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The relationship between neuropsychological and ecological measurements of executive functioning in childhood and the prediction of mathematics performance. A pilot study.

Lorena Zorrilla-Silvestre[1], María Jesús Presentación-Herrero [2], Jesús Gil-Gómez [3].

[1] Department of Education, University Jaume I, Castellón.
[2] Department of developmental, educational, social and methodology Psychology, University Jaume I, Castellón.
[3] Department of Education, University Jaume I, Castellón.

Spain

Correspondencia: Lorena Zorrilla Silvestre. Facultad de Ciencias Humanas y Sociales, Departamento de Educación.Universidad Jaume I, Av. de Vicent Sos Baynat, s/n (Campus de Riu Sec) 12071 Castellón (España).
E-mail: zorrilla@uji.es

Abstract

Introduction. This study explored the variables of executive functioning (EF) that permitted the evaluation of EF both at home and at school. The objective was to compare the results of the evaluations of these functions in children aged 5 to 6 years, and see to what extent these variables predicted mathematics performance best.

Method. Sixty-six third year early childhood education students took part, who were given verbal memory and visuospatial tests, of inhibition, of estimation of mathematical performance and the *Behavior Rating Inventory of Executive Function* (BRIEF), carrying out a correlational and descriptive study.

Results. The results showed correlations between the evaluation of children with neuropsychological tests and the ecological assessments of teachers and parents; and between the BRIEF evaluations, in the metacognitive domain.

Conclusion. The measurement that best predicted mathematics performance was the teacher BRIEF, especially in working memory.

***Keywords**:* Executive Function, BRIEF, neuropsychological tests, mathematics achievement, preschool education.

Relación entre medidas neuropsicológicas y ecológicas de funcionamiento ejecutivo en Preescolares y su predicción del rendimiento matemático. Un Estudio Piloto

Resumen

Introducción. En este estudio se exploraron las variables de funcionamiento ejecutivo (FE) que permitieron evaluar el FE tanto en el hogar como en el colegio. El objetivo fue comparar los resultados obtenidos en las evaluaciones de estas funciones en niños de 5 a 6 años, y comprobar qué medida de estas variables predice mejor el rendimiento matemático.

Método. Participaron 66 alumnos de tercer curso de Educación Infantil a los que se les administraron pruebas de memoria verbal y viso-espacial, de inhibición, de estimación del rendimiento matemático y el *Behavior Rating Inventory of Executive Function* (BRIEF), llevando a cabo un estudio correlacional y descriptivo.

Resultados. Los resultados mostraron correlaciones entre la evaluación de los niños con pruebas neuropsicológicas y las valoraciones ecológicas de profesores y padres; y entre las valoraciones del BRIEF, en el dominio de metacognición.

Conclusión. La medida que mejor predijo el rendimiento matemático fue el BRIEF de profesores, especialmente en la memoria de trabajo.

Palabras Clave: Funcionamiento ejecutivo, BRIEF, pruebas neuropsicológicas, rendimiento matemático, educación infantil.

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Introduction

Executive functions (EF) have been defined as the processes that associate ideas, movements and simple actions that guide the resolution of complex behaviors with the finality of reaching an objective (Anderson, Jacobs, & Anderson, 2008; Flores-Lázaro, Castillo-Preciado, & Jiménez-Miramonte, 2014; Meltzer, 2013). In this regard, different authors such as Diamond (2013), Korzeniowski (2011), Luria (1988), Stuss, & Benson (1986), Van De Voorde, Roeyers, Verté, & Wiersema (2010), and Welsh, & Pennington (1988) considered EF to encompass a series of cognitive processes among which anticipation, choosing objectives, planning, the choice of conduct, self-regulation, self-control and the use of feedback stand out. This said capacity included functions of regulation or of management such as the possibility of initiating behavior and regulating emotions, inhibiting the actions of stimuli, selecting goal directed actions, planning and organizing a means to solve complex problems using flexible problem solving strategies such as necessary and evaluating behavior.

