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Domain-specific predictors for fluency calculation at the beginning of primary school education

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Abstract

Introduction. This study analyses the predictive role of several specific components of early numerical skills on the fluency calculation.

Method. A total of 122 students (Mean age = 69.89 months; SD = 3.44), 54 girls and 68 boys participated in the study. The early numeracy skills were assessed by the end of pre primary school education, and fluency calculation at the first year of primary school.

Results. A multiple linear stepwise regression analysis showed a predictive model that explained 27.9% of the variance in fluency calculation. This model suggested that verbal counting (β = .377), resulting counting (β = .191) and estimation (β = .159), were the most important numerical variables explained fluency calculation in first graders primary school.

Discussion and Conclussions. Numerical skills predicted fluency calculation, however, was not predicted by relational math skills. The extensive importance of fluency calculation on learning mathematics is discussed.

Keywords: Fluency calculation, Early numeracy, Domain-specific predictors, Counting

Resumen

Introducción. El presente estudio trató de analizar el papel predictor sobre la fluidez de cálculo de los distintos componentes de carácter específico que constituyen las habilidades numéricas tempranas.

Método. Se empleó una muestra de 122 alumnos (M edad = 69.89 meses; d.t. = 3.44), de los cuales 54 fueron niñas y 68 niños. Las habilidades numéricas tempranas fueron evaluadas al finalizar la educación infantil y la fluidez del cálculo en el primer curso de educación primaria.

Resultados. El resultado del análisis de regresión lineal múltiple arrojó un modelo predictivo que explicó el 27.9% de la varianza en la fluidez de cálculo. El conteo verbal (β = .377), conteo resultante (β = .191) y estimación (β = .159), fueron la variables numéricas tempranas que explicaron en mayor medida la fluidez de cálculo en 1º de Educación Primaria.

Discusión y Conclusión. Las habilidades de tipo numérico predijeron la fluidez de cálculo, sin embargo, no fue así en el caso de las habilidades relacionales. Se discute la importancia del conteo como dominio para el aprendizaje de las matemáticas.

Palabras Clave: Fluidez de cálculo, Habilidades numéricas tempranas, Predictores específicos, Conteo.

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Introduction

Acquisition of an appropiated mathematical performance is one of the most significant goals for primary education students. Current difficulties in learning mathematics may have implications for children's everyday life and academic future. An early identification of children at risk of math difficulties allow us prompt educative remedial intervention (Aragón, Aguilar, Navarro, & Araújo, 2015; Núñez del Rio & Lozano Guerra, 2003). This early intervention can have positive consequences for his/her future academic experience (Clements & Sarama, 2011). Mathematical thinking is considered as an essential part within the human cognitive functions. Some research has focused on the study of the individual differences and the early identification of students at risk (Aragón, Delgado, Aguilar, Araujo, & Navarro, 2013; Navarro, Aguilar, Garcia, Menacho, Marchena, & Alcalde, 2010). Currently, these differences and performance in math should be considerered by two types of predictors: domain-general and domain-specific. Passolunghi, Lanfranchi, Altoé, & Sollazzo (2015) considered, on the one hand, the importance of domain-general predictors, consisting of those higher cognitive processes that predict performance in school tasks, but not in a single specific content. Some examples for this type of cognitive components are general intelligence and working memory (Bull, Espy, & Wiebe, 2008; Aragón, Navarro, Aguilar, & Cerda, 2015). On the other hand, domain-specific predictors are those skills predicting performance in a specific area, such as counting skills in mathematics (De Smedt, et al., 2009).

This classification between general and specific factors is important in clarifying why some children have serious difficulties in mathematics despite an optimal performance in domain-general predictor’s tasks (Landerl, Bevan, & Butterworth, 2004). There is no question about the importance of domain-specific predictors for success achievement in matematics and particularly in calculation. For example, traditionally the ability of children to detail the number sequence is a strong predictor for numerical tasks performance, such as solving simple adding tasks (Martins-Mourao & Cowan, 1998, Ho & Fuson, 1998). These results were verified by recent research (Cowan & Powell, 2014; Johansson 2005).

