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Executive Functions and High Intellectual Capacity in School-Age: Completely Overlap?

Funciones ejecutivas y alta capacidad intelectual en niños en edad escolar: ¿se superponen por completo?

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Abstract:
Objective: To analyze the relationship between the dimensions of the executive function and intellectual capacity in children with high academic performance. Method: an analytical, observational, prospective study with a non-random sample of 104 children between 7 and 11 years of age, belonging to educational institutions in Medellín, Colombia, divided into groups according to the measure of Total Intellectual Capacity (TIC): 1. Those with an average TIC of between 85-115. 2. Children with higher IC or those with scores ranging from 116-129 and 3. Children with TIC of ≥ 130, known as exceptional talents. They are provided executive function tests that are in compliance with bioethical conditions. Results and conclusions: The Intellectual Capacity is not a concept analogous or synonymous to executive function. This study demonstrates that the common element among all participants is high academic performance and an absence of alteration of the executive function. Finally, an adequate executive functioning makes high academic performance possible.

Resumen
Objetivo: Analizar la relación entre las dimensiones de la función ejecutiva y capacidad intelectual en niños escolarizados con alto rendimiento académico. Método: investigación de tipo analítica, observacional, prospectiva, con muestra no aleatoria de 104 niños entre los 7 y 11 años de edad pertenecientes a instituciones educativas de Medellín-Colombia, dividida en tres grupos de acuerdo con la medida de Capacidad Intelectual Total (CIT). 1. Aquellos con CIT promedio entre 85-115. 2. Niños con CI superior; puntuaciones entre 116-129 y 3. Niños con un CIT ≥ 130; talentos excepcionales. Se les suministro pruebas de función ejecutiva con cumplimiento de condiciones bioéticas. Resultados y conclusiones: La Capacidad Intelectual no es concepto análogo ni sinónimo de función ejecutiva. Este estudio demostró que el elemento común entre todos los participantes es un alto rendimiento académico y una ausencia de alteración de la función ejecutiva. Finalmente, un adecuado funcionamiento ejecutivo posibilita un alto rendimiento académico.

Palabras claves:
capacidad intelectual, función ejecutiva, rendimiento académico.

Key words:
intellectual capacity, executive function, academic performance.

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Introduction

Neuropsychology proposes the study of the cognitive components that affect human beings. It offers the explanation as to how they solve problems, set goals, and control their behavior—elements that have been conceptualized under the terms of intellectual capacity and executive function.

The construct of Intellectual Capacity (IC), as a measure of intelligence, is perhaps one of the most addressed and studied subjects in the field of psychology due to the complexity of defining it—giving rise to numerous theories and models. Traditional psychometrics has constructed a composite and standardized IC score derived from the intelligence measurement scales. This measurement is referred to as Intellectual Quotient (IQ) and is defined by Thurstone (1947) as the psychometric representation of what is known as the g factor. Neuropsychology— the discipline that establishes the relationship between brain and behavior—has taken on the task of developing research works aimed at explaining cognitive and behavioral phenomena based on models of multiple factors or dimensions (Ardila, & Ostrosky, 2012; Carroll, 1993; Cattell, 1963; Guilford, 1985; Spearman, 1923; Thurstone, 1947.)

From the cognitive neuropsychological perspective, the concept of intellectual capacity is assumed as a construct that is part of the measure of intelligence and is composed of different factors that integrate our ability to understand complex ideas, reason, make use of experience to solve problems, and adapt to our environment, as. Moreover, it apparently uses the frontoparietal network, as well as the cognitive construct: executive function (Duggan & Garcia-Barrera, 2015). In this sense, there exist models like that of Cattell (1963) that divides the psychometric *g* factor into fluid and crystallized intelligence, thereby serving as basis for other works, such as the third edition of the Wechsler Intelligence Scale; the Carroll model (1994), that consists of three strata: primary abilities, broad abilities, and general intellectual ability; and the theoretical and speculative integration model, which explains the possible dissociation between executive functioning and intelligence (Duggan & Garcia-Barrera, 2015).

From the factorial model, executive functions (EFs) have also been understood as a construct of multiple dimensions or factors. This term is defined as the ability to make association of ideas, movements, and actions aimed at solving novel problems by generating predictions or anticipations of consequences, as well as imagined solutions (Pineda, Merchán, Rosselli, & Ardila, 2000; Tirapu-Ustárroz, Muñoz-Céspedes, & Pelegrín-Valero, 2002; Tirapu-Ustárroz, Cordero-Andrés, Luna-Lario, & Hernáez-Goñi, 2017). These functions go through sequential development throughout childhood and adolescence, becoming more intense during childhood, under the increasing complexity model (Anderson, 2001; Kerr & Zelazo, 2004). This model proposes that, during childhood development, each subdimension of the EFs evolve at its own pace to create a functional integration that accounts for a progressively more complex system. (Zelazo, Mulller, Frye, & Marcovitch, 2003; Best & Miller, 2010; Flores Lázaro & Ostrosky-Shejet, 2012; Flores-Lázaro, Castillo-Preciado, & Jiménez-Miramonte, 2014).

