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How preschool executive functioning predicts several aspects of math achievement in grades

1 and 3: A longitudinal study

Highlights

- EF components measured in 5-year-old children substantially predict mathematical achievement in grade 1 and especially in grade 3.
- WM was found to be more predictive of math performance than inhibition.
- Supporting executive skills could be a useful strategy in early childhood mathematics education.

Abstract

This longitudinal study analyzes whether selected components of executive function (EF) measured in the preschool period predict several indices of math achievement in primary school. Six EF measures were assessed in a sample of 5-year-old children (N=175). The math achievement of the same children was then tested in grades 1 and 3 using both a composite math score and three single indices of written calculation, arithmetical facts and problem solving. Using previous results obtained from the same sample of children (Usai et al., 2014), a confirmatory factor analysis examining the latent EF structure in kindergarten indicated that a two-factor model provided the best fit for the data. In this model, inhibition and working memory (WM)-flexibility were separate dimensions. A full structural equation model was then used to test the hypothesis that math achievement (the composite math score and single math scores) in grades 1 and 3 could be explained by the two EF components comprising the kindergarten model. The results indicate that the EF components measured in the preschool period substantially predict mathematical achievement in grade 1 and especially in grade 3. The math composite scores were predicted by the WM-flexibility factor at both grade levels. In grade 3, both problem solving and arithmetical facts were predicted by the WM-flexibility component. The results empirically support interventions that target EF as an important component of early childhood mathematics education.

Keywords: Executive function; Preschool; Mathematics; School readiness

How preschool executive functioning predicts several aspects of math achievement in grades 1 and 3: A longitudinal study

In recent decades, substantial gains have been made in identifying the preschool precursors of later math achievement and among the various cognitive processes found to be associated with or predictive of math skills, executive function (EF) appears to be particularly important. In adults (Miyake et al., 2000) and older children (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003), EF has been conceptualized as a multicomponent construct comprising several functions, primarily working memory, set-shifting and inhibition.

A number of studies have shown a developmental link between EF and math performance, especially in school-aged children (see, for example, Agostino, Johnson, & Pascual-Leone, 2010; Mazzocco & Kover, 2007; van der Ven, Kroesbergen, Boom, & Leseman, 2012). Fewer studies have been conducted on preschoolers, although increasing evidence indicates that emerging math skills are significantly correlated with concurrent measures of EF in younger children (Best, Miller, & Naglieri, 2012; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Espy et al., 2004; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Lan, Legare, Ponitz, Li, & Morrison, 2011; Miller, Müller, Giesbrecht, Carpendale, & Kerns, 2013). Furthermore, longitudinal studies suggest that EF facilitates the acquisition of emerging math skills (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; McClelland et al., 2007; Passolunghi & Lanfranchi, 2012; Röthlisberger, Neuenschwander, Cimeli, & Roebbers, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010). These longitudinal studies are particularly relevant because they facilitate the identification of the cognitive precursors of math achievement before school entry and contribute to the development of interventions that may enhance the skills necessary for children's learning of early math concepts.

EF and math achievement: Critical issues

Although it is generally agreed that EF plays a role in early math achievement, it is not clear whether all EF processes are equally involved in math learning or how EF affects different aspects of math performance. The majority of studies have found that working memory (WM) is a significant predictor of math achievement (Bull et al., 2008; Miller et al., 2013; Passolunghi & Lanfranchi, 2012; Passolunghi, Mammarella, & Altoè, 2008), and several studies have found that early math performance is associated with inhibition (Blair & Razza, 2007; Clark et al., 2010; Espy et al., 2004) or with both WM and inhibition (Bull et al., 2008). However, many of these studies examined only one aspect of EF and its effect on a single task, rendering them unable to identify the net contribution of each EF component while controlling for others. Similarly, the studies that used a composite or a single complex EF measure (Best et al., 2011; McClelland et al., 2007; Röthlisberger et al., 2013; Welsh et al., 2010) could not identify the specific contributions of the various EF processes, for example inhibition or WM.

These problems are closely associated with the difficulty of separating the different EF processes. Several studies conducted in the last decade showed that the latent structure of EF might undergo change between early childhood and adulthood, suggesting that the organization of EF may change in the course of development and that EF might be a relatively undifferentiated construct in young children and becomes more modular only with age (Zelazo & Müller, 2002). Using a confirmatory statistical approach, early studies found that a single undifferentiated executive control factor best described the latent EF structure in early childhood and in preschoolers (Hughes, Ensor, Wilson, & Graham 2010; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011). Diverging from these results, Miller, Giesbrecht, Müller, McInerney and Kerns (2012) reported that a two-factor model consisting of WM and inhibition showed a better fit to the data in a sample of preschoolers between the ages of 3 and 5 than did a single-factor model or a three-factor model composed of WM, inhibition, and

shifting. Similarly, Usai, Viterbori, Traverso, and De Franchis (2014) found that a two-factor model in which inhibition and WM/flexibility were separate dimensions provided the best fit to the data at both 5 and 6 years of age. These two studies suggest that the differentiation of EF processes is already apparent in early childhood and that inhibitory processes emerge as a separate dimension as early as preschool. A two-factor structure was also described by Lee, Bull, and Ho (2013) for children between the ages of 5 and 13, but in contrast to Miller and Usai's studies, the latent structure identified comprised an updating and combined inhibition-switch factor. These studies indicate that the shifting component of EF is not separable in preschoolers. Given that the independent contribution of each EF component to achievement can be evaluated only when some differentiation among EF components is apparent (Bull & Lee, 2014), the findings about the latent structure of EF in early childhood suggest that the contribution of shifting to math performance is not easily assessed in preschoolers.