The predicting skills of mathematics performance in children are included under the early numeracy skills concept. These skills would include both relational skills (such as comparisons), and numerical skills, such as counting and estimating a mental number line (Ger-

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sten, Jordan & Light, 2015). Several studies support the relation between early numeracy skills and students performance in higher primary education grades (Clements & Sarama, 2009; Sarama & Clements, 2009). Particularly in relation to the predictive role of early numeracy skills in the appropriate performance of calculation at the beginning of primary school education (Jordan, Kaplan, Locuniak, & Ramineni 2007; Locuniak & Jordan, 2008), and subsequent courses (Cowan & Powell, 2014; Koponen, Aunola, Ahonen, & Nurmi 2007; Mazzocco & Thompson 2005).

At this point we mention that although appropriate and accurate calculation is a goal to be achieved by primary school students, and a fundamental pedagogical goal for teachers, to reach fluency calculation is also other learning objective pursued. We understand fluency as an easy and precise way with which students solve a delivered task. In early mathematics area, fluency calculation refers to the skill when student is carrying out an arithmetic task, in a flexible, accurate, efficient and appropriate way (Kilpatrick, Swafford, & Findell, 2001). These are key features in many everyday and school circumstances, such as solving arithmetic problems (Fuchs et al., 2006, 2010). Therefore, to achieve an optimal fluency level in math facts facilitates students to perform more complex assignments, such as multidigit tasks. It is necessary to accuracy elucidate basic combinations of small and complex numbers and also to achieve those complex combinations with two or more numbers tasks.

It should be also mentioned that the basic combinations will require a specific knowledge of the relations between numbers based on rules, concepts and principles, such as the counting principles and reversibility (Gelman & Gallistel, 1978). Thus, those students after the first year of primary school do not reach the domain of the most basic additive combinations will possibly have significant difficulties in the acquisition and fluency when performing subtraction, multiplication and division tasks. Consequently, their performance in any type of arithmetic requirement, both mental and written, will be significantly affected in contrasting to their peers (National Mathematics Advisory Panel, 2008), and bring inconveniences for instruction in more complex math concepts and in the development of higher arithmetic reasoning (Gersten et al., 2005).

Success in solving basic numerical combinations requires a set of rules and concepts that can not be reduced to the plain memorization of numeric facts. According to current research on number sense, memorizing of basic combinations should mean -for a flowing and optimum performance-, the comprehension of a well-structured knowledge building and interconnected with those elementary mathematics thoughts (Baroody, Bajwa, & Eiland, 2009). These authors assert that main problems source with basic math combinations -and, consequently, with the fluency calculation-, is closely related to the number sense enhancement, and skills established in the years before to the formal education.

That is a reason why research should not exclusively focus on domain-general precursors, such as memory (Koponen et al., 2007), but pay also attention to domain-specific precursors, and its corresponding explanatory weight of fluency calculation. Both independently contribute to the meaning of fluency calculation variation in primary school children (Cowan & Powell, 2014). In short, the detailed study of the specific components constituting the early numeracy skills and their predictive role in the fluency calculation is the main purpose of this study.

Main Goal and Hipothesy

The main target of this study was to analyze whether if the specific predictors of mathematical learning evaluated at the end of the pre primary school education (5 y.o. children) are related to the fluency calculation when children reach 6 years old. We hypothesized a predictive relationship between domain-specific precursors of mathematical learning and fluency calculation at the end of the first year of primary school education.

Method

Participants

Participants attended to four schools: two semi public and two public. The schools were located in a geographic zone with an average socio-economic range. Participants were a total of 122 students attending to the last year of preprimary school education during the first gathering data session, and the first year of primary school education in the second gathering data session.

Students age in the first assessment session, ranged between 64 and 76 months, with an average of 69.89 months and a standard deviation of 3.44. Considering the total sample, 54

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participants were girls, whose ages ranged between 64 and 76 months (*M* = 69.94, *SD* = 3.58). Participants males were 68, whose ages ranged between 64 and 76 months (*M* = 69.84, *SD* = 3.58). The second evaluation session was performed on the same sample 12 months later.