So far, research on the correlation between these two constructs of human cognition are few, and most were just focused on pathological or traumatic phenomena (Damasio & Anderson, 1993; Mahone et al., 2002) and only some of them address this correlation in healthy children and adolescents (Ardila, Pineda, & Rosselli, 2000; Arffa, Lovell, Podell, & Goldberg, 1998; Arffa, 2007; Friedman et al., 2006; Welsh, Pennington, & Grossier, 1991; Montoya-Arenas, Trujillo-Orrego, & Pineda-Salazar, 2010; Arán Filippetti, 2011; Arán Filippetti, Krumm, & Raimondi, 2015; Monette, Bigras, & Lafrenière, 2015).

The purpose of this study is to thus determine whether high academic performance is dependent on intellectual capacity or executive functions, given that in the last decades, much of cognitive neuroscience's research has focused on explaining the functions of the prefrontal cortex—described as a high order of human cognition. (Milner, 1982; Donders & Kirsch, 1991; Ardila et al., 2000; Friedman et al., 2006; Arffa, 2007; O'Reilly, 2010; Verdejo-García & Bechara, 2010; Stuss, 2011; Flores Lázaro, Tinajero Carrasco, & Castro Ruiz, 2011; Schmidt, Burge, Visscher, & Ross, 2016).

Children with high academic performance are regarded by the public and private educational community of Medellín as children with superior intelligence. This status, however, has to be validated through a neuropsychological assessment that certifies cognitive functioning and demonstrates an above-average intellectual capacity.

In order to avoid influence of confounding variables, this research was conducted on samples of narrow-range age groups (7 to 11 years old), which implies a similar pace of executive function development. The influence of gender, schooling, and socioeconomic stratum was controlled.

For the development of this study, a hypothetical model was postulated, one which supposes the existence of a concept with multiple dimensions called IC (Carroll, 1993), composed of abilities classified into three strata corresponding to three different levels of intelligence's generality. The model visualizes: in stratum I, a series of specific factors; in stratum II, fluid intelligence, crystallized intelligence, general memory and learning, visual and auditory perception, cognitive speediness, processing/decision-making speed; and, in stratum III, the general factor (*g*) of intelligence. All these elements will be measured using the Wechsler Intelligence Scale for Children (WISC-III), which is consistent with this theory due to its factorial and psychometric nature.

This study also proposes the existence of a different construct of multiple dimensions known as EFs. In this regard, Stuss (1992) assumes that the functions of the prefrontal cortex make up a system with independent but interactive hierarchical functions. This model, just like IC, is composed of three dimensions: the first one corresponds to the sensory and perceptual system; the second one, to the executive control or the function of supervision of the frontal lobes, which, in turn, consists of specific sub-functions (anticipation, selection of objectives, and preparation of plans); and the third one, to the levels of self-consciousness and self-reflection. The instruments used for measuring these elements were: The Wisconsin Card Sorting Test, the Verbal Fluency Test, the Stroop Color and Word test, the Tower of Hanoi, and the Ruff Figural Fluency test.

Lastly, the existence of three constructs is proposed: The first one is known as talented or gifted children, that is, children with the *capacity for a very superior performance in any socially valuable area of human behavior* (Passow, 1993). This study will be conducted with children with very superior IC according to the WISC-III, that is, with scores greater than or equal to 130. The second construct is composed of children with superior intelligence, with scores between 116 and 129, also called "specific talents" in the Colombian educational context. The third one consists of children with average intelligence, scoring between 85 and 115 (Wechsler, 1997). It is also worth noting that none of the children evaluated present cognitive alterations or psychopathological disorders.

Method

An analytical, observational, cross-sectional study of children aged between 7 to 11 years, residing in the city of Medellín (Colombia), with average intelligence, superior intelligence, and very superior intelligence, conducted with the purpose of determining the relationship between the dimensions of intellectual capacity and executive function in children with high academic performance.

Participants

The research was developed with children with average, superior, and very superior intelligence; aged 7 to 11 years; residing in the city of Medellín (Colombia); and who exhibited high academic performance.

Academic performance has been defined as the ability of a student to meet the requirements of an academic program (Stelzer & Cervigni, 2011) or, as proposed by Garbanzo (2007), "the sum of different and complex factors that act on the person who learns, and has been defined with a score attributed to the student's achievement in the academic tasks" (p. 46). Therefore, the children were selected by their teachers based on this criterion, as well as on a cumulative grade point average greater than or equal to 4.5/5.0, and an interview semi-structured for school-aged children or adolescents (Sattler, 2003).

