

diagnosis refers to risk of thinness, and for boys and girls located below -2 deviations, the diagnosis is for thinness.

Neuropsychological Assessment

Wechsler Intelligence Scale for Children-Fourth Edition (WISC IV): it enables to obtain the Verbal IQ (VIQ), the Performance IQ (PIQ) and the Full Scale IQ (FSIQ) for children. This test provides composite scores that represent intellectual functioning in specific cognitive domains: Verbal Comprehension Index, Perceptual Reasoning Index, Working Memory Index and Processing Speed Index, as well as a composite score representing the child's general intellectual capacity, or his/her Full Scale IQ. Reliability coefficients for the composite scales vary from 0.88 to 0.97 and in the test - retest the corrected average stability coefficients for the composite scales are in the range of 0.90 [38].

Infant Neurological Assessment Battery (ENI for its Spanish acronym): This test has been designed to be applied to children aged 5 to 16 years, with the aim of assessing neuropsychological characteristics of school age. Reliability and validity were calculated from a test-retest application in which correlation coefficients were found ranging from 0.86 to 0.99, indicating that the test scoring is consistent across different assessors. The following subtests were used in the study: semantic and phonemic verbal fluency (recall of specific information under restricted conditions), graphic fluency (creating unique designs under restricted conditions), Tower of Mexico (planning and organization of figures), Digit regression (task that explores working memory) [39].

Wisconsin Card Sorting Test: It is the most widely used test to assess cognitive flexibility. It is directly related to the formation of concepts and especially to the difficulty in forming initial concepts, maintaining them once they have been formed, recognizing category changes and hypothesis changes while the subject is given negative feedback. Application age is between 7 and 89 years. Reliability coefficients range from 0.39 to 0.72 with a mean age of 0.57 and a median of 0.60 [38].

Color-word test (Stroop): The Stroop task measures cognitive processes related to executive function, such as flexibility and the ability to inhibit automatic responses (inhibitory control). Likewise, the dimension of assessing processing speed information is added to the task. The application age is from 7 to 80 years. Regarding the reliability of this test, an index of 0.86 is identified for the word condition; for the color condition, an index of 0.82, and for the color and word condition, an index of 0.73. In terms of validity, the test presents significant statistical validity when it has been compared with the following measures that assess similar constructs: Nelson-Denny Reading Test, Woodcock-Johnson Psycho-Educational Battery-Revised, and the Wide Range Achievement Test- 3 (WRAT 3) [40].

Procedure

Two sites of a district school located in a low socioeconomic area were chosen for the study. The parents of the children were called to a meeting where they were requested to sign the informed consent and answered questions about the children's neurological history. Afterwards, the children’s nutritional assessment was carried out in order to classify them based on their nutritional status.

Subsequently, 51% of the children from each group were taken at random (thinness, risk of thinness and normal weight) and the intelligence test was applied to them. This allowed filtering 50% of the children from each group. Later they were assessed individually in approximately two hours per child in a space within the school premises which had appropriate environmental conditions. Individual and group reports were given to parents and the school.

Finally, the statistical analysis was conducted using the statistical package SPSS-20 where the first stage consisted of a descriptive analysis of the data concerning the neuropsychological variables (executive functions). Data are presented according to measures of central tendency (mean, median, standard deviation, upper and lower limit) depending on the number of right answers to each of the tests administered. The assumption of normality was proven with the use of the Kolmogorov-Smirnov test for samples larger than 50. At a second stage, in order to determine statistically significant differences between the executive functioning of school children with malnutrition due to thinness, risk for thinness and control group, an analysis of the scores obtained in each neuropsychological test was carried out by means of the parametric Anova test of one factor, in cases where the normality of the data collected was found in the application of these tests, and the non-parametric Kruskal-Wallis test was employed in cases where this condition was not met. The level of significance established for this research was Alpha < 0.05.

RESULTS

To characterize the sample's executive functioning, the natural scores obtained by the children of the three groups (thinness, risk of thinness and control) in each of the tests applied to them were taken as references. Table **2** shows the mean and standard deviation (SD)