Another important issue affecting EF assessment is that of task impurity, which refers to the concurrent involvement of several cognitive processes in the performance of an EF task. In fact, because EF regulates other cognitive processes, executive tasks generally measure other non-executive abilities, and task performance therefore cannot be considered an absolute measure of EF. Consequently, the results of studies that rely on individual EF tasks can be difficult to interpret because performance may reflect the effects of non-executive demands in addition to executive demands.

To alleviate these problems, researchers have suggested the combined use of multiple EF measures and confirmatory factor analysis techniques. Latent variable approaches allow the common variance among tasks with different non-executive requirements to be extracted, which provides a more accurate reflection of genuine EF performance.

Math as a componential ability

Most studies of math skills, with a few exceptions (Lan et al., 2011; Röthlisberger et al., 2013), have not investigated how multiple components of mathematical skills are related to EF and have instead relied on a comprehensive measure of math achievement, which can produce only general conclusions (e.g., Blair & Razza, 2007; Bull et al., 2008; Clark et al., 2010; McClelland et al., 2007; Passolunghi & Lanfranchi, 2012). As emphasized by Cragg and Gilmore (2014), it is possible that EF contributes differently to specific math skills.

In the present study, we considered three specific components of mathematics - arithmetic facts, word problem solving, written calculation and – that may involve EF at different levels and that represent three significant math acquisitions in primary school.

Reviewing the literature, WM was found to be related to all the math tasks we considered. As regards arithmetical facts, Geary (1993) suggests that poor working memory resources not only lead to difficulty in executing calculation procedures, but may also affect learning of arithmetic facts. Barrouillet and Lépine (2005) reported different explanations accounting for the relationship between WM capacity and retrieval of arithmetic facts. For example according to some theories (Barrouillet, Bernardin, & Camos, 2004) low working memory would imply a reduced amount of attentional resources available to activate knowledge from long-term memory, resulting in slower and less efficient retrieval processes.

Word problem solving involves several distinct cognitive processes in which the role of WM appears to be important, as underlined in a number of studies (LeBlanc & Weber-Russell, 1996; Passolunghi & Siegel, 2001; Swanson & Sachse-Lee, 2001): comprehending the problem, constructing a problem model, planning, and monitoring single subgoals. LeBlanc and Weber-Russell (1996), for example, reported that 49 to 57% of variance in children's word problem solving accuracy was accounted for by WM tasks. According to Swanson and Beebe-Frankenberger (2004), the influence of WM performance on problem

solving is particularly related to a child's ability to accurately access information (e.g., appropriate algorithms) from long-term memory to solve a problem.

Written calculation is based on the knowledge of procedures, and the role of WM could be necessary to select, monitor and implement the right algorithm. However, whereas in mental computation it is necessary to hold partial information (e.g., partial results and the amount to be carried) until reaching the final result, solving a written computation may require less involvement of the temporary information storage. Nevertheless, Passolunghi and Pazzaglia (2004), comparing two groups of primary school children with high and low memory-updating abilities, found that they showed a significant difference in calculation ability, even if the arithmetic operations were presented in written format.

As regards inhibition, its role in math achievement and performance is less clear. In arithmetic fact retrieval inhibition is required to suppress competing responses (Barrouillet, Fayol, & Lathulière, 1997). For example, while retrieving the answer 6 in response to 3×2 , children had to suppress 5 as the solution to $3 + 2$. These cross-operation errors are caused by a difficulty inhibiting the incorrect responses in a set of possible responses. Deschuyteneer and Vandierendonck (2005) suggested that to complete the retrieval process, a choice of the response is required, after the automatic activation of associated responses occurred.

The contribution of inhibitory abilities in word problem solving was reported by some studies (Passolunghi, Cornoldi, & De Liberto, 1999; Passolunghi & Siegel, 2001), especially when the text of the problem contains data that need to be selected to develop an adequate mental problem solving model. Such a hypothesis posits that inhibition processes may help children prevent irrelevant information from entering WM during the processing of problem-solving (Passolunghi & Siegel, 2001) and thus enable children to disregard alternative interpretations that are not central to the task. This hypothesis is in line with those models that explain individual differences in memory performance as related to inhibitory mechanisms

(Conway & Engle, 1994). Yet Swanson and Beebe-Frankenberger (2004), for example, found no evidence that inhibition contributes to arithmetic word problems.

In summary, many studies have confirmed the association between EF and different math abilities. Nevertheless, a comprehensive model including both different aspects of EF and different components of math abilities in the early stages of mathematical learning is still lacking.

The present study

The general aim of the present study was to examine the longitudinal relationship between emerging EF skills prior to school entry and mathematics achievement among school-age children in the first and third grades. Of special interest was identifying whether specific executive skills are particularly relevant to certain aspects of mathematics achievement in the early grades of primary school.

Since family characteristics and general cognitive functioning are also associated to school attainment, to evaluate the net contribution of EF on math ability, we took into account such factors. In particular, regarding family characteristics, socioeconomic status and parental education were found to be important predictors of children's school success (Duncan, Brooks-Gunn, & Klebanov, 1994). In particular, Espy et al. (2004) found that maternal education was related to early mathematical competency as well as to EF.