The sample size was calculated assuming a correlation coefficient of 0.25, with a power of 80% and a confidence of 95%. There were a total of 96 participants in the sample, an amount that was subsequently increased by 10% to cushion possible losses, bringing the final sample size to 106 participants. The study followed the Convenience Sampling Technique and included 32 children with very superior capacity (talented children), 29 children with high or superior intelligence, and 43 children with average intellectual capacity—all of them from medium and high socioeconomic strata and belonging to four private educational institutions in the city of Medellín.

The instruments used for the evaluation of the IQ and the EFs were the following:

The Wechsler Intelligence Scale for Children—Third Edition (WISC-III). Spanish version adapted by Castillo (Wechsler, 1997). This test is essential in finding out how subjects process information and determine the non-cognitive variables that influence their performance. It is organized into Verbal and Performance scales, which, in turn, are divided into subscales. The first scale is composed of vocabulary, arithmetic, similarities, information, and comprehension; the second consists of picture completion, coding, object assembly, block design, and story arrangement. In addition, it contains some complementary subtests: symbol search, digit span, and mazes.

This test aims to assess the IC of children aged 6 to 16 years and 11 months, and can provide scale scores, intelligence quotients (FSIQ, VIQ, PIQ), and index scores (VC, PO, PS, and FFD) by age. The instrument is applied individually. The ten central subtests take from 50 to 70 minutes to administer, and the three complementary subtests, from 10 to 15 minutes.

The WISC-III was the latest edition available at the time of the study, which had standardization studies on the Latin American population, showing correspondence and internal consistency with the original American test (Ramírez & Rosas, 2007).

The Wisconsin Card Sorting Test (WCST). This tool was created by Grant and Berg (1948) to assess human capacity for abstract reasoning and the ability to change cognitive strategies in response to eventual environmental modifications—competencies associated with the functioning of the dorsolateral prefrontal area of the human brain. This is considered as the most widely used test in the neuropsychological field for the evaluation of the EFs (Ardila, Rosselli, & Puente, 1994; Denckla, 1996; Harris, 1995; Stuss & Benson, 1986). This test is applicable to anyone from the age of 6 years and 6 months to 89 years old. It is, however, worth noting that there are still only a few normative studies conducted that cover an ample population of children as samples.

The Verbal Fluency Test. Phonetic (/f/, /a/, /s/) and semantic (animals and fruits). This test is measured by the number of words produced for each category in one minute, is considered a test of controlled and programmed verbal production, and is sensitive to alterations in the functioning of the left prefrontal areas (Ardila et al., 1994). This test has standardized scores for Latin American children (Ardila et al., 1994; Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejía, 1998).

The Ruff Figural Fluency Test (RFFT). This test is a non-verbal fluency test analogous to the FAS test. It is divided into five different tasks and commonly consists of a sheet divided into 35 squares with five dots inside each of them. In the first part, the dots are symmetrically distributed. This test provides several measures: number of trials, number of unique designs, errors (poorly developed designs), and perseverative errors (repeated valid designs) (Lezak, 1995).

The Stroop Word-Color Conflict Test. This test is used to evaluate the anterior area of the cingulum since it assesses the selective attention, that is, the capacity to inhibit an automated behavior so as to give room to another, in response to the change of contextual codes. It is a test that sorts people with frontal damage from people in normal conditions (Golden, 1981; Harris, 1995).

Tower of Hanoi. This method is a measure of organization, cognitive flexibility, operational memory, planning and anticipation of behaviors, and visual and spatial programming of a sequence of movements. It has different versions, but all of which use rings of various colors and sizes and have the same objective, that is, moving the pieces from the left peg to the right, one by one, until reproducing the model represented graphically, taking into account the following rules: only one disk can be taken at a time and it has to be moved to another peg; when a disk is placed on top of another, the disk on top must be smaller than the one below. The tower should be completed by making as few moves as possible. The test considers time, number of moves, and type of errors (Álvarez, 2006; Emick & Welsh, 2005).

Procedure

For the development of this research, several educational institutions in Medellín and other organizations that support the Department of Education in providing services to the population with special educational needs—specifically to talented children—were contacted for the purpose of requesting access to databases of the population that demonstrated high academic performance, average intelligence, or exceptional ability, all of which with no medical history of developmental or neuropsychiatric disorders.

Once access to the databases was obtained, 153 children between 7 to 11 years of age were invited to participate. The participants signed the informed consent and assent with the approval of their parents and their institutions—which provided the facilities for the application of the instruments—upon accepting participation in the research. The project was supported by the Bioethics Committee of the Universidad de San Buenaventura.

The evaluation procedure consisted of two initial sessions, during which the WISC-III was administered to all the participants, followed by an interview to filter the population according to the inclusion and exclusion criteria of the project. Subsequently, with the obtained data, a sample of 104 children was selected: 43 with average intellectual capacity, 29 with superior intellectual capacity, and 32 with very superior intellectual capacity. The proportion of subjects was consistent with the calculation of the initial sample. The subjects selected were then invited to a third session in which they were assigned the tasks of executive functions.

