Cognitive Inhibitory Control and Arithmetic Word Problem Solving In Children with Attention Deficit/ Hyperactivity Disorder: A pilot study*

Control inhibitorio cognitivo y resolución de problemas verbales aritméticos en niños con déficit de atención e hiperactividad: un estudio piloto

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Abstract
A sample of 30 subjects, 10 with Attention Deficit and Hyperactivity Disorder (ADHD) and 20 non-ADHD children, statistically controlled by age, gender, academic grades and normal full scale intelligence quotient, was selected. To measure cognitive inhibitory control, a math problem solving ability test containing four problems for each level with verbal and numerical irrelevant content was administered. ADHD children exhibited significantly inferior performance in choosing correct answers ($p = 0.011$) with a large effect size ($d = 1.00$) and a significantly superior number of irrelevant answers ($p = 0.004$) with a very large effect size. In conclusion ADHD children showed a cognitive inhibitory control disorder, measured by math problem solving ability.
Keywords authors
Cognitive inhibitory control, arithmetic problem solving, ADHD.
Keywords plus
Attention Deficit Disorder with Hyperactivity, Cognitive Grammar (LC), Arithmetic, Problems, Exercises.

Resumen
Se midió el control inhibitorio cognitivo en una muestra de 10 participantes con trastorno de déficit de atención con hiperactividad (TDAH) y 20 sin TDAH, controlados estadísticamente por edad, sexo, notas del colegio y coeficiente intelectual. La medición se hizo mediante una prueba de resolución de problemas aritméticos con cuatro problemas para cada nivel, con contenido verbal y numérico irrelevante. Los niños con TDAH tuvieron muchas menos respuestas correctas y un más alto nivel de trastorno de control inhibitorio cognitivo.
Palabras clave autores
Control cognitivo, inhibitorio, resolución de problemas verbales aritméticos, TDAH.
Palabras clave descriptor
Trastorno por déficit de atención con hiperactividad, gramática cognoscitiva, aritmética, problemas, ejercicios.

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Attention deficit and hyperactivity disorder (ADHD) is a very common problem among school-aged children, and its prevalence has been estimated at 8 – 12% in the United States (American Psychiatric Association, 2000; Biederman, 2005). In Colombia the prevalence of ADHD symptoms was estimated between 16 and 22% in school children (Pineda et al., 1999). A final prevalence, using psychiatric gold standard diagnosis was calculated between 12 and 16% in children and adolescents, with a significantly different distribution by gender, where males predominated 2:1 (Cornejo et al., 2005; Pineda et al., 2003).

Neuropsychological studies have proposed that ADHD has underlain an executive function (EF) deficit associated with high variability between cases (Sengupta et al., 2008; Willcut et al., 2005). This EF deficit could explain the difficulties that ADHD children have to perform sequential, controlled and planned tasks (Sengupta et al., 2008). This deficit has been attributed to the cognitive inhibitory control (CIC) on the working memory (WM), which fails to monitor the strategies and step-by-step performance, of complex and multimodal tasks (Barkley, 1997; Passolunghi, Marzocchi & Fiorillo, 2005; Rapport et al., 2001). This hypothesis is supported by convergent data derived from neuropsychological and neuroimaging studies, which implicate inhibitory deficit related to fronto-striato-cerebellar dysfunctions in ADHD children and adolescents (Castellanos et al., 2002; Chadderdon & Sporns, 2006; Durston, 2003; Giedd et al., 2001, Willcut et al., 2005).

Because the main goal in mathematic teaching and learning is to develop the ability to resolve a variety of complex step by step organized tasks, mathematical problem solving (MPS) has special importance in the study of ADHD. It represents a very ecological approach similar to school work, where ADHD children and adolescents have the most severe difficulties (Wilson, Fernandez & Hadaway, 2007).