In global terms, EF enabled the establishment of structured thought of a very diverse nature. They were like a constellation of cognitive abilities destined to resolve unexpected or changing situations, and it was possible to group them into a series of dimensions or components for their study (Bausela & Santos, 2006; Lezak, 1995; Stuss & Levine, 2000).

Executive functions were involved in cognitive function and in socio-emotional performance, requiring adequate assessment as much as of the characteristics of the problem to solve as of the immediate, medium and long-term consequences of the selected answer. While this required the participation of the different sensory systems, EF were characterized by their independence from the *input*, i.e., they coordinated and regulated responses according to what desire was to be achieved independently from the available information (Verdejo-Garcia & Bechara, 2010). In a similar vein, Liberman, Giesbrecht & Müller (2007) in their study, established relationships between EF and emotional aspects from ecological measurements. They considered children with good inhibitory and verbal ability regulated their emotions better.

EF in Infant Education

Traditionally, it was considered that EF could not be evaluated at early stages due to their complexity and prolonged development. However, according to Anderson (2002), it was possible to identify the emergence and development of EF in preschoolers including in babies.

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Baker, Rogers, Owen, Frith, Dolan, Frackowiak, & Robbins (1996) showed that children aged 4 to 8 years, progressively improved the number of moves they had to realise to complete tasks thanks to an increase in the ability to form mental representations and manipulate them. Similarly, Garcia-Molina, Enseñat-Cantallops, Tirapu-Ustárroz, & Roig-Rovira (2009) concluded that children developed their EF during their first 5 years and this development would influence positively or negatively their ability to cope with new situations and adapt to changes in their daily lives. Several studies showed that children aged between 3 and a half and 4 and a half-years old had difficulties to guide their actions inhibiting the dominant response. Although these improved with age, children of 6 had virtually no difficulties in carrying out the action (Diamond, 2002; Gerstadt, Hong, & Diamond, 1994). These findings indicated that at the ages of between three and four years progress of the inhibitory process of both the cognitive and motor dominant responses existed, such as waiting responses with a motivational content and that in children older than 4 these skills had practically been established. From this, it was considered that inhibitory control may be a process that allowed the proper development of other EF (Barkley, 1997).

Other research has shown that during infancy there was an important improvement in working memory capacity as well as in the visuospatial and the listening and verbal modes, which continued even beyond the ages of 6 and 7. Therefore, their development was later than that of other processes, such as inhibitory control, with which it was related (Liberman, Giesbrecht, & Muller, 2007). Lang & Perner (2002) concluded that preschool children between 3 and 5 years demonstrated a significant improvement in change activities that required active information maintenance.

Executive functioning and Difficulties Learning Mathematics

Some longitudinal studies developed in the line of this present research have had the aim of studying the predictive capacity of executive functions on mathematical achievement. Thus finding, for example, significant relationships between planning measures, inhibitory control, cognitive flexibility, attention control or working memory (WM) in the last year of preschool and subsequent performance in mathematics. This highlighted the role that difficulties in one or the other of these functions may play in the etiology of difficulties learning mathematics (DLM) (Bull & Scerif, 2001; Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; Rimm-Kaufman, Curby, Grimm Nathanson & Brock, 2009).

Recently, Toll, Van der Ven, Kroesbergen & Van Luit (2011) found that the executive function that best predicted DLM was working memory, followed in importance by inhibition, while not finding any predictive power in cognitive flexibility. The most surprising thing was that WM had a higher predictive value than those preparatory math skills. Many studies have examined the contribution of EF in DLM using standardized neuropsychological tests, but few proposals to assess them more ecologically comparing both measurements had been made in the way that this study set out to do.

Objectives and hypothesis

The reason we focused on the study of EF in Early Childhood Education, specifically planning, WM and inhibition, was the fact that it was at that stage where functions began to develop that later mark the primary stage. For this, we considered it necessary to have a better view of how these develop and show, both at school and in the family environment, so as, to be able to improve their developmental conditions. In this sense, the following objectives for study were established:

1. To compare the results of the neuropsychological assessment of EF in childhood with the assessments made by parents and teachers.