Table 2: Means and Standard Deviations Obtained for the School Children

Executive Function	Test	Nutritional Diagnosis						Comparison
		Thinness (n=35)		Risk (n=37)		Control group (n=35)		F (p)
		Mean	SD	Mean	SD	Mean	SD	
Verbal Fluency	Semantic	9,09	3,01	10,92	2,37	14,83	2,56	42,623[a] (0,000)
	Phonemic	5,91	2,95	7,38	3,50	12,14	3,40	34,163[a] (0,000)
Visual Fluency	Semantic	7,54	4,61	10,54	7,05	12,57	4,30	7,411[a] (0,001)
	Non-Semantic	4,97	3,49	5,05	3,65	8,37	4,44	8,814[a] (0,000)
Problem Solving	México´s Pyramid Correct	10,40	0,94	10,27	1,30	10,97	0,16	21,217[a] (0,000)
	Movement	2,37	1,71	5,43	2,15	5,57	2,96	13,055[b] (0,001)
Working Memory	Digits	3,46	1,14	4,05	1,17	4,83	1,09	19,922[b] (0,000)
	Wisconsin	1,14	1,41	1,59	1,57	2,91	2,16	15,432[b] (0,000)
Flexibility	Wisconsin Correct	24,78	19,08	30,96	18,31	51,67	20,85	18,457[a] (0,000)
	Errors	37,62	18,00	34,46	18,32	29,90	12,63	1,933[a] (0,150)
	Perseverations	43,23	23,27	40,68	23,91	22,94	18,74	8,771[a] (0,000)
	Categories	1,14	1,16	1,49	2,022	2,77	1,66	20,612[b] (0,000)
Inhibitory Control	Stroop Word-color	16,74	6,26	21,84	9,974	26,06	8,44	10,789[a] (0,000)
	Interference	-3,01	7,55	-0,52	11,50	5,32	7,30	7,833[a] (0,001)

[a]Normal (Anova one factor); [b]No- Normal (Kruskal-Wallis).

obtained for each group in each of the executive function variables analyzed.

Means and standard deviations (SD) for school children in malnutrition situation for Thinness, Risk of Thinness and Control Group in each of the variables analyzed show differences in the performance of each group. In general, children of the control group and those of risk of thinness tended to score higher than

Table 3: Significant Differences Based on the Post Hoc Test

Executive Function	Test	Nutritional Diagnosis		Mean Difference	Sig ≤ 0.05
Verbal Fluency	Semantic	Thinness	Risk	-1,833	0,012
			Control group	-5,743	0,000
		Risk	Thinness	1,833	0,012
			Control group	-3,910	0,000
		Control group	Thinness	5,743	0,000
			Risk	3,910	0,000
	Phonemic	Thinness	Control group	-6,229	0,000
		Risk	Control group	-4,764	0,000
		Control group	Thinness	6,229	0,000
			Risk	4,764	0,000
Visual Fluency	Semantic	Thinness	Control group	-5,029	0,001
		Control group	Thinness	-5,029	0,001
	Non- Semantic	Thinness	Control group	-3,400	0,001
		Risk	Control group	-3,317	0,001
		Control group	Thinness	3,400	0,001
			Risk	3,317	0,001
Problem Solving	México´s Pyramid corrects	Thinness	Risk	-3,061	0,000
			Control group	-3,200	0,000
		Risk	Thinness	3,061	0,000
		Control group	Thinness	3,200	0,000
Cognitive Flexibility	Wisconsin: corrects	Thinness	Control group	-26,89029	0,000
		Risk of Thinness	Control group	-20,70937	0,000
		Control group	Thinness	26,89029	0,000
			Risk	20,70937	0,000
	Wisconsin: Perseveration	Thinness	Control group	20,286	0,001
		Risk	Control group	17,733	0,003
		Control group	Thinness	-20,286	0,001
			Risk	-17,733	0,003
Inhibitory Control	Stroop Word-Color	Thinness	Risk	-5,095	0,031
			Control group	-9,314	0,000
		Risk	Thinness	5,095	0,031
		Control group	Thinness	9,314	0,000
	Stroop interference	Thinness	Control group	-8,332	0,001
		Risk	Control group	-5,841	0,020
		Control group	Thinness	8,332	0,001
			Risk	5,841	0,020

children of the thinness group in most tests that assess EF. This was observed specifically in verbal fluency tasks (semantic and phonemic), visual fluency (semantic graphic fluency, and non-semantic graphic fluency), problem solving (Mexico's pyramid corresponding to correct designs with minimal movement), cognitive flexibility (Wisconsin errors scoring) and inhibitory control (Stroop's Word- Color score and interference). However, in the test scores of the Mexico pyramid corresponding to the correct designs and the number of correct responses, perseverations, categories and failure to maintain the Wisconsin´s principle, a very homogeneous performance of the school children with thinness, and thinness risk was evident.

Table **2** shows the analysis of the group differences in executive functioning and its significance level.

The results obtained in the assessment of executive functions show that the state of malnutrition had a significant effect on most of the variables analyzed in school children 7-12 years. This difference reached significance in thirteen of the fourteen tests analyzed. Statistically significant differences were found between the three groups of school children assessed on the following executive functions: semantic verbal fluency, phonemic verbal fluency, semantic graphic fluency, non-semantic graphic fluency, working memory, problem solving, cognitive flexibility and inhibitory control. However, there were no statistically significant differences in terms of the level of errors in the Wisconsin Test with respect to Cognitive Flexibility between the performance of school children with malnutrition and the control group, which suggests that the three groups tend to have a similar performance and number of errors on this test.