Arithmetic word problems (AWP) contain not only numerical information, but also literature, and narrations, which introduce more complex information to challenge the CIC, regarding irrelevant, intrusive or non-related information. Hence, AWP may contain literal and numerical information which is irrelevant to its solution but enriches it semantically (Passolunghi et al., 2005; Marzocchi, Lucangeli, De Meo, Fini & Cornoldi, 2002). As suggested above, CIC is a self-conscious kind of mental activity directed to suppress irrelevant or unnecessary information from the working memory (Barkley, 1997; Rapport et al., 2001; Wilson & Kipp, 1998). ADHD children and adolescents have EF or motivational dysregulation, which would affect the quality and the quantity of errors in problem-focused activities, especially when the problem is a collection of interfering information (Sonuga-Barke, 2002).

The CIC shows notable development effects (Nigg, 2000). Children in second grade have impaired abilities to suppress the total amount of irrelevant information of the working memory (Bray, Hersh & Turner, 1985; Bray, Justice & Zahm, 1983). In third grade, children have a partial ability to suppress the irrelevant information. By fifth grade, apparently this kind of inhibition can be accomplished successfully (Harnishfeger & Pope, 1996). For the above reasons, comparative studies need to take into account children's school achievements and ages.

Actually, some studies have found that the CIC plays an important role in the subject's success while resolving AWP. Necessarily, the CIC is used to suppress the irrelevant information, while maintaining relevant information in the WM, and while using it in step-by-step problem solving (Passolunghi et al., 2005; Marzocchi et al., 2002).

The purpose of this paper is to challenge the hypothesis that Colombian ADHD children, attending fourth and fifth grade (levels in which AWP solving is taught and children have successfully gained the ability to suppress the irrelevant information from them by using CIC, according to Harnishfeger & Pope, 1996), in Schools in the city of Medellín –capital of the Department of Antioquia– whose inhabitants have been considered in several studies as genetically isolated, have a CIC deficiency when resolving AWP, compared to peer non ADHD children. If the hypothesis is correct,

the significant variables of AWP could be used as part of neuropsychological protocol in future genetic ADHD studies.

Method

Participants

Medellin was selected to perform this study, because it has been proven by several genetic studies that the city has a population with high prevalence of ADHD when comparing it to other areas of the country (Cornejo et al., 2005; Pineda et al., 2003). Children of the fourth and fifth school levels where selected because, according to Harnishfeger and Pope (1996) AWP solving is taught at these levels and children normally have achieved the ability to suppress irrelevant information.

After a consent form was sent to the parents of 114 children, and the 50 children whose parents consented to their participation were assessed through the Checklist for parents and teachers, the WISC-III and the tests to measure skills in math and reading comprehension, a sample of 30 subjects was ultimately selected: 10 ADHD and 20 non-ADHD children, statistically controlled by age (9 to 12 years old), gender, grade level (fourth and fifth grade) and a normal full scale intelligence quotient (FSIQ), was intentionally selected (see Table 2). The Conners Rating Scale (CRS) for parents and teachers was used to select suspicious ADHD and non ADHD children of the group (Conners, 1996) which have been validated for ADHD diagnosis in Colombia (Pineda et al., 1999). All ADHD children scored over the 90 percentile (*T* score ≥ 72), which is considered by Colombian standards as a possible indication of the presence of ADHD (sensitivity 100%; specificity 97%), non ADHD children scored under the 55th percentile (*T* score = 51), (sensitivity 93%; specificity: 100%) (Pineda et al., 1999). The instrument used to verify the diagnosis was the Evaluation of Attention Deficit and Hyperactivity Disorder Scale (EADH Scale) which has a liability coefficient of 0,91, a validity of 0,93 corrected alpha and a convergent validity EDAH/DSM-IV of 0,77 (Farré & Narbona, 2003). The EDAH scale found that ADHD children obtained a percentile of 98 $\pm$ 2 considered as an indicative score for this disorder. Table 2 summarizes the scores of the variables' criteria (see Table 2).