As concerns general cognitive functioning, some researchers suggested that the key factor underlying the relationship between EF, in particular WM, and learning is IQ (Nation, Adams, Bowyer-Crane, & Snowling, 1999), whereas others found a modest overlap between WM and IQ and found that WM showed unique links to academic attainment compared to IQ (Alloway, & Alloway, 2010). Given these findings, we took into account such factors.

A latent factor approach was used to limit task impurity in EF assessment and to obtain more accurate measures of EF that better reflect the real executive skills of preschool children. A componential view of math performance was used to examine whether the contribution of executive skills differs across mathematics abilities.

The specific aims of the study were as follows:

1. To describe the relationships between emerging EF at age 5 and mathematics achievement at age 6 and age 8 using a latent factor approach.
2. To analyze the specific contribution of several EF components at age 5 to written calculation, arithmetical facts and problem-solving math skills at age 6 and age 8.
3. To examine the extent to which associations between preschool EF abilities and later mathematics achievement persist when the contributions of other concurrent predictors, such as general cognitive functioning and maternal education, are taken into account.

According to previous research, when evaluated concurrently, math abilities and EF were found to be associated. Generally, both WM and, to a lesser extent, inhibition were found to be related to problem-solving (Passolunghi & Siegel, 2001; Swanson & Sachse-Lee, 2001) and arithmetical fact retrieval (Barrouillet et al., 1997; Lamaire et al., 1996). Written calculation was less studied and was found to be associated in particular with WM (Passolunghi & Pazzaglia, 2004). Less is known about longitudinal relationships between EF and subsequent math skills. We hypothesize that both WM and inhibition could be related to problem-solving and arithmetical facts, as also suggested by the literature. We also hypothesize that written calculation is less related to EF, in particular to inhibitory processes.

Method

Participants

Children who attended the last year of preschool at one of 23 public preschools were recruited for the study in the main town in a northwestern region of Italy. In Italy, preschool education enrolls children from 3 to 5, whereas primary school provides education for children aged 6 to 10. In each preschool, both the teachers and parents were informed of the aims of the study. Parents who decided to participate in the study were asked to provide informed consent and complete a questionnaire designed to gather information about their families.

To be eligible for the study, the children were required to be attending their final year of preschool; to speak Italian as a first language; and to have no diagnoses of any neurological, psychiatric, or developmental disorders. The families of 206 typically developing children agreed to participate in the study; 31 children were excluded from the study because they did not complete the testing due to prolonged absence from school ($n=8$) or because they scored below the 10th percentile on the Colored Progressive Matrices Test ($n=23$). The final sample comprised 175 children (99 males and 76 females) between 63 and 76 months old ($M=68.5$ months, $SD=3.4$ months). At grade 1, 129 children (73 males and 56 females) completed the second assessment. The mean age for these children was 6 years and 8 months ($SD=3.58$; range=75 to 90 months). At grade 3, 118 children (69 males and 49 females) completed the third assessment. The mean age for these children was 8 years and 8 months ($SD=3.36$; range= 98 to 111 months). Between wave 1 and wave 2, 46 children in moving from preschool to primary school could not be located. Nevertheless, no differences emerged in preschool EF measures, general intellectual functioning and maternal education levels between the children that continued the study and the children that dropped out.

Of the 165 mothers who provided this information at time 1, 13% had received a middle school education, 45% had a high school education and 42% had a university degree.

Procedure

All of the children were tested three times: in the spring of their final year of preschool and again at the end of their first and third years of primary school. The preschool assessment involved a comprehensive battery of seven tests evaluating various cognitive abilities related to general cognitive functioning and EF. At grade 1 and grade 3, the children's math achievement was evaluated. Each child was assessed individually in a quiet room at school by trained graduate students. The tasks were administered in a fixed order to allow for the control of session length and variation of tasks according to the materials, response modalities and abilities required. It was also suggested that a fixed order is preferred for the investigation of individual differences (see Wiebe et al., 2008).

Measures

Executive Function tasks. To assess EF, the following tasks were administered.

Circle Drawing Task (CDT). The Circle Drawing Task is a measure of inhibition of an ongoing response (Geurts, Vertè, Oosterlaan, Roeyers, & Sergeant, 2005; Marzocchi et al., 2008). In the task, the participants are presented a circle 17 cm in diameter drawn with the words "start" and "stop" indicating the points at which they should begin and finish tracing. The child must trace the circle with his or her finger from the starting to the ending point. The task is administered twice, first with neutral instructions ("trace the circle"), followed by inhibition instructions ("trace the circle again, but this time as slowly as you can"). Greater inhibition times indicate that the participant is better able to inhibit (slow down) a continuous tracing response. Time in seconds was recorded for each trial. The score was calculated as the ratio of the slowdown to the total time using the following formula: $T2-T1/T2+T1$, where T1 and T2 are the times recorded for the first and second trials, respectively.