Statistical Analysis

The study sample was described according to demographic characteristics, through the calculation of the absolute and relative frequency for the qualitative variables such as gender and stratum, and for the quantitative variables such as age and schooling, as well as for the results of the intellectual capacity and executive function tests. The mean and the standard deviation were also calculated. The average, superior, and very superior intelligence groups were compared by using a Kruskal-Wallis nonparametric ANOVA. The Spearman's correlation coefficient was calculated between the dimensions of the IC and those of the EFs for each study group. $\alpha < 0.05$ was assumed as the level of statistical significance. Data were processed using the SPSS statistical package, version 20.

Results

The study population consisted of 104 children with high academic performance, distributed into three groups: The first was composed of 43 children (58.1% boys and 41.9% girls), of which 37% belonged to the middle socioeconomic stratum and 62%, to the high socioeconomic stratum. The intellectual capacity of this group is in the average range, the average age is 9 years, and the average schooling is 3.2. The second group consisted of 29 children (41.4% boys and 58.6 girls), 27% of them belonged to the middle socioeconomic stratum and 72%, to the high socioeconomic stratum. The average intellectual capacity is 122 (superior range), the average age is 9 years, and the average schooling is 3. The third group, with 32 subjects (50% boys and 50% girls), displayed very superior intelligence, has an average age of 9.1 and a schooling of 3.5. 40% of the children in this group belonged to the middle socioeconomic stratum and 59.4% to the high.

Table 1.
Demographic characteristics of school-aged children with average, superior, and very superior intelligence in the city of Medellín, Colombia.

	Average Intelligence 85-115 N: 43		Superior Intelligence 116-129 N: 29		Very Superior Intelligence 130 ≥ N: 32			
Variables	Mean	SD	Mean	SD	Mean	SD	Statistic[1]	*p*-value
Age	9	1,3	9,2	1,3	9,1	1,3	F: 0,18; df1:2;df2:101	0,831
Schooling	3,2	1,4	3	1,4	3,5	1,3	F:0.97; df1:2; df2: 101	0.382
Gender frequency (%)							2,0;df:2	0,375
Male	25	(58)	12	(41,4)	16	(50)		
Female	18	(41,9)	17	(58,6)	16	(50)		
Stratum frequency (%)							1,2 df:2	0,545
Medium	16	(37,2)	8	(27,6)	13	(40,6)		
High	27	(62,8)	21	(72,4)	19	(59,4)		

1. ANOVA F-test for the quantitative variables and Chi-square test for the qualitative ones.
* N: Sample size.

Table 1 shows the distribution of the sample based on the performance in the measure of intellectual capacity in school-aged children of Medellín.

Table 2.
Intellectual capacity of school-aged children in the city of Medellín.

	Average Intelligence 85-115 N: 43		Superior Intelligence 116-129 N: 29		Very Superior Intelligence 130 ≥ N: 32	
Intellectual Capacity	Mean	SD	Mean	SD	Mean	SD
General intelligence (TIQ)	104,5	6,7	122,3	4	138,6	7,3
Crystallized intelligence (VIQ)	107,4	11,6	121,4	6,1	135,3	8,8
Fluid intelligence (PIQ)	101	8,3	119,4	9	135,8	9,7
Verbal comprehension	109	13	119,6	23,1	136,8	10,6
Perceptual organization	101	11	119,5	12	135,8	9,8
Freedom from distractibility	103,5	18,4	113,4	12	121,9	14,2
Processing speed	105	17	110,2	16,6	114,8	18

N: Sample size. SD: Standard Deviation

Table 2 describes and compares the performance in executive-function tasks of school-aged children of Medellín with high academic performance and average, superior, or very superior intelligence. Significant differences ($p<0.05$) were found in phonemic and semantic FAS.

Table 3.
Executive functions in children with high academic performance.

	Average Intelligence 85-115 N: 43		Superior Intelligence 116-129 N: 29		Very Superior Intelligence 130 ≥ N: 32		
Executive Function	Mean	SD	Mean	SD	Mean	SD	*p*-value
Planning (p)							
WCST Perseverative errors	9,7	10,6	5,3	7,2	7,4	6,1	0.310
Tower of Hanoi Moves	29,6	15,8	28,9	12,2	30	18,5	0,957
Cognitive flexibility (CF)							
WCST Categories	5,3	1,2	5,8	0,5	5,5	0,9	0,126
WCST Percentage of perseverative errors	8,2	8	4,6	5,7	6,5	4,5	0,081
Tower of Hanoi Moves	29,6	15,8	28,9	12,2	30	18,5	0,957
STROOP Word-Color	47	7,8	47,5	5,2	51,5	13,6	0,116
Inhibitory Control (IC)							
STROOP Word-Color	47	7,8	47,5	5,2	51,5	13,6	0,116
Fluency (F)							
Phonemic FAS	17,6	6,4	22,5	20,6	22,4	8,6	0,014*
Semantic FAS	25,1	5,8	29	7,7	29,8	6,3	0,005*
Ruff Figural Fluency	50,4	21	60,1	19,3	61,9	28,5	0.070
Working Memory (WM)							
Tower of Hanoi Moves	29,6	15,8	28,9	12,2	30	18,5	0,957
Ruff Figural Fluency	50,4	21	60,1	19,3	61,9	28,5	0.070
Attention							
WCST Failures in keeping the principle	1,1	1,6	0,6	1	0,8	1,3	0,356
STROOP Color	76,9	10,8	81,4	14,7	79	11,5	0,297
STROOP Word-Color	47	7,8	47,5	5,2	51,5	13,6	0,116
Abstract Reasoning (AR)							
WCST Categories	5,3	1,2	5,8	0,5	5,5	0,9	0,126
WCST Percentage of responses of the conceptual level	67,3	14	73,7	12,4	68,3	14	0,144
Processing Speed (PS)							
STROOP Word	116,3	12,5	119,2	12,7	117	11,4	0,622
STROOP Color	76,9	10,8	81,4	14,7	79	11,5	0,297
Tower of Hanoi Time	218,3	155,5	181,6	120,1	161	118,4	0,189