Table 1
Demographic characteristics and intellectual capacity of the groups

Variables	NO ADHD (*N*: 20)		ADHD (*N*: 10)		Comparisons	
Gender	*n*	(%)	*n*	(%)	X^2 Statistic	*p* value
Male	18	90	8	80	0,58	0,448
Female	2	10	2	20		
Grade	*n*	(%)	*n*	(%)	X^2 Statistic	*P* value
Fourth	5	25	2	20	0,09	0,760
Fifth	15	75	8	80		
Variables	*X*	*SD*	*X*	*SD*	Statistic	*p* value
Age in years	10,10	0,6	10,6	0,8	*t:* -2,02	0,062
FSIQ	99	11,1	95	9,8	*u:* 80,0	0,378

ADHD: Attention and Hyperactivity Disorder, FSIQ: Full Scale Intelligence Quotient, *n*: Frequency, %: Percentage, *X*: Mean, *SD*: Standard Deviation, Statistic X^2: Statistic Chi Square, Statistic *U*: U of Mann-Whitney, Statistic *t*: Student T for independent samples.

Source: own work.

In order to exclude children with reading comprehension disabilities and math learning disabilities, all the children selected were within the normal range, for the compound of reading comprehension skills (Children without ADHD: Mean 104, *SD*: 20; Children with ADHD: 97, *SD*: 12), and for math skills (Children without ADHD: Mean 102, *SD*: 6; Children with ADHD: Mean 96, *SD*: 8), according to the Academic Achievement Tests of the Woodcock-Johnson III Battery (Mather & Woodcock, 2005).

Table 2
Summary of scores on the CRS for parents and teachers and EDAH Scale in the groups of children with and without ADHD

Variables	NO ADHD (*N*: 20)		ADHD (*N*: 10)		Comparisons		
	X	*SD*	*X*	*SD*	Statistic *U*	*p* value	Effect size
Checklist Parents							
Inattention	27,9	27	94,3	4,5	0,000	0,000*	3,07*
Hyperactivity-Impulsivity	27,7	26,9	94,5	4,7	0,000	0,000*	3,1*
Total Score	28	27	95	5	0,000	0,000*	2,99*
Checklist Teachers							
Inattention	22,5	26,6	97,9	2,8	0,000	0,000*	3,55*
Hyperactivity-impulsivity	22,5	26,8	97,8	2,8	0,000	0,000*	3,52*
Total Score	23	27	98	3	0,000	0,000*	3,23*
EDAH	39	24	98	2	0,000	0,000*	2,98*

TDAH: Attention Deficit/Hyperactivity Disorder, *X*: Mean, *SD*: Standard Deviation, EDAH: Evaluation of Attention Deficit and Hyperactivity Disorder Scale, *U*: U of Mann-Whitney, *: Large effect size and $p < 0.01$ statistical significance.

Source: own work.

Materials

We used a number instruments in order to collect data. The Math Problem Solution Ability Test, SPM was specially created to measure inhibitory control in math problems solution. It presents four problems per school level, each containing verbal and numerical irrelevant content (see Annex A for an example).

In order to screen target children for the presence of ADHD, and to find out whether further assessment was needed, we used the Checklist for parents and Children has items based on the DSM-IV (Diagnostic and Statistical Manual of Mental Disorders) for the diagnosis of children with ADHD (Attention Deficit and Hyperactivity Disorder). Teachers completed the EDAH Scale (Evaluation of Attention Deficit and Hyperactivity Disorder Scale), which is a questionnaire used to diagnose the presence of ADHD in children.

Two compound skills indexes were also used: the Compound of Skills in Math of the Academic Achievement Tests of the Woodcock-Johnson III Battery (Mather & Woodcock, 2005), comprised of the results of the Arithmetic and Math fluency tests, applied to children to determine whether or not they have math skills according to their ages; and the Compound of Skills in Reading Comprehension of the same battery (Mather & Woodcock, 2005), comprised of the results of the tests: Text' comprehension and Reading vocabulary, they are applied to children to determine whether or not their reading comprehension skills there are appropriate for their age. The Wechsler Intelligence Scale for Children (WISC-III) was used to measure the IQ of children.