Instruments

Early Numeracy Test-revised (ENT-r). Test for early mathematical knowledge assessment for students from 4 to 7 years. A computerized Spanish version was used (TEMT-i) (Van Luit et al., 2015), which overcomes the pencil and paper version limitations and adds derived advantages in using new technologies in the early mathematical evaluation (Araújo, Aragón, Aguilar, Navarro, & Ruiz, 2014). The main purpose of this test is to evaluate the early numeracy knowledge and identify students who may show risk of Mathematics Learning Disabilities (MLD). This test has three parallel versions (A, B and C). In the present study we specifically worked with the B version to evaluate the total students. Each version has 45 items and the maximum score is 45 points (one for each correct item). Administration time fluctuates between 30 and 45 minutes. The administration is individual. TEMT-i- includes two subtest; first, focused on the evaluation of four types of relational concepts such as: comparisons, classifications, correspondence and seriaciones, each of them evaluated through 5 items; and second, TEMT-i includes five subtest to evaluate numerical concepts such as: verbal counting, structured counting, resulting counting (the child has to count sets of objects without pointing), general knowledge of numbers (student must add the points he/she got after rolling two dices and then place the token on the “game of the goose” board, as appropriate), and numbers estimation on a number line. Each numerical concept is evaluated by 5 items. Cronbach's alpha of this test was .90.

Fluency Calculation Test (Canals, Carbonell, Estaún, and Añaños, 1991). In order to analyze the fluency calculation (defined as the fast and accuracy when carrying out math calculations, Cowan & Powell, 2014), a test that takes into account both properties for calculation, was selected. This test includes 64 math tasks, presented in a horizontal positioning (e.g.: 5 + 2 = ?). Participants must solve as many math operations as possible in a maximum of one minute. The test initialy presents four training items, so that the evaluator finds that the student appropiatly understands the task. Once the student solves the training items, the evaluator starts the 1 minute test duration timer. Each correct math task is scored with 1 and 0 incorrect. The total score is the number of correct responses by one minute. This test is composed of subtests assessing fluency in the four basic math facts. In this study considering the age of the participants, the adding subtest items were used.

Procedure

In this study two assessment sessions were conducted in two consecutive years. A first evaluation session took place at the end of the pre primary school academic year (on May and June); and the second session one year later. For the time of the second assessment session, students were enrolled in first grade of primary school education. In the initial assessment session, participant's early mathematical competence was evaluated by TEMT-i. In the second assessment session, a year later, particpants were evaluated with the Fluency Calculation Test (adding subtest items). Both evaluations sessions were carried out by well trained and qualified researchers. The research was carried out after obtaining the teachers and participants' parents informed consent.

Data Analysis

The aim of this study was to analyze the predictors variables for fluency calculation in primary education. Consequently, the predictive value of domain-specific precursors over math performace were examined. Both relational and numerical mathematical skills were evaluated with the TEMT-i. Them, a linear stepwise regression analysis was calculated in order to establish what predictive variables (broadly considered by research) of mathematical competence were related to the criterion variable (fluency calculation).

Results

First, in considering the main target of the study (to provide predicting value for fluency calculation in pre primary school education), the descriptive statistics of the variables evaluated were examined (table 1).

Table 1. Descriptive statistics of the predictor and criterion variables.

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	M	*SD*
Fluency calculation	7.57	2.67
Comparison	4.66	.63
Classification	2.16	1.04
Correspondence	3.35	1.19
Seriation	2.22	1.11
Verbal counting	2.75	1.01
Structural counting	3.13	1.27
Resulting counting	2.55	1.21
General knowledge of numbers	2.94	1.04
Estimation	1.03	1.26

Before regression analysis calculation, the sample matched the significant assumptions and requirements for the use of such statistical analysis.

Table 2. Multiple linear stepwise regression model.