2. To compare the BRIEF questionnaire results in its two versions. For parents and for teachers, and know the existing relationships between the two assessments.

3. To find out which measurement of the EF variables (inhibition, change, emotional or behavioral control, initiative, planning, WM, organisation of material and monitoring) best predicts mathematics performance.

For their part, the advanced *hypotheses* were:

Hypothesis 1: There would be a significant correlation between the results of the neuropsychological assessment and that of the parents and teachers in the EF variables (inhibition, change, emotional or behavioral control, initiative, planning, WM, organizing materials, monotoring).

Hypothesis 2: There would be a significant correlation between the scores given by teachers and parents.

Hypothesis 3. The measurement of the EF variables that predicted mathematical performance best would be that of teachers.

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Method

Participants

The study was conducted with a sample of 66 preschool children, 37 boys and 29 girls from different schools in the province of Castellón (6 public and 1 fee paying), randomly selecting 6 students per classroom at the tutors' discretion. The exclusion criteria applied were an Intelligent Quotient (IQ) less than 70 and greater than 130, students with special educational needs or evidence they may be present and late starters into the educational system. The chronological age of the participants ranged between 5 and 6 years, and all were attending the third year of primary education (P5). The equivalent IQ score of all the participants was extracted from a conversion table (Sattler, 1982) of the direct scores obtained in the cube and vocabulary tests of the Wechsler Preschool and Primary Scale of Intelligence (hereafter WPPSI-R).

Instruments

Verbal memory

Digit span subtest from the Weschler Intelligence Scale (1980). This consisted of two tasks: direct and reverse digit memory recall. In the direct memory task the child had to repeat the same series of numbers read orally by the evaluator. In the task of reverse memory, the child had to repeat the sequence in reverse order of the numbers read orally by the evaluator.

Memory Test Count (Case, Kurland, & Goldberg, 1982). This test consisted of a series of cards with blue and yellow dots arranged randomly. The aim was to count the number of blue points, say them out loud and then after having a series of cards, remember the number of blue dots listed in the correct order.

Visual-spatial working memory

Odd -one out (Henry & MacLean, 2003). In this task the subject saw a card with three figures presented in a row and had to identify which figure was different. At the end of each trial, the child had to remember its right location by pointing at a board with blank positions.

Maze Test (Porteus, 2003). A maze was shown to the subject with a route drawn on it. Then, the subject was asked to trace the same route on a blank maze otherwise identical to the initial one.

Inhibition control and /or impulsivity.

Sun / moon task (Musso, 2009). This consisted of two conditions. In condition A, a child was shown a page with 30 pictures of suns and moons randomly arranged in rows and columns. Children were instructed to respond “sun” to images with sun and “moon” to moon images as quickly as possible (within 45 seconds). Immediately after, condition B was presented, in which they were asked to quickly respond “sun” when the assessor showed a moon, and vice versa.

Tapping Test (NEPSY; Korkman, Keny, & Kirk, 2007). Two situations were presented to the subject: In the first, congruent, situation, the subject had to do what the examiner does, when he/she gave one or two taps on the table; in the second, incongruous, test, when the examiner tapped, the subject had to give two, and when the examiner gave two, the subject had to give one.

BRIEF (*Behavior Rating Inventory of Executive Function*, Gioia, Isquith, Guy, & Kenworthy (1996)). This was a scale consisting of two questionnaires, one for parents and one for teachers, designed to assess the behavioral aspects of EF at home and at school, respectively. Each questionnaire contained 86 items that provided global information on EF from two main domains: the behavioral control index composed of scales of inhibition, emotional control and change; and the metacognition index composed of initiative, WM, organization of materials, planning and monitoring , as well as a global EF score.

IQ measurement

Subtest of the WPPSI -R (*Wechsler Preschool and Primary Scale of Intelligence, Wechsler, 1967*).

Vocabulary subtest. This measured verbal fluency and vocabulary management and required the subject to tell the meaning of 32 words of increasing difficulty.