Procedures

The 30 children were assessed using the SPM. It was verified that the two groups had no statistical differences between them. Data was analyzed using SPSS version 15.0, the statistics used were to compare frequencies between the two groups and Chi Square statistic was used, an U of Mann-Whitney for non-normal distribution of the data

and Student's *t* for normal distribution of the data. The effect size was also used for comparison of the variables. A significance level of 0.05 was used as the alpha to control type I error in the study, with a confidence level of 95 %.

Results

When comparing the math problem solving performance of the groups of children with and without ADHD, it was possible to reject the null hypothesis for the following variables:

The ability to choose the image which best represents the problem, namely the ability to represent. Was observed in a mean percentile of 38 (*SD* = 33) in children without ADHD, and a mean percentile of 20 (*SD* = 25) in the children with ADHD, suggesting a significant statistic difference between them ($p = 0.049$), with a medium Cohen d effect size ($d = 0.61$). Neither group of children reached the expected mean percentile (50, *SD* = 10).

Categorization was observed in a mean percentile of 46 (*SD* = 27) for the children without ADHD and of 18 (*SD* = 18) for the children with ADHD, showing a significant statistic difference between them ($p = 0.009$), with a very large effect size ($d = 1.22$). It was not possible to reject the null hypothesis for the remaining variables, meaning the results obtained are statistically similar (See Table 3).

The children without ADHD attained a mean of correct answers of 7 (*SD* = 3), while the children with ADHD only reached a mean of correct answers of 4 (*SD* = 3), showing a statistically significant difference between them ($p = 0.011$), and a large effect size ($d = 1.00$). Finally, the group of children without ADHD obtained a mean of 1 (*SD* = 1) of irrelevant answers, in comparison with the group of children with ADHD which obtained a mean of 3 (*SD*: 2) showing a statistically significant difference between them ($p = 0.004$) and a very large effect size ($d = 1.26$).

It was not possible to reject the null hypothesis for the rest of the variables, therefore, the results were not conclusive for them (See Table 4).

Discussion

The main finding of this study is a significantly lower performance when choosing correct an-

Table 3
Math problem solving performance of children with and without ADHD

	Problem Solving						
Variables (Percentiles)	**NO ADHD (*N*: 20)**		**ADHD (*N*:10)**		**Comparisons**		
	X	*(SD)*	*X*	*(SD)*	***U* Statistic**	***p* value**	**Effect size**
Comprehension	42	29	36	31	78,0	0,325	0,20
Representation	38	33	20	25	59,0	0,049*	0,61*
Categorization	46	27	18	18	43,5	0,009**	1,22**
Solution Strategy	36	21	36	23	99,0	0,964	0,00
Operative solution	11	3	10	0	90,0	0,309	0,47
Self-evaluation	42	28	44	21	91,5	0,694	0,08

ADHD: Attention Deficit and Hyperactivity Disorder, X: Mean, *SD*: Standard Deviation, *U*: U of Mann-Whitney, *: Medium effect size and $p < 0.05$ statistical significance, **: Very large effect size and $p < 0.01$ statistical significance.

Source: own work.

Table 4
Results from the math problem solving performance test for children with and without ADHD

Variables (Number)	Cognitive inhibitory control						
	NO ADHD (*N*: 20)		ADHD (*N*: 10)		Comparison		
	X	*(SD)*	*X*	*(SD)*	Effect size	*U* Statistic	*p* value
Correct Answers	7	3	4	3	1,00*	42,5	0,011*
Partial Answers	2	1	2	2	0,00	98,5	0,946
Wrong Answers	2	1	3	2	0,63	72,5	0,213
Irrelevant Answers	1	1	3	2	1,26**	38,0	0,004**

ADHD: Attention Deficit and Hyperactivity Disorder, *X*: Mean, *SD*: Standard Deviation, *U* of Mann-Whitney, *: Large effect size and $p < 0.02$ statistical significance, **: Very large effect size and $p < 0.01$ statistical significance.