Tower of London (ToL). The Tower of London test (Shallice, 1982) is a complex task for assessing planning ability. However, empirical evidence suggests that inhibition is the predominant process involved when younger children perform the task (Lehto et al., 2003;

Miyake et al., 2000; Senn et al., 2004). Task reliability was explored in a sample of 1,036 children from 4 to 13 years of age employing the same task administration procedure used in the present study: the Cronbach alpha was .46 (Fancello, Vio, & Cianchetti, 2006). The Chronbach alpha calculated in our sample was .22. The apparatus includes two wooden boards with three pegs of different sizes; for each wooden board there are three wooden balls of different colors (red, green, and blue); the balls each have a hole through the middle so they can be placed on the pegs. The longest peg can hold all three balls, the middle peg holds two balls and the shortest peg holds one ball. The child was given one of the two wooden boards with its balls and the examiner kept the other. Participants are told that the aim of the task is to reproduce the arrangement of balls shown by the examiner on his wooden board. The children are warned about some rules to follow: they must move the balls one at a time using only the number of movements announced by the examiner, and they are not allowed to place any balls on the table. If the child violates a rule or does not respect the limit on the number of movements, the problem is administered again, up to three times. For each trial, the child receives 3 points for a perfect solution on the first attempt, 2 points for a perfect solution on the second attempt, 1 point on the third attempt, and 0 points in the event that he/she violates the rules or is unable to place the balls in the correct position. The task comprises 12 trials with no time limit to complete them. The total score is calculated as the sum of correct solutions, with a maximum total score of 36 (Fancello et al., 2006).

Backward Digit Span (BDS). The Backward Digit Span task is a traditional WM test that requires the child to recall a sequence of spoken digits in reverse order. The Chronbach alpha calculated in our sample was .67. After a practice trial, testing begins with three trials of two digits. The number of digits then increases by one every three trials until three lists are recalled incorrectly. The test-retest reliability for the BDS was .64 in a sample of 709 children from 59 to 140 months (Alloway, Gathercole, & Pickering, 2006). The score is

calculated as the maximum list length at which two sequences are correctly recalled and one point was granted for length 1.

Dual Request Selective Task (DRST). The Dual Request Selective Task (Re, De Franchis, & Cornoldi, 2010) is a visual-spatial WM task specifically developed for preschool children. Several previous studies have shown that it has good psychometric properties and is appropriate for the assessment of children as young as 5 (Re & Cornoldi, 2007). Task reliability was explored in a sample of 509 children aged between 4 and 6 years: both the Cronbach alpha (.81) and split half (.80) revealed a good reliability (Lanfranchi & Vianello, 2008). The Chronbach alpha calculated in our sample was .72.

This task is suitable for assessing participants' ability to maintain information in WM while performing a concurrent task. The child is required to control the given information in WM while performing some action on the material and receiving interference from irrelevant information. The participant is presented with a 4 x 4 (17 cm x 17 cm) chessboard divided into 16 squares. One of the squares is red and is always located in the same position. The experimenter shows a path taken by a small frog on the chessboard to the child, who has to: 1) clap his or her hands when the frog jumps onto the red square and 2) remember the frog's starting position on a pathway on the chessboard. The task has five levels of difficulty, according to the number of steps in the pathway: 2, 3, 4, 5, and 6. All the pathways include a step in the red square. Each child completed 10 trials, two for each pathway length. Before beginning the experimental session, the experimenter provides practice trials by moving the frog through two squares. The session begins when the experimenter is certain that the child has understood the task. A trial is scored as correct only when the child performs both tasks correctly (i.e., clapping hands and remembering the starting square). The score was the total number of correct trials completed. The minimum score is 0 and the maximum is 10.

Semantic Fluency. A Semantic Fluency task was used to measure the children's capacity to shift between categories. The literature shows that two main processes are activated by this task, both in adults (Hirshorn & Thompson-Schill, 2006) and in children (Kavé, Kigel, & Kochva, 2008): clustering, which is temporally mediated, and switching, which is a frontally mediated executive process (Unsworth, Spillers, & Brewer, 2011). The test-retest reliability for the same task administration procedure used in the present study is .85 (Bisiacchi, Cendron, Gugliotta, Tressoldi, & Vio, 2005). The Chronbach alpha calculated in our sample was .53. The children had a total of four minutes to say how many different words they knew for each of four separate categories: colors, animals, fruits, and cities. Repeated words were not considered in the final score, which included only the total number of correct words.

Dimensional Change Card Sort (DCCS). The Dimensional Change Card Sort (Zelazo, 2006) task is a commonly used measure of EF in children between the ages of 3 and 5 that evaluates switching abilities. The test-retest reliability obtained in other studies is .92 (Weintraub et al., 2013). The Chronbach alpha calculated in our sample was .81. Children are required to sort a series of bivalent test cards, first according to one dimension (e.g., color) and then according to another dimension (e.g., shape). Target cards (a blue rabbit and a red boat) are affixed to the front of two boxes. The experimenter presents a series of cards (red rabbits and blue boats) and introduces the child to the "color game," in which the child must place all of the red cards in the box with the red boat affixed and all of the blue cards in the box with the blue rabbit affixed (pre-switch, six items). After the child performs five out of six correct trials, the experimenter announces that they will stop playing the color game and will begin playing the "shape game." The children are then asked to put all of the rabbits in the box with the red rabbit and all of the boats in the box with the blue boat (post-switch, six items). When at least five of the six trials have been performed correctly, the experimenter

introduces a new game, explaining that if there is a border on the card, it should be sorted according to the color, but if there is no border, then it should be sorted according to the shape (border version, twelve items). Before presenting each card, the experimenter announces the rule, describes the card (e.g., “Here’s a red one. Where does it go?”), and hands the card to the child. The test is stopped if the child does not pass five out of six trials in the first two sessions. The score was the proportion of total correct trials (out of 24 trials).