Cube subtest. The subject had to build cube drawings of increasing complexity. This subtest assessed the ability to analyze, synthesize and reproduce abstract geometric designs.

Assessing mathematics performance

Questionnaire for estimating the mathematics performance in infant education. It was elaborated for this research starting in the infant curriculum. It consisted of 23 items divided into 4 factors: numbering, basic operations, geometry and estimated size measurement, and another teacher-evaluated item in terms of overall student math performance.

Procedure

After obtaining permission from the Ministry of Education, Culture and Sports and the School Board at each school (Spain), the collection of data went ahead. The order of test administration was identical at the seven schools, at the same period in the timetable and in different weeks. The EF tests were administered individually by the researcher in a dedicated room in the school free from distraction. The BRIEF questionnaires were handed to teachers and parents who filled them out with the help of the researcher when necessary. Once collected, the data was entered into the statistical program and analyses were carried out.

Statistical analysis

The research was characteristic of a descriptive correlational design study, since the aim was to show the extent to which certain variables are related. The design included a predictive analysis, in order to determine which of all the EF variables best predicted mathematics performance.

The software used to perform all the analyses was the SPSS 19.0 program. Initially, correlation analyses between the direct scores of the EF tests administered to the subjects with the teacher assessments and correlation analyses of the direct scores along with the parent assessments were carried out. Later, correlations between the parent and teacher assessments given in the BRIEF were calculated. Finally, the measurement of EF variables that best predicted mathematics performance was examined, from the linear regression analysis between numbering factors and the operations from the questionnaire that were completed by the teacher, the sum of the aforesaid factors and the teacher evaluation on mathematics performance with the neuropsychological testing and the parent and teacher BRIEF questionnaire.

Results

Prior to this, the normalcy of the mathematics tests was analyzed with the Kolmogorov-Smirnov test. Furthermore, the potential impacts of age, sex and IQ were controlled. No statistically significant differences in any of the tasks assigned to the participants were found.

Relationship between the results obtained in the evaluation of the children and the parent and teacher assessments for inhibition and WM.

There were statistically significant negative correlations between the direct scores of all the neuropsychological tests with all the factors of initiative, working memory, planning, and monitoring factors and, therefore, the domain of metacognition and with the global index of the scale, measured by the teachers. Working memory was the factor which reached the highest values in inverse figures (r = -.505, *p* = .000). In the parents' section, it was also working memory which correlated significantly with the highest number of tests, especially with the reverse figure span (r = -.335, *p* = .008). On the other hand, a low and negative correlation between the sun / moon and the emotional control factor was observed (r = -.293, *p* = .23) assessed by teachers, with no existing correlation between inhibition tests and the factor of inhibition, assessed by teachers and parents. Table 1 shows the correlations between the EF of verbal WM, visual-spatial WM and inhibition evaluated in the child subjects and the teacher and parent valuations of the same functions performed through the BRIEF.

Table 1
Correlations between the EF variables assessed by neuropsychological tests with those evaluated by parents and teachers with the BRIEF questionnaire.

		Inhibition		*WM*			
		Sun/moon task	*Tapping test*	*Digit Span*	*Reverse Digit Span*	*Counting*	*Odd One Out*
Teacher	*Emotional control*	-.293*	-	-	-	-	-.300*
	Initiative	-	-	-.331**	-.483**	-.443**	-.290*
	WM	-	-	-.360**	-.505**	-.412**	-.361**
	Planning organization	-	-	-.296*	-.493**	-.331**	-.300*
	Monitoring	-	-	-.280*	-.369**	-.336**	-.356**
		-	-	-	-.466**	-.357**	-

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	Metacognition			.321**			.326**
	Global composite index	-	-	-.282*	-.406**	-.297*	-.300*
Parent	*Shift*	-	-	-.271*	-	-.261*	-
	WM		-.354**	-.272*	-.335**		-.256*
	Planning organization	-	-	-.305*	-	-.297*	-.261*
	Metacognition	-	-	-.281*	-	-	-

Note. **. The correlation was significant at the level of 0.01 (bilateral).
*. The correlation was significant at the level of 0.05 (bilateral).