				Change statistic				
Model	*R*	R^2	R^2 *corrected*	*Typical Error Estimation*	*Change R2*	*Change F*	*Sig. Change F*	*Durbin Watson*
1	.494a	.244	.237	2.33	.244	38.65	.000	
2	.521b	.272	.259	2.29	.028	4.57	.000	1.895
3	.544c	.296	.279	2.26	.025	4.16	.000	

Note: a. Predictor variables: (Constant), Verbal Counting; b. Predictor variables: (Constant), Verbal Counting, Resulting Counting; v. Predictor variables: (Constant), Verbal Counting, Resulting Counting, Estimation; d. Dependent variable: Fluency calculation.

As can be seen in table 2, after the stepwise multivariate regression analysis, three models were found. Each model had its own explanatory statistical strength. The third model offered a higher explanatory function. Consequently based on R^2 values, 29.6% of variance in the outcome of fluency calculation could be explained by three variables introduced in the adjusted model: verbal counting, resulting counting and estimation. However, the value for R^2 corrected, considering the number of variables and participants involved in the study, showed that 27.9% of variance for fluency calculation could be predicted by three variables introduced in this stepwise regression model.

Table 3. Coefficients of multiple linear regression model.

Model	*Non standardized coefficients*		*Standardized coefficients*			*Collinear statistics*	
	B	*Typ. Error.*	*B*	*t*	*Sig.*	*Tolerance*	*VIF*
3 (Constant)	3.418	.629		5.436	.000		
Verbal counting	.998	.239	.377	4.175	.000	.731	1.368
Resulting counting	.419	.198	.191	2.119	.036	.736	1.358
Estimation	.336	.165	.159	2.040	.044	.986	1.014

Table 3 shows different coefficients for the regression model. We see the *t* value was associated with an error probability less than .05 in the three variables included in the predictive model (verbal counting, resulting counting and estimation). Also, the results of *t* test and the critical values contrasted that the null hypothesis for the regression coefficient obtained a zero value. It was assumed that the three variables included in this model supported the rationalization for the dependent variable variance. Similarly, the standardized coefficients reported about which of the variables introduced into the model had a higher statistical weight in predicting the dependent variable (fluency calculation). According to the *Beta* coefficients displayed in table 3, verbal counting (β = .377), resulting counting (β = .191) and estimation (β = .159) were the variables explaining further fluency calculation one academic-year later (when children hold the first grade of primary school education). These coefficients aimed verbal counting as the highest statistical predictor for fluency calculation, followed by the resulting counting and estimation, although they had a lower predictive rank.

It is remarkable that from the numerical subtests, both structural counting and general knowledge of numbers variables were excluded from the model. The total relational subtest variables: comparison, classification, correspondence and seriation, evaluated from TEMT-I, were also excluded (table 4).

Table 4. Standardized coefficients, *t* values and statistical significance for excluded variables from the model.

	B	*t*	*Sig.*
Relational Subtests			
Comparison	-.064	-.801	.425
Classification	-.124	-1.575	.118
Correspondence	.018	.216	.829
Seriation	.065	.015	.988
Numerical Subtests			
Structured counting	.001	.015	.988
General knowledge of numbers	.024	.278	.782

In order to check the statistical model validity, several statistical procedures were computed. The independence of the residual values was calculated through *D* Durbin-Watson statistical test (D = 1.895). Because *D* was close to 2, the absence of positive self correlation was confirmed (close to 0 values) and negative (close to 4). Similarly, the absence of collinearity was also assumed and therefore the stability of the estimations by obtaining high tolerance values and low *VIF* (table 3).

Discussion and Conclussions

The results maintain that early math skills tested at the end of pre primary education had a significant impact on predicting fluency calculation in the first grade of primary education. The three variables that showed higher statistical significance in predicting the dependent variable were numerical subtests. The results were expected because according to the principles by Piaget & Szeminska (1943) logical skills, such as classification or seriation, are the sustantial basis for acquiring numerical concepts. However, as more sophisticated learning is achieved, they are becoming less important in explaining number sense acquisition.