General intellectual functioning. Fluid intelligence was assessed using the Colored Progressive Matrices Test (CPM; Raven, 1947). CPM consists of 36 items. Each item contains a figure with a missing piece. Below the figure, six pieces are presented, only one of which correctly completes the figure. The participants are instructed on successive trials to point to the piece that best completes the pattern. The score was the total number of correct responses.

Mathematics. Math performance was assessed with the following tasks.

The Battery of Calculation Ability. To evaluate calculation ability, two subtests from the standardized Battery of Calculation Ability (AC-MT; Cornoldi, Lucangeli, & Bellina, 2002) were used: written calculation and arithmetical facts. The written calculation task consists of two addition and two subtraction problems using two-digit numbers for grade 1 and two addition, two subtraction, two multiplication and two division problems using three-digit numbers for grade 3. The accuracy score is calculated as the total number of correct responses in the task at both grade levels (range: 0 to 4 in first grade; 0 to 8 in third grade). The test-retest reliability for the written calculation task is .74 and .38 for the first and the third grade respectively (Cornoldi et al., 2002); in our sample Chronbach alpha was .83 and .48 for the first and the third grade, respectively.

The arithmetical facts task evaluates basic knowledge of addition and subtraction using one-digit numbers for grade 1 and multiplication for grade 3. A response is considered

correct only if it is given immediately and not after computation (before than 5 seconds). The score was the total number of correct response (range: 0 to 6 in first grade; 0 to 12 in third grade). In our sample Chronbach alpha was .68 and .78 for the first and the third grade, respectively.

Arithmetical Problem Solving. Three arithmetical problems were administered to the children in each grade. In grade 1, the arithmetic problems were prepared by a group of primary school teachers and included two subtraction and one addition problem (i.e., Yesterday Chiara received 12 presents for her birthday. Today she received 6 presents. How many presents did Chiara receive in all?). In grade 3, three arithmetical problems from the standardized progressive matrices battery (SPM) were used (Lucangeli, Tressoldi, & Cendron, 1998), in which each problem requires two operations (i.e., The school that Giacomo and Antonio attend has organized a school trip. All the students will take part in this trip. In the school, there are 12 classes of 23 students each. In addition, 27 teachers, 7 mothers, and 7 fathers will take part in the trip. In all, how many people will take part in the school trip?). After the experimenter read the text, the problems were administered individually. The score used for the analysis was the accuracy with which the child identified the appropriate operation for solving the problem (range: 0 to 3 in the first grade; 0 to 6 in the third grade). The test-retest reliability for the third grade problems is .85 (Lucangeli et al., 1998); in our sample Chronbach alpha was .59 and .79 for the first and the third grade, respectively.

The written calculation, arithmetical facts and problem solving scores were considered separately and were used to create a composite score of math achievement.

Statistical Analysis

Descriptive analyses, zero-order (Pearson) correlations among measures, and ANOVAs in which the CPM, EF and math measures were treated as dependent variables and

gender and mothers' level of education as independent variables were performed. Outliers in the EF tasks that were more than 3 standard deviations from the mean were few and accounted for less than .5% of all scores; these were pruned and treated as missing values.

A composite score for general math performance was calculated following the procedure used by Espy et al. (2004). The raw scores from each math task were transformed into z scores using the sample's overall mean and standard deviation (Table 1). Two composite scores (MATH1 and MATH3) were calculated separately for each grade level by averaging the z scores of the math variables. Principal component analyses of the math variables (written calculation, arithmetical facts and problem solving) at grades 1 and 3 were performed to verify that the math variables could be reduced to one component. CPA results showed that the math variables loaded on one component for grade level (54% of variance explained in 1st graders and 57% in 3rd graders; all factor loadings $>.55$ and ranging between $|.65|$ and $|.85|$ for 1st grade and $|.74|$ and $|.77|$ for 3rd grade). Because all of the math variables contribute to a single variable, a composite score was calculated.

A longitudinal model of math achievement at grades 1 and 3 was developed using kindergarten EF measures as predictors. In accordance with the two-step approach recommended by Anderson and Gerbing (1988), two latent variable techniques were used: confirmatory factor analyses (CFA) and full structural equation modeling (SEM; Bollen, 1989). As concerns CFA, the same data set and the same two-factor CFA model as in Usai et al. (2014) were used. The results revealed two EF components (inhibition and a mixed WM-flexibility factor) in kindergarten. The full structural equation model was used to test the hypothesis that math achievement (the composite math score and the single math scores) at grades 1 and 3 could be explained by these two EF components. These analyses were conducted using EQS 6.1 software (Bentler, 2006) and were based on the covariance matrix. The fit of each model to the data was evaluated by examining multiple fit indices

(Schermelleh-Engel, Moosbrugger, & Mueller, 2003): the χ^2 statistic, the root mean square error of approximation (RMSEA), the standardized root mean square residual (SRMR), Bentler's comparative fit index (CFI), the non-normed fit index (NNFI).