SD: Standard Deviation

In addition, the level of correlation between the performance in the intellectual capacity and the executive function was evaluated in each group. In the case of children with average intelligence, significant correlations were found among *executive functioning* dimensions (attention, cognitive flexibility, fluency, inhibitory control, planning, and processing speed) and *general intellectual capacity, crystallized and fluid intelligence*.

Table 4.
Correlation between the measure of intellectual capacity and executive function in school-aged children with high academic performance and average intelligence. Medellín, Colombia.

	Average Intelligence (85-115) N=43						
Executive Functions	TIQ	VIQ	PIQ	VCI	POI	FFDI	PSI
Planning (p)							
WCST Perseverative errors	-,165	,032	-,294	,049	**-,361***	**-,337***	-,008
Tower of Hanoi Moves	,052	,021	,042	-,022	,169	,065	-,214
Cognitive flexibility (CF)							
WCST Categories	,234	,018	,217	-,005	,183	**,330***	,114
WCST Perseverative responses	-,135	,053	**-,276**	**,071**	**-,340***	**-,349***	-,007
WCST Percentage of perseverative responses	-,158	,044	**-,305***	**,059**	**-,365***	**-,330***	-,029
Tower of Hanoi Moves	,052	,021	,042	-,022	,169	,065	-,214
STROOP Word-Color	-,131	-,273	,189	**-,321***	,189	,08	,199
Inhibitory Control (IC)							
STROOP Word-Color	-,131	-,273	,189	**-,321***	,189	,08	,199
Fluency (F)							
Phonemic FAS	-,035	,194	-,13	-,248	-,018	,66	-,004
Semantic FAS	,29	**,352***	-,005	**,331***	,03	,038	,044
Ruff Figural Fluency	-,057	,067	-,172	,07	-,239	,145	,152
Working Memory (WM)							
Tower of Hanoi Moves	,052	,021	,042	-,022	,169	,065	-,214
Ruff Figural Fluency	-,057	,067	-,172	,07	-,239	,145	,152
Attention							
WCST Failures in keeping the principle	**-,415****	**-,320***	-,111	-,269	-,059	-,23	-,009
STROOP Color	-,188	-,149	-,114	-,088	-,187	-,073	,214
STROOP Word-Color	-,131	-,273	,189	**-,321***	,189	,08	,199
Abstract Reasoning (AR)							
WCST Categories	,234	,018	,217	-,005	,183	**,330***	,114
WCST Percentage of responses of the conceptual level	,080	,020	,167	-,019	,265	,293	,002
Processing Speed (PS)							
STROOP Word	-,128	-,063	-,104	-,095	-,232	,151	**,412****
STROOP Color	-,188	-,149	-,114	-,088	-,187	-,073	,214
Tower of Hanoi Time	-,072	-,031	-,090	,073	,026	-,282	**-,345***

N: Sample size. TIQ: General intelligence. VIQ: Crystallized intelligence. PIQ: Fluid intelligence. VCI: Verbal comprehension. POI: Perceptual organization. FFDI: Freedom from distractibility. PSI: Processing speed.
*The correlation is significant.
Spearman's correlation coefficient.

As for the group composed of children with superior intelligence, the measure of general intellectual capacity correlated statistically with the measure of cognitive flexibility, attention, and abstract reasoning; the *crystallized intellectual capacity* correlated with planning, abstract reasoning, and processing speed; and the *fluid intelligence*, with attention. As regards the subdimensions of the *measure of IC*, verbal comprehension in children with superior intelligence correlated strongly with planning, cognitive flexibility, abstract reasoning, and processing speed.

Table 5.
Correlation between the measure of intellectual capacity and executive function in school-aged children with high academic performance and superior intelligence. Medellín, Colombia.