Relationships between the parent and teacher assessments using the BRIEF Questionnaire.

There existed a significant mean correlation in the factor of inhibition (r =.371, p =.004) in the domain of behavior control, while in the domain of metacognition there was a higher and significant correlation between the assessments made by parents and teachers, especially in WM (r = .576, p =.000). Table 2 presents the correlations between the evaluations given in the BRIEF questionnaire by teachers and parents.

Table 2
Correlation between parent and teacher rating using the BRIEF

	Inhibition	Change	Emotional Control	Behavior Regulation Index (BRI)	Initiative	Working Memory	Planning	Organization of materials	Monitoring	Metacognicion	Global composite index
Parents-Teachers	.371**	-	-	.272*	.441**	.576**	.469**	.266*	.432**	.478**	.422**

Note. **. The correlation was significant at the level of 0.01 (bilateral).
*. The correlation was significant at the level of 0.05 (bilateral).

Prediction of mathematics achievement according to the measurements of the EF variables

Table 3 shows the contribution of EF measurement variables to the prediction of mathematics performance from the results of linear regression analysis carried out with the number factors and the operations of the questionnaire completed by teachers and the teacher assessment of mathematics performance by the students. In this case, the IQ was introduced into the first block and the measures of the EF variables into the second.

In all of the factors, the IQ was significant, in explanation along with other variables. The numbering factor was predicted by the visual-spatial test, (ΔR^2 =.118; *p* =.011) that along with IQ, (ΔR^2 =.175; *p* = .004) explained 29.3% of the total variance; by the IQ, the WM and the organization of material evaluated by the teacher explained 67.7 % of the total variance; and the WM was the only factor valued by the parents that explained 29.4% of the variance.

The total variance of the mathematics operations was explained in 50.8 % by verbal working memory tests such as the Reverse digit span and counting, in 53.5 % for the IQ and the WM according to teacher evaluation and in 39.6% for the WM and inhibition as evaluated by parents. Finally, the reverse digit span, counting and IQ explained 42.9% of the teacher-given value of student mathematical performance, IQ and the initiative variable valued by the teacher predicted a factor of 69.6%, and IQ, WM and inhibition with the parent questionnaire predicted 56%.

Table 3
Results for the linear regression analysis of EF variables on mathematics performance

		β	R^2	ΔR^2	*p*
Numbering factor					
Neuro-psychological tests	*IQ*	.185	.175	.175	.004
	Odd One Out	.415	.293	.118	.011
Teacher Brief	*IQ*	.234	.182	.182	.003
	WM	-.477	.617	.435	.000
	Organization of material	-.313	.677	,059	.007
Parent Brief	*IQ*	.303	.172	.172	.005
	WM	-.367	.294	.122	.010
Operation Factors					
Neuro-psychological	*IQ*	.229	.224	.224	.001
	Reverse Dig-	.372	.433	.209	.000

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tests	*its*				
	Counting	.331	.508	.075	.016
Teacher Brief	*IQ*	.299	.234	.234	.000
	WM	-.579	.535	.301	.000
	IQ	.269	.221	.221	.001
Parent Brief	*WM*	-.538	.367	.145	.003
	Inhibition	.299	.437	.071	.028
Teacher Evaluation					
	IQ	.200	.191	.191	.000
Neuro-psychological tests	*Reverse Digit Span*	.385	.358	.168	.000
	Counting	.295	.429	.070	.010
Teacher Brief	*IQ*	.206	.210	.210	.000
	Initiative	-.742	.696	.487	.000
	IQ	.271	.216	.216	.000
Parent Brief	*WM*	-.682	.494	.278	.000
	Inhibition	.291	.560	.060	.005

Discussion and conclusion

The term EF makes reference to processes and skills for carrying out a behavior (Anderson, Jacobs, & Anderson, 2008; Flores-Lazarus, Castillo-Preciado, & Jimenez-Miramonte, 2014; Meltzer, 2013) consisting of variables such as working memory, organization and planning, inhibition response, cognitive flexibility, attention capacity or the control of one's own emotional state (Diamond, 2013; Korzeniowski, 2011; Van De Voorde, Roeyers, Verte, & Wiersema, 2010). According to authors such as Garcia et al. (2013) and Van der Ven, Kroesbergen, Boom, & Leseman (2013) the poor malfunctioning of these EF was related to problems in mathematical thinking, so this study has investigated the relationship existing between neuropsychological and ecological measures of executive functioning in children and what measurement best predicted mathematical performance to act accordingly.

The *first objective* of this study was to determine to what extent there was a significant correlation in measuring EF variables by neuropsychological testing and teacher and parent evaluation. The results show that while there was no relationship between the tests which measured inhibition and the domain of behavioral control in the BRIEF, the relationships between instruments that measured WM and the metacognitive domain were significant, especially between the standardized tests and the teacher assessments. The results partially replicated the findings of Liebermann, Giesbrecht & Müller (2007), in that there was no relationship between the assessments provided by parents in emotional control and the scores obtained with specific tests that measure EF. On the other hand, in accordance with previous reports, in EF tasks in preschoolers (Carlson, 2005; Gathercole, Pickering, Ambridge, & Wearing, 2004; Zelazo, Müller, Frye, & Marcovitch, 2003), the measurements of working memory showed significant tendencies, whether measured in an everyday environment or measured in the laboratory. This may have been because daily behaviors related to EF and behavioral control may correspond to more general EF processes and not to more specific aspects thereof. For this reason, it was difficult for parents and teachers to answer specific behavioral questions from general impressions.

The *second objective* of the research focused on knowing the relationships between the teachers and parent assessments of the executive functions of children. In relation to the domain of metacognition a correlation did exist among all factors, highlighting a high score on the working memory and planning. Yet, on the contrary, in the domain of behavioral control no correlation existed due to the factors of emotional change and control. This shows that learners seemed to control their emotions better in the school context than in the family context. Therefore, a complementary analysis of the information provided by observers of different significant contexts to obtain a better understanding of child EF is considered necessary; we would also propose that teachers provide guidance to parents on how to get children to monitor and improve their emotions in the family context.

In light of the results referring to the *third objective*, the regression analyses carried out with the EF variable measurements were notable. All measurements of the variables along with IQ contributed to explain the performance of the chosen mathematical factors. Specifically, the measurement that most predicted each factor was the teacher-completed BRIEF followed by the parent-completed ones. Surprisingly, the neuropsychological tests were those that least predicted basic mathematics skills. This data indicates that a clear prediction of good mathematical competence in preschool by multiple measurements from independent sources can be acquired (Clark, Pritchar, & Woodward, 2010).

The first finding of note was the statistically significant correlation between the test of verbal working memory, the reverse digit span, and the teacher and parent assessment especially in WM, planning and monitoring. However, none of the inhibition tests correlated significantly with the domain of behavioral control in the BRIEF. These results confirmed the validity of ecological evidence such as the BRIEF for the measurement of metacognition, it being more reliable than the assessment by the teacher. Another noteworthy finding was the non-correlation between the teacher-provided scores on the behavioral and emotional control of the child and those provided by the parents. This may have been because children adopt a certain behavior or another depending on the context in which they find themselves and the norms established in them, creating different perceptions of their behavior. This partially rejects the hypothesis established in the study insofar as the assessments by teacher and parent evaluations coincided in all variables.

The last finding to highlight was the importance of teacher evaluation as a predictor of mathematics performance, just as was established in our hypothesis. The results showed that teacher evaluation was the best predictor of the numbering operations factor and the overall factor of evaluation, even more so than with standardized neuropsychological tests. Thus, by only administering the metacognition domain part of the BRIEF carried out by teachers this study predicted between 53.5 % and 69.6 % of mathematics performance in children aged 5. However, assessing the findings should consider certain limitations, such as the small sample size and the fact the questionnaire estimating mathematics performance in Infant School was completed by the teachers without a previous pilot study that analyzed its validity and reliability.

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In memory of Maria Luisa Sanchiz Ruiz.

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