Table **3** presents the analysis of Post Hoc comparisons between groups using the Tukey Test. Findings show a statistically significant difference between the group with the nutritional diagnosis of thinness and the control group on executive functioning of school children with respect to domains such as semantic verbal fluency, phonemic verbal fluency, semantic graphic fluency, non-semantic graphic fluency, problem solving, cognitive flexibility and inhibitory control. That is to say that only the average scores for the Thinness group and the Control group (normal weight) showed a significant difference in the five factors or domains of the executive functions analyzed.

DISCUSSION

This study found a strong association between the effect of child malnutrition and poor performance in executive tasks which are related to self-determination, understood as the ability to know one's own strengths and limitations, sense of authority, strategic behavior (planning, monitoring, daily review of actions), autonomy (action free of external interference) and organization of discourse, verbal fluency, proper consistency in language and understanding longer texts, among others [41-43].

It was evident that school children in the thinness condition have a poorer performance in verbal fluency, visual fluency, working memory, cognitive flexibility and inhibitory control compared with students in risk of thinness and with normal weight (control group). However, in the Mexico Pyramid tasks corresponding to the correct designs (Problem Solving), category index and failure to maintain the Wisconsin's principle, the children with thinness, risk of thinness and control group showed similar performance.

The analysis of the data obtained in the assessment of the different components involved in executive functioning showed that school children 7-12 years in condition of malnutrition for thinness present clinically significant difficulties with regard to the control group and the population mean in all processes assessed.

The poor performance occurred especially in verbal fluency tasks, semantic and non- semantic graphic fluency, digit regression, correct responses index, errors, perseverations and categories of the Wisconsin Test and in the interference score of the Stroop Test. In summary, these children evidence alterations in the ability to: 1. Keep the information mentally while working on it or updating it. 2. Access the phonological lexicon and the semantic system based on cues. 3. Change and regulate behavior according to the demands of the environment. 4. Focus on one task and finish it without external environmental control. 5. Classify context elements according to a previously established definition construct and 6. Activate and produce verbal and nonverbal elements in fluency tasks which are goal-oriented activities that must be maintained throughout the task and require mental flexibility to move from one category to another and sustained attention in order not to generate intrusions. These results are consistent with previous research that had identified widespread alterations of executive functions in children with malnutrition thinness (severe malnutrition) [27, 44].

Moreover, in terms of Verbal Fluency, Visual Fluency, Problem Solving, Working Memory, Cognitive Flexibility and Inhibitory Control in students at-risk of thinness for malnutrition, the neuropsychological tests results show that these children have a better performance and an adequate development in their capacity to: 1. Delete or stop inappropriate habitual actions and information (inhibitory control). 2. Identify and organize a sequence of events in order to achieve a specific goal (planning). 3. Produce words that start with a phoneme or letter and belong to a semantic category, inhibiting the words that do not belong to the specified category and implementing strategies to generate the greatest number of words within the stipulated time (verbal fluency). Nevertheless, in this group of school children as with the group of children in the thinness condition, difficulties are evident in: 1. The ability to change a pattern of action or thought when the assessment results indicate that it is not efficient, or when there are changes in environmental conditions and / or the conditions in which a specific task is being performed. 2. Presence of rigid and persevering behavior, and 3.The establishment of new behavioral repertoires along with a lack of ability to use operational strategies.

The findings in the risk of thinness group allow evidencing that while it is true that some processes of the executive function are preserved, poor performances occur in skills that involve the adoption of feedback, which is the basis for the subsequent generation of flexibility during adolescence, an adaptive mechanism that would allow a greater capacity to respond to life demands, take fewer risk behaviors and reduce the chance of error in problem solving [41, 43-46].

Additionally, it is important to add that the results cannot be explained in terms of IQ, years of education, age of children, type of school and socioeconomic stratum, since the groups had been matched on these variables, being consistent with associating the effect of malnutrition on executive functioning.

Taken together, the results presented have important implications for the clinical and educational fields. In the clinical context, evidence highlights the importance of carrying out stimulation and rehabilitation interventions with students in malnutrition conditions, especially in stages previous to the critical periods of maturation of brain structures that support the EF. For physicians who examine children with malnutrition, this study shows the importance of making the referral to Neuropsychology and Physical Medicine services that may favor their inclusion in special programs aimed to stimulating their cognitive functions. On the other hand, in the educational context is necessary to take into account the plurality of features present in the cognitive structures of students that the teacher has to deal with in the classroom, as these differences, strengths, weaknesses, and social and health realities affect the processes of learning, development, educational progress, as well as the entrance to higher education and the competitiveness at that level.

Thus, at the clinical level, progress can be made from description to explanatory hypotheses that allow not only understanding the impact of malnutrition on executive functions but also intervening more effectively in the risk factors that affect the development of higher cognitive processes of children.

Finally, future research should include a larger sample, additional measures of executive functioning, a longitudinal design and the implementation of different statistical procedures that allow for inferences about the population.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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