	Superior Intelligence (116-129) N:29						
Executive Functions	TIQ	VIQ	PIQ	VCI	POI	FFDI	PSI
Planning (p)							
WCST Perseverative errors	,171	**,435***	-,203	**,474****	-,091	-,237	-,245
Tower of Hanoi Moves	,009	,119	-,082	,122	-,152	-,100	,161
Cognitive flexibility (CF)							
WCST Categories	**-,408***	-,337	-,136	-,349	-,310	,250	,362
WCST Perseverative responses	,178	**,433***	-,199	**,461***	-,081	-,231	-,239
WCST Percentage of perseverative responses	,161	**,435***	-,211	**,479****	-,091	-,228	-,267
Tower of Hanoi Moves	,009	,119	-,082	,122	-,152	-,100	,161
STROOP Word-Color	-,141	-,171	,031	-,170	-,035	,125	,238
Inhibitory Control (IC)							
STROOP Word-Color	-,141	-,171	,031	-,170	-,035	,125	,238
Fluency (F)							
Phonemic FAS	-,306	-,155	-,180	-,007	-,147	,025	,104
Semantic FAS	-,025	-,131	,017	-,050	,193	-,029	-,303
Ruff Figural Fluency	-,077	-,081	,000	-,058	-,069	-,077	,252
Working Memory (WM)							
Tower of Hanoi Moves	,009	,119	-,082	,122	-,152	-,100	,161
Ruff Figural Fluency	-,077	-,081	,000	-,058	-,069	-,077	,252
Attention							
WCST Failures in keeping the principle	**,519****	**,043**	**,375***	,096	,264	-,275	,135
STROOP Color	,070	-,176	,235	,145	,126	**-,473****	,082
STROOP Word-Color	-,141	-,171	,031	-,170	-,035	,125	,238
Abstract Reasoning (AR)							
WCST Categories	**-,408***	-,337	-,136	-,349	-,310	,250	,362
WCST Percentage of responses of the conceptual level	-,179	**-,511****	,273	**-,526****	,150	,158	,186
Processing Speed (PS)							
STROOP Word	-,002	-,152	,188	-,064	,085	-,049	,221
STROOP Color	,070	-,176	,235	,145	,126	**-,473****	,082
Tower of Hanoi Time	,049	**,433***	-,246	**,431***	-,275	-,106	-,068

*p<0.05, **p<0.005
N: Sample size. TIQ: General intelligence. VIQ: Crystallized intelligence. PIQ: Fluid intelligence. VCI: Verbal comprehension. POI: Perceptual organization. FFDI: Freedom from distractibility. PSI: Processing speed.

Lastly, in the group of children with very superior intelligence, no statistically significant correlations were found between executive functioning and the measure of intellectual capacity and its dimensions.

Table 6.
Correlation between the measure of intellectual capacity and executive function in school-aged children with high academic performance and very superior intelligence.

	Very Superior Intelligence N=32						
Executive Functions	TIQ	VIQ	PIQ	VCI	POI	FFDI	PSI
Planning (p)							
WCST Perseverative errors	,257	,216	,116	-,034	,044	,316	-,288
Tower of Hanoi Moves	-,115	-,117	-,155	-,174	-,153	-,152	-,204
Cognitive flexibility (CF)							
WCST Categories	-,179	-,039	-,181	,123	-,035	-,022	,169
WCST Perseverative responses	-,182	-,162	-,050	-,132	-,110	-,296	-,217
WCST Percentage of perseverative responses	-,099	-,046	-,026	-,002	-,090	-,322	-,222
Tower of Hanoi Moves	-,115	-,117	-,155	-,174	-,153	-,152	-,204
STROOP Word-Color	,061	-,023	,124	,065	,002	-,067	,058
Inhibitory Control (IC)							
STROOP Word-Color	,061	-,023	,124	,065	,002	-,067	,058
Fluency (F)							
Phonemic FAS	-,231	-,214	-,047	-,107	-,074	-,328	,133
Semantic FAS	-,006	,019	,043	,076	-,153	,172	,291
Ruff Figural Fluency	-,186	-,126	-,149	-,063	-,195	-,020	,209
Working Memory (WM)							
Tower of Hanoi Moves	-,115	-,117	-,155	-,174	-,153	-,152	-,204
Ruff Figural Fluency	-,186	-,126	-,149	-,063	-,195	-,020	,209
Attention							
WCST Failures in keeping the principle	,257	,216	,116	-,034	,044	,316	-,228
STROOP Color	,063	-,003	,130	,069	-,002	-,069	,067
STROOP Word-Color	,061	-,023	,124	,065	,002	-,067	,058
Abstract Reasoning (AR)							
WCST Categories	-,179	-,039	-,181	,123	-,035	-,022	,169
WCST Percentage of responses of the conceptual level	,032	-,005	,095	-,016	,033	,147	,160
Processing Speed (PS)							
STROOP Word	-,178	-,051	-,194	,067	-,291	-,068	,104
STROOP Color	,063	-,003	,130	,069	-,002	-,069	,067
Tower of Hanoi Time	-,028	,030	-,118	-,022	-,066	,075	-,201

N: Sample size. TIQ: General intelligence. VIQ: Crystallized intelligence. PIQ: Fluid intelligence. VCI: Verbal comprehension. POI: Perceptual organization. FFDI: Freedom from distractibility. PSI: Processing speed.

Discussion

The purpose of this study was to determine whether the high academic performance of children is linked to intellectual capacity or executive functions. To this end, three population groups with high academic performance as the common characteristic were selected. The differences in terms of executive functioning and correlations between the measure of intellectual capacity and executive function were analyzed for each group.

Differences in the executive function dimension known as conceptualization—which comprises phonemic and semantic verbal fluency—were identified in children with average and very superior intelligence. However, when the sample was analyzed by groups, correlations between the dimensions of intellectual capacity and executive function were observed in children with average and superior intelligence, but not in children with very superior intelligence. Previous studies showed low correlations between intellectual capacity dimensions and verbal fluency tasks associated with executive functions in adolescents from public educational institutions in Colombia (Ardila et al., 2000) and talented children (Montoya-Arenas et al., 2010).

From the psychometric perspective, these findings could mean that the scores in the intellectual quotients of the Wechsler Intelligence Scale do not show a strong statistical relationship with the measurement of the EF. However, this does not mean that such correlation absolutely does not exist in the clinical assessment.

The analysis on executive functioning and academic performance provides evidence that, with age, the latter increases in dimensions that include verbal fluency, working memory, planning, cognitive flexibility, selective and sustained attention, and inhibitory control; showing a process of development in the areas of association related to the executive ability to solve problems, favoring the learning processes. This explains the high academic performance of subjects with normal intellectual capacity (Castillo-Parra, Gómez, & Ostrosky-Solís, 2009; Fonseca, Rodríguez, & Parra, 2016).

In a study with normal adults, Obonsawin et al. (2002) correlated the measured general intellectual capacity with the Wechsler Adult Intelligence Scale—Revised (WAIS-R) and conventional executive tests. The study revealed that the results of the executive tests correlated significantly with the results of the used measure of intellectual capacity, and that the executive tests constitute an excellent instrument for measuring general intelligence.

These results of the said research are consistent with that of the current study, given that certain relationships between these two constructs can be found in subjects with average and superior capacity. On the other hand, individuals with very superior capacity are considered as subjects with special educational needs, since they do not meet the criteria of "normality" due to their above-average general cognitive performance.

In this regard, Ardila (1999) stated that the assessment of intellectual capacity by means of the Wechsler Intelligence Scales does not take into account dimensions of EF, hence the correlations between these two constructs are biased by sociocultural characteristics or conditions of the population in which the study is conducted. García-Molina, Tirapu-Ustárroz, Luna-Lario, Ibáñez, & Duque (2010) concluded that intelligence and EF are not interchangeable terms and, therefore, have to be assessed independently.

The study measured dimensions such as general intelligence or *g* factor, crystallized intelligence, and fluid intelligence; as well as some subdimensions, such as verbal comprehension, perceptual organization, freedom from distractibility, and processing speed; finding that, in the groups with average and superior intelligence, these have low and medium correlation with some EF dimensions, such as planning, cognitive flexibility, phonemic verbal fluency, attention, abstract reasoning, processing speed, and inhibitory control, according to the theoretical model implemented.

This observation was made after comparing the results of children with high academic performance, who were assigned an intelligence measuring test and who were distributed in groups. Upon analyzing the performance in executive function tasks and comparing the results of the groups, no significant differences were observed, which means that the EF does not determine the intellectual capacity of an individual or vice versa. These results are consistent with the findings of the research works of Welsh, Pennington, and Groissier (1991); Donders and Kirsch, (1991); and Johnstone, Holland, and Larimore (2000).

The present investigations contradict the findings of Welsh et al. (1991), who did not find correlations between IC and EF in children aged 6 to 12 years old. Although the IQ does not determine the development of the EFs, it is true that it is related to them. Therefore, it is not accurate to say that the one determines the other, but that they are correlated, since they are part of an integral mechanism of brain functioning in which functions must not be isolated, but considered as components of a dynamic and complex system (Luria, 1973).

The absence of a correlation between dimensions of IC and dimensions of EF in children with very superior intelligence is not due to the lack of a real relationship between executive functioning and intellectual capacity—it is even assumed that these individuals perform significantly above the rest of the population, corresponding to 5% of the general population. Instead, it can be explained by the characteristics and purposes with which the instruments were built, that is, their validity and reliability.

The instruments used to measure the executive function were designed to assess deficits derived from structural, metabolic, and other type of disorders of the central nervous system—where cognitive activity occurs. Consequently, these instruments do not determine the superior performance and thus do not reflect the executive function performance of these individuals. In other words, they were not created to measure in parallel the executive function and the intellectual capacity in their different dimensions, just as some authors have suggested in the past (Denckla, 1996; Stuss, 1992; Welsh et al., 1991; Goldstein & Naglieri, 2013).

Certain correlations between the dimensions of IC and EF found in this study demonstrate that the WISC-III shows the presence of some components that require novel problem-solving patterns, their maintenance throughout time, or the need to manipulate them flexibly when circumstances change. It contradicts the statements of Ardila (1999) and Montoya-Arenas, Trujillo-Orrego, & Pineda-Salazar (2010), who stated that the Wechsler's Intelligence Scales do not represent a significant activation of the cognitive functioning, since it is a task whose result depends on the individual's academic performance; therefore, it is not a novel stimulus, and the activation is made by cognitive processes such as language and, especially, working memory. (Giofrè, Mammarella, & Cornoldi, 2013).

The existence of weak or medium correlations between both measures in some specific population groups gives rise to questions pertaining to the findings of Damasio and Anderson (1993), who stated that the impairment of executive function, due to frontal lobe lesions, does not alter the intellectual capacity of an individual, given that the prefrontal cortex and its various regions (dorsolateral, orbitofrontal, and medial) are connected with diverse subcortical structures, forming frontal-subcortical circuits with independent functions and, therefore, the alteration of the EF dimensions depends on the region or circuit affected by the lesion.

Duncan, Burgess and Emslie (1995) compared patients with frontal lobe disorders and the results they obtained from the WAIS-R suggested that intellectual capacity must be measured according to the dimensions of fluid Intelligence (G*f*) and crystallized intelligence (G*c*), as proposed by Cattell (1963), and that the latter is more resistant to brain damage, thanks to its deep cultural influence. The fluid intelligence, however, which is a more biological component, is affected by frontal lobe lesions.

In an analytical correlational study between executive function and intelligence, Arán-Filippetti, Krumm, and Raimondi (2015) found a relationship between the G*c* and G*f* and the executive domains. However, correlations were weak in general, which confirms that intelligence and EF are independent components of cognition that overlap only in some aspects and in some evolutionary stages more than in others.

Based on the above, it would be necessary to understand that, when it comes to analyzing brain functioning, it is not advisable to state, in a categorical or deterministic way, that intellectual capacity and its dimensions are components isolated or independent from the other cognitive functions; mainly of those corresponding to the frontal lobe functioning—frequently associated with the development of intelligent behavior.

The current research determined that the EF dimension evaluated through the WCST correlates with the measure of the intellectual capacity of individuals with average intelligence and especially so in children with superior intelligence. This differs significantly from the findings of Arffa, Lovell, Podell, and Goldberg (1998), who found that children and adolescents with very superior IC performed better in the WCST than those with average and superior IC.

After reviewing the data published by that study, it was observed that the authors performed the comparative analysis of the groups using normative WCST scores extracted from other studies with populations of different characteristics. In addition, they derived the conclusions from multivariate analyses of variance with groups of ten individuals and used a stepwise regression analysis (a procedure that is not suitable for the size of the sample). Therefore, the results seem to be merely statistical noise generated by the procedures followed for the analyses.

And as for the tables, the authors included the averages only, omitting the standard deviations—thus it is not possible to calculate the size of the effect to determine the clinical significance of the data.

Conclusions

The results obtained from the execution of the tests that only evaluate the EF make it possible to establish statistically significant differences in verbal fluency between children with average and children with very superior intelligence, but not in children with superior intelligence.

Intelligence is a multidimensional construct that incorporates metacognitive skills associated with the functioning of the frontal lobe. However, it is not a concept analogous or synonymous with the neuropsychological construct of Executive Function.

The neuropsychological tests that assess the Executive Function with a greater relation to the measure of intellectual capacity are the Wisconsin Card Sorting Test, the Stroop Test, and the Tower of Hanoi (time).

The measure of general intellectual capacity in children with superior intelligence correlates statistically with the measure of cognitive flexibility, attention (monitoring), and abstract reasoning; the crystallized intellectual capacity correlates with planning, abstract reasoning, and processing speed; and the fluid intelligence, with attention (monitoring).

With regard to the subdimensions of intellectual capacity, verbal comprehension in children with superior intelligence correlates strongly with planning, cognitive flexibility, abstract reasoning, and processing speed.

As for Executive Functioning in children with average intelligence, attention, cognitive flexibility, fluency, inhibitory control, planning, and processing speed correlates with general intellectual capacity, crystallized intelligence, and fluid intelligence.

This study proved that the common characteristic among all the participants is high academic performance and an absence of Executive Function disorders. It is therefore concluded that an adequate development of the Executive Function favors high academic performance, but does not guarantee a very superior intellectual capacity.

Recommendations

The authors suggest performing longitudinal studies in which the continuum of the development of Executive Functions is observed in relation to academic performance. It would also be useful to invert the hypothesis and investigate the impact of academic training on superior cognitive functioning.

In this population, it would be very convenient to conduct studies on emotional processing and social cognition in children with high academic requirements and superior cognitive performance.

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