In this study two types of math skills were studied, and they were essential for early numerical competency. But only some numerical skills predicted fluency calculation. Specifically, verbal counting, resulting counting and estimation generated -in this hierarchical order- more statistical significance and were proposed in the predictive model. These findings may be because verbal counting, understood as the ability to properly recite a number sequence, is an essential requirement in developing calculation strategies (Johansson, 2005). Consequently, fluency and accurate counting seems critical to establish associations with long-term memory between the promted math task and the response. Thus, it is possible to progress from the use of calculation strategies as an approach to solve the task, to a much more efficient process, such as the recovery of the answer from long-term memory.

Specifically, verbal counting is a method for early resolution of mathematical tasks. And as soos as this skill progresses, the student notices regularities in numerical sequence, promoting the development of new and more precise strategies for solving mathematical tasks (Koponen, et al., 2007) and justifying its role in the current study.

Noël and Rousselle (2011) proposed that counting should be the key to success in early mathematics. So much so, that counting skills assessed in pre primary education predicted mathematics achivement in primary education (Van Marle, Chu, Li, & Geary, 2014), as was found in this study. On many other cases they have been linked early counting skills and optimal performance in math (Locuniak & Jordan, 2008). Therefore, to exhibit insufficient or undeveloped counting skills are related to mathematics difficulties (Gersten, et al., 2005). Consequently it is convenient to implement these skills at an early stage in order to prevent future problems in learning math.

On the other hand, the second variable predicting fluency calculation was resulting counting (counting with no pointing). Within this group of counting activities, subitizing tasks were included. Subitizing is the rapid, accurate, and confident judgements of numbers performed for small numbers of items (Baroody, 2011). In this study, as well as other research, this ability helped to explain individual differences in mathematics (Geary, Hoard, Nugent, & Byrd-Craven, 2008), even at the end of primary school (Reigosa-Crespo, et al., 2013). Because subitizing (like counting) can be understood as a processes for numbering exact quantities, they should be differentiated by paying special attention to the conditions of each item, showing the counting activity as a slower and harder process than subitizing.

One recent work sustaining the subitizing predictive role was published by Reigosa-Crespo, et al., (2013). In this study, both counting and subitizing performance predicted fluency calculation, although subitizing was the only statisticaly significant value. Therefore, these basic numerical skills are considered domain-specific predictors, not only as tools promoting the acquisition of mathematical competence, but also modulating the learning of these skills during the primary school education.

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Finally, the third predictor variable included in the linear regression model was estimation. As in our study, Booth and Siegler (2008) found a significant explanatory relationship between numerical estimation, evaluated to first graders, and student arithmetic performance assessed some time later. Before the intervention procedure, they conducted a pretest study to estimate the interrelationships between the two variables. They found high correlation between estimation and addition tasks, using a simple adding tasks measure, similar to that used in our work. The correlation between estimation and addition on Booth and Siegler (2008) was (r = .41; p < .01), higher than that obtained between calculation and short memory term, a general-domain predictor (r = .21; p < .05). This emphasizes the importance of domain-specific over domain-general predictors (Fuch, et al., 2010) in explaining the mathematical performance, and the need to pay attention to such factors.

Similarly, there are several studies focused on the importance of estimation. For example, a previous study conducted by Booth & Siegler (2006) showed that individual differences in learning the number line clearly correlated with mathematics performance in all grades evaluated. The acquisition of counting and integration of the numerical sequence properties should help to establish the roots for learning higher magnitude numbers, helping the construction of the representation there on a mental number line (Feigenson, Dehaene, & Spelke, 2004). These issues also sustain that the three factors identified by this study as fluency calculation predictors are closely related.

As some limitations of the study, it would be convenient to provide information of any control measure related to general-domain issues, such as intelligence or executive functions. Similarly, the absence of an assessment of the fluency calculation after 6 years age was also other potential weakness of the study. Furthermore, it is considered necessary to evaluate more complex math tasks, such as multiplication and division, after progressing participants age. Those limitations should be a starting point for future studies in this research subject.

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