Source: own work.

swers ($p = 0.011$) with a large effect size ($d = 1.00$), which means that the data obtained did not overlap by 55.4%, besides, children with ADHD obtained a significantly higher number of irrelevant answers ($p = 0.004$) with a very large effect size, indicating that the data did not overlap in 65.3%. These findings replicate the ones obtained by Marzocchi et al. (2002) and Passolunghi et al. (2005). This data was obtained based on the number of correct, partial, incorrect and irrelevant answers chosen by the children in solving the problems presented to them.

Many authors state that cognitive inhibitory control is the process through which unnecessary or irrelevant information is suppressed, and consequently it has relevance to the solution of a problem (Aaron, 2007; Everett & Lajeunesse, 2000; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000; Roselli, Ardila, Pineda & Lopera, 1997; Wilson & Kipp, 1998; Witzki & Howerter, 2000). Generally neuro-anatomically, the source of control is associated with the prefrontal cortex (PFC), and the control target with the posterior cortical and sub-cortical regions (Aaron, 2007). Examples of neuro-anatomical connections between region or process sources, which have an active inhibitory effect over a region or process target, are: 1) The fronto-thalamic circuit, where the prefrontal cortex inputs into the reticular nucleus and the latter sends GABAergics to the thalamus, actively inhibiting the thalamic cells and potentially limiting information input; 2) The frontostriatal or fronto-subthalamic circuit; and 3) The front-amygdalin circuit, where the fronto-medial inputs to the amygdale excite the GABAergic cells, which suppress amygdaline activity (Amaral & Price, 1984; Quirk et al., cited by Aaron, 2007).

Not all the authors are in favor to the application of the term "inhibition" to cognitive control. One initial objection is that it is considered absurd that PFC should actively suppress the multiple cortical and sub-cortical focuses during the hours the human being is awake. Instead, it is considered more logic that the human being simply expands the relevant information through the top-down base of the sensorial areas (Miller & D'Esposito, 2005; Miller & Cohen, 2001; Hillyard & Anllo-Vento, 1998 cited by Aaron, 2007). A second objection questions the explicative usefulness of the inhibition inferred from the effects of injuries in the performance of subjects (Gregory, 1961; Kimberg & Farah, 1993; Morton & Munakata; 2002 cited by Aaron, 2007). However, as mentioned before, there are circuits that have been observed through functional magnetic resonance, which play a role in inhibitory function as a process

which contradicts the objections expressed by the authors (Amaral & Price, 1984; Quirk et. al., cited by Aaron 2007).

This pilot study provides support to the hypothesis that one of the main problems in children with ADHD (included the difficulties to solve a mathematic problem) lies in a lack of cognitive inhibitory control reflected by the high number of irrelevant answers given by these children.

Evidence that supports the previous assertions exist, obtained through rapid event functional magnetic resonance, that there is an alteration in the neuro-anatomic substrate of cognitive control in children with ADHD, which shows a reduction in the frontal-striate-temporal-parietal connections, failure in the activation of the prefrontal cortex and the caudate nucleus, reduced magnitude and extension in the activation of frontal and left pre-motor regions, absence of frontal-right activation which is associated to an appropriated inhibitory answer and a weak activation of the right insula instead (Vahadilla, Bunge, Dudukovic, Zalecki, Elliott & Gariela, 2005); findings that have been supported by other research that equally show atypical frontal connections in children with ADHD (Durston et. al., 2003; Shweitzer et. al.. 2000; Bush et. al., 1999; Vaidya et. al. 1998).

For Barkley (1999) the main problem of children with ADHD does not lie in cognitive inhibitory control but in behavioral inhibitory control. Barkley (1999) considers that the problem in children with ADHD its purely behavioral, so he does not consider the possible existence of dysfunction of cognitive inhibitory control; but there are researchers that have proven otherwise and support the existence of alterations on it (Passolunghi et al., 2005; Vahadilla, Bunge, Dudokovic, Zalecki, Elliot & Gabriela, 2005; Durston et al., 2003; Marzocchi et al., 2002; Shweitzer et. al., 2000; Bush et. al., 1999; Rubia et. al. 1999; Vaidya et. al., 1998).