The χ^2 test was used to evaluate the appropriateness of the CFA model; non-significant values indicate minor differences between the covariance matrix generated by the model and the observed matrix and, thus, an acceptable fit. The RMSEA is a measure of approximate fit; it measures how closely the covariances predicted by the model match the actual covariances. RMSEA values $\leq .05$ represent a good fit, values between .05 and .08 represent an adequate fit, values between .08 and .10 represent a mediocre fit, and values greater than .10 are unacceptable (Browne & Cudeck, 1993). The SRMR is the square root of the averaged square residuals (i.e., the differences between the observed and predicted covariances). SRMR values $< .10$ are acceptable, but values smaller than .05 represent a good fit (Schermelleh-Engel et al., 2003). The CFI compares both the covariance matrix predicted by the model and a null model with the observed covariance matrix. The NNFI calculates how much better the researcher's model improves the model fit than the null model while controlling for degrees of freedom. CFI and NNFI values greater than .97 are indicative of a good fit, and values greater than .95 indicate an acceptable fit (Schermelleh-Engel et al., 2003).

Results

The descriptive statistics for the six EF measures and the CPM collected in kindergarten and for the math measures collected in grades 1 and 3 are shown in Table 1. The skewness and kurtosis coefficients were relatively low, except on the switching task (DCCS); therefore, an arcsin transformation was applied to these scores to normalize the distribution of the proportional data. The raw descriptive statistics for the DCCS were mean=17.63, s.d.=3.80, skewness=-1.58, kurtosis=3.51.

No differences in intellectual functioning and EFs were found between males and females. No gender differences were found on written calculation or problem solving tasks in either grade (grade 1 and grade 3). In grade 3, females performed worse than males on the arithmetical facts task, $F(1,116)=6.40$ $p=.013$ $\eta_p^2=.05$ (females: $M=9.49$, $SD=2.67$; males: $M=10.63$, $SD=2.21$).

Level of maternal education did not significantly influence intellectual functioning, EF or math performance, with two exceptions. In the last year of kindergarten, $F(2,164)=5.53$ $p=.005$, $\eta_p^2=.06$, children of mothers with a university degree showed a better performance ($M=29.90$, $SD=6.77$) on the fluency task than children whose mothers had the lowest level of education ($M=25.48$, $SD=4.74$, Tukey post-hoc $p<.05$). Similarly, in grade 3, $F(2,107)=3.36$ $p=.039$, $\eta_p^2=.06$, children of mothers with a university degree showed a greater accuracy ($M=6.58$, $SD=1.49$) on the written calculation task than children whose mothers had the lowest level of education ($M=5.39$, $SD=2.02$; Tukey post-hoc $p<.05$). Children whose mothers had a high school degree did not perform differently than the others ($M=5.92$, $SD=1.79$).

Table 1

Descriptive statistics of kindergarten EF measures and math measures from grades 1 and 3.

		N	Minimum	Maximum	Mean	Std. Dev.	Skewness	Kurtosis
EF at Kindergarten	CDT	175	-.077	.910	.552	.228	-.666	-.043
	ToL	175	8	33	22.983	4.352	-.571	.816
	DRST	175	0	10	4.629	2.705	.065	-1.081
	BDS	175	1	4	2.040	.591	.161	.441
	Fluency	175	10	46	27.914	6.491	.207	.267
	DCCS	175	.253	1.571	.861	.254	.273	2.543
	CPM	175	13	30	17.680	3.387	.966	.740
Math at 1st grade	WritCalc1	129	0	4	2.915	1.223	-.975	.113
	ArithFacts1	126	0	6	5.112	1.318	-2.139	5.020
	ProbProc1	128	0	3	1.961	.836	-.665	.112
	MATH1	129	-2.218	.932	-.003	.738	-.911	.251
Math at 3rd grade	WritCalc3	111	0	7	6.135	1.729	-.857	.087
	ArithFacts3	117	0	12	10.154	2.466	-1.795	3.382
	ProbProc3	118	0	6	3.050	1.758	.275	-1.223
	MATH3	118	-2.620	1.210	-.002	.759	-.607	.174

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London in kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS= Backward Digit Span in kindergarten; Fluency=semantic Fluency in kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; WritCalc1=correct responses in written calculation in grade 1; ArithFacts1=correct responses in arithmetic facts in grade 1; ProbProc1=correct answers in problem solving procedure in grade 1; MATH1=composite score for general math performance in grade 1; WritCalc3=correct responses in written calculation in grade 3; ArithFacts3=correct responses in arithmetic facts in grade 3; ProbProc3=correct answers in problem solving procedure in grade 3; MATH3=composite score for general math performance in grade 3.

Correlations between EF and math measures

The math measures collected in grades 1 and 3 are significantly correlated with general cognitive functioning and with the EF measures collected in kindergarten (Table 2).

Table 2

Zero-order correlations (pairwise comparisons) between executive and general cognitive tasks and math measures. Zero-order correlations across math measures are reported at the bottom of the table.

	WritCalc1	ArithFacts1	ProbProc1	WritCalc3	ArithFacts3	ProbProc3
CDT	.15	.16	.22*	.10	.03	.01
ToL	.18*	.22*	.33**	.12	.08	.17
DRST	.14	.18*	.21*	.18	.27**	.34**
BDS	.32**	.28**	.39**	.23*	.36**	.35**
Fluency	.07	.08	.18*	.12	.22**	.30**
DCCS	.32**	.20*	.19*	.19*	.27**	.28**
CPM	.16	.06	.28**	.37**	.11	.19*
Maternal education	.09	.11	.09	.25*	.14	.18
ArithFacts1	.42**	-				
ProbProc1	.37**	.12	-	-		
WritCalc3	.20*	.29**	.32**	-		
ArithFacts3	.23*	.19*	.34**	.34**	-	
ProbProc3	.27**	-.16	.30**	.36**	.38**	-

*p<0.05; **p<0.01

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London in kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS= Backward Digit Span in kindergarten; Fluency=semantic Fluency in

kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; Maternal Education: mother's level of education; WritCalc1=correct responses in written calculation in grade 1; ArithFacts1=correct responses in arithmetic facts in grade 1; ProbProc1=correct answers in problem solving procedure in grade 1; WritCalc3=correct responses in written calculation in grade 3; ArithFacts3=correct responses in arithmetic facts in grade 3; ProbProc3=correct answers in problem solving procedure in grade 3.

In particular, accuracy on the problem-solving task is the most strongly associated with EF in both grades. In fact, problem-solving correlates with all of the EF measures in grade 1 and with most of the EF measures in grade 3 (with the exception of CDT and ToL). The arithmetical facts score is significantly correlated with DRST, BDS and DCCS in both grades. However, it is significantly correlated with ToL only in grade 1 and with Fluency only in grade 3. Written calculation appears to be less associated with EF measures but correlates in both grades with BDS. In grade 1, it also correlates with ToL and DCCS, but in grade 3, only the correlation with DCCS remains, though the relationship is weaker.

General cognitive functioning as measured by CPM is more strongly associated with math performance, especially written calculation and problem solving, in grade 3 than in grade 1. Finally, maternal education is only marginally associated with math performance.

Among the EF measures, therefore, the BDS and the DCCS show the strongest associations with math performance. Problem solving appears to be more strongly associated with EF.

Modeling the relations between the EF measures

The CFA model illustrated in this section is the same as that reported in Usai et al. (2014). Here we provide a brief summary of the results. Zero-order correlations among the six measures of EF were generally low, ranging from -.02 to .37, and only the correlations between BDS and TOL (.33) and between BDS and DCCS (.37) were statistically significant.

To determine the EF structure, three models representing three different theoretical hypothesis were tested: a one-factor model to test the single executive control model proposed by Wiebe et al. (2008), a three-factor model inspired to the Miyake et al. (2000) EF taxonomy and a two-factor model based on the hypothesis suggested by Miller et al. (2012). The examination of fit indices revealed that the two-factor model consisting of inhibition and a mixed WM-flexibility factor provided the best fit to the data (see Usai et al., 2014 for details on model comparison). The fit indices are all good: $\chi^2=9.481$, $p=.30$, CFI=.983, NNFI=.968, SRMR=.043, RMSEA=.033, 90% CI=[.000, .098]. The estimate of the correlation between the latent variables was large (.63). The 95% confidence interval for the correlation was [.45, .76].

The factor loadings were all significant (t values > 2). The proportion of variance in the individual task scores explained by the latent variables varied across tasks. The R^2 values were .48 for the ToL, .18 for the CDT, .57 for the BDS, .27 for the DCCS, .11 for the DRST and .08 for Fluency. At this age level, the two latent executive factors accounted for the largest portion of variability for the ToL and for the BDS. More details and a discussion of the model can be found in Usai et al. (2014).

Modeling the relation among EF, general cognitive functioning and maternal education as predictors of math achievement

The SEM included the two latent EF factors established previously (inhibition and WM-flexibility), the observed math composite scores from the first and third grade assessments and the two control variables (general cognitive score and mother's education level).

Structural paths were added to the model such that each executive factor and control variable predicted each math factor (see Figure 1). A path from the composite math score at grade 1 to the composite math score at grade 3 was also included.

In SEM modeling, unidirectional arrows leading from one factor to another factor denote which factor is the independent variable and which is the dependent variable. Because this analysis is correlational in nature and functions as a complex multiple regression analysis, the loadings indicate that changes in the independent variables co-occur with changes in the dependent variables. In a longitudinal design, in which the independent variables are observed before the dependent variables, the loadings function as estimates of the degree to which change in the independent variable (after controlling for the other factors it correlates with) predicts change in the dependent variable.

The fit indices show that the model fits well with the data: $\chi^2=25.425$, $p=.383$, CFI=.990, NNFI=.981, SRMR=.052, RMSEA=.023, 90% CI=[.000, .081]. As Figure 1 shows, the mixed executive factor is the only predictor of math achievement both for first and third graders (both $ps<.05$). The inhibition factor does not significantly predict math performance in grade 1 or grade 3. The model accounts for 48% of the math composite score variance in grade 1 and 63% in grade 3.

Modeling the relation among EF, general cognitive functioning and maternal education as predictors of single math scores

To investigate the role of the latent executive dimensions on each of the math tasks (written calculation, arithmetical facts and problem solving) longitudinally, controlling for general cognitive score and mother's education level, three analyses were performed. The models are shown in Figures 2, 3 and 4.

For written calculation (Figure 2), the fit indices are good and the chi-square value is not significant: $\chi^2=31.269$, $p=.18$, CFI=.930, NNFI=.874, SRMR=.061, RMSEA=.049, 90% CI=[.000, .096]. The model accounts for 20% of the accuracy variance in the written calculation task in first grade and 27% in third grade. The written calculation task was significantly predicted by only WM-flexibility in first grade. The written calculation task in

grade 1 did not significantly predict the written calculation task at grade 3, controlling for the others variables. Consequently, as shown in Figure 2, the relationship between these two variables was not included.

For arithmetical facts (Figure 3), the model fit the data well and the chi-square value is not significant: $\chi^2=21.393$, $p=.615$, CFI=1.000, NNFI=1.059, SRMR=.048, RMSEA=.000, 90% CI=[.000, .067]. The model accounts for 18% of the accuracy variance in the arithmetic facts task in first grade, but neither of the factor loadings are significant, indicating that none of the predictors alone predicts variability in the specific math component. Contrarily, 45% of the variance registered with the arithmetic facts task in third grade was predicted by the WM-flexibility.

For problem solving (Figure 4), the model fit the data well and the chi-square value is not significant: $\chi^2=30.168$, $p=.179$, CFI=.954, NNFI=.914, SRMR=.056, RMSEA=.048, 90% CI=[.000, .095]. The model accounts for 54% of the accuracy variance in the problem-solving task in first grade, but neither of the factor loadings are significant, indicating that none of the predictors alone predicts variability in the specific math component. Contrarily, 52% of the variance registered with the problem solving task at third grade was predicted by the WM-flexibility.

The roles of general cognitive functioning and maternal education

CPM scores and maternal education levels were included as predictors of math scores to clarify the associations between EF and math proficiency. General cognitive functioning, as measured by CPM, was positively correlated with only the mixed executive factor in all of the models (Figures 1, 2, 3, 4). Maternal education was positively correlated with the inhibition factor in all the three models and with the mixed executive factor in model 3 (Figure 2). However, the influence of both variables on math performance was limited. CPM scores and

maternal education levels significantly predicted only written calculation performance in grade 3 (Figure 3).

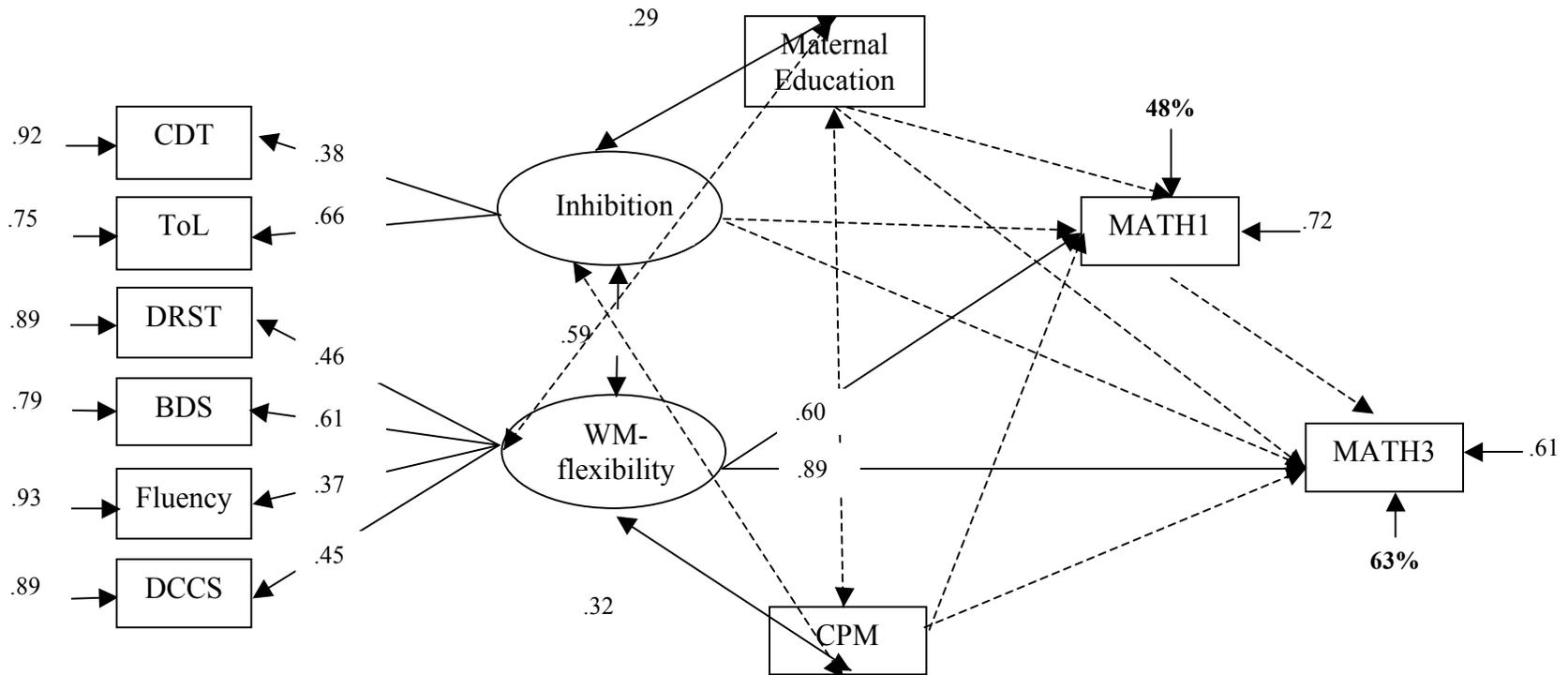


Figure 1. Structural model specifying the relationships among executive functioning, control variables and math composite scores at grade 1 and at grade 3. Values are standardized estimates. Dashed lines indicate non-significant estimates.

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London in kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS=Backward Digit Span in kindergarten; Fluency=semantic Fluency in kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; Maternal Education: mother's level of education; MATH1=composite score for general math performance in grade 1; MATH3=composite score for general math performance in grade 3.