The test for mathematic problem solving ability (MPS test) (Lucangeli, Tressoldi & Cendron, 1998) controls comprehension, categorization, representation, operative solution, choosing of a solution strategy and self-evaluation; those are variables immersed in the dimensions of executive functioning (EF), except for the representation which is not a variable of EF but it is an important step within the math problem solution. Of the previously mentioned variables, altered ability of representation ($p = 0.049$) was altered, although with a medium effect size ($d = 0.61$), indicating a non - overlapping of data in 38.2%. Categorization was also altered ($p = 0.009$) with a very large effect size ($d = 1.22$), which means that data was not overlapped in 62.2%. The alteration of the ability of representation and categorization in children with ADHD has been shown in other studies (Chelune, Ferguson, Koon & Dickey, 1986; Gorenstein, Mammatto & Sandy, 1989; Renz, Pugzles, Milich, Lemberger, Bodner & Welsh, 2003; Shue & Douglas, 1992). The prefrontal cortex is the anatomical substrate of executive functions (Slachevsky, Pérez, Silva, Orellana, Prenafeta, Alegría & Peña, 2005); neuro-anatomically, particularities which explain difficulties in executive functioning in children with ADHD have also been found, such as morphological changes demonstrable in neuro-imaging, in the prefrontal cortex (usually on the right side), basal ganglia, cgulate gyrus, corpus callosum, and cerebellum. At functional level, studies like PET and SPECT, have shown a reduction of metabolism of glucose in the right prefrontal cortex and a reduction of blood supply to the striatum and the motor cortical areas (Velez, et al. 2004).

It is important to emphasize that because cognitive inhibitory control is part of the executive functions (Aaron, 2007; Nigg, 2000) it is not surprising that the anomalies observed neuro-anatomically and neuro-functionally in children with ADHD in the performance of tasks which demand particular cognitive inhibitory control or other tasks which measure different dimensions of the executive function are similar or even equal, because they share the same neuro-anatomical substrate in the prefrontal cortex in relationship with other sub-cortical areas (Aaron, 2007). According to Barkley (1997) the executive functions are centered in behavioral self-regulation, hence, cognitive inhibitory control is not considered as part of them. However, once again, this is due to

the theoretical position of Barkley (1997), who does not agree with their existence.

The variables deriving from the MPS test (Lucangeli et al., 1998) could be used to measure specific features of the executive function and could also have certain specificity and sensibility to the diagnosis of ADHD. The following could be said for the effect size founded for each variable: Choosing correct answers (d = 1.00) could have a possible specificity and sensibility of 84 to distinguish between children without and with ADHD (Cohen, 1988). Choosing irrelevant answers (d = 1.26) could have a possible specificity and sensibility of 90. Representation (d =: 0.61) could have a possible specificity and sensibility of 73, and Categorization (d = 1.22) could have a possible specificity and sensibility of 88. This could be determined if the test becomes validated.

There are two problematic elements in this study: 1) the variability of the data, and 2) that none of the children reached the expected mean for the variables measured by the test used (Mean = 50, SD = 10). This may be so because the mean used was derived from Italian population, which has different cultural and education characteristics, factors that have been established as influential in the solution of a mathematic problem (Puente, 1993). However, in the present study the impact of those factors has been reduced because the same standardized scoring was used for both children with and without ADHD.

Likewise, having established the influence of low IQ, arithmetic learning disorder and specific reading disorder, in the ability to solve a mathematic problem (Passolunghi et al., 2005; Marzocchi et al., 2002), these disorders have also been deemed possible comorbidities of ADHD. However, those factors were controlled by the design of the research, ensuring that none of the children included in the study had a previous diagnosis of those disorders, and it was also corroborated with the application of the WISC-III and the Academic Achievement Tests of the Woodcock-Johnson III Battery (Mather & Woodcock, 2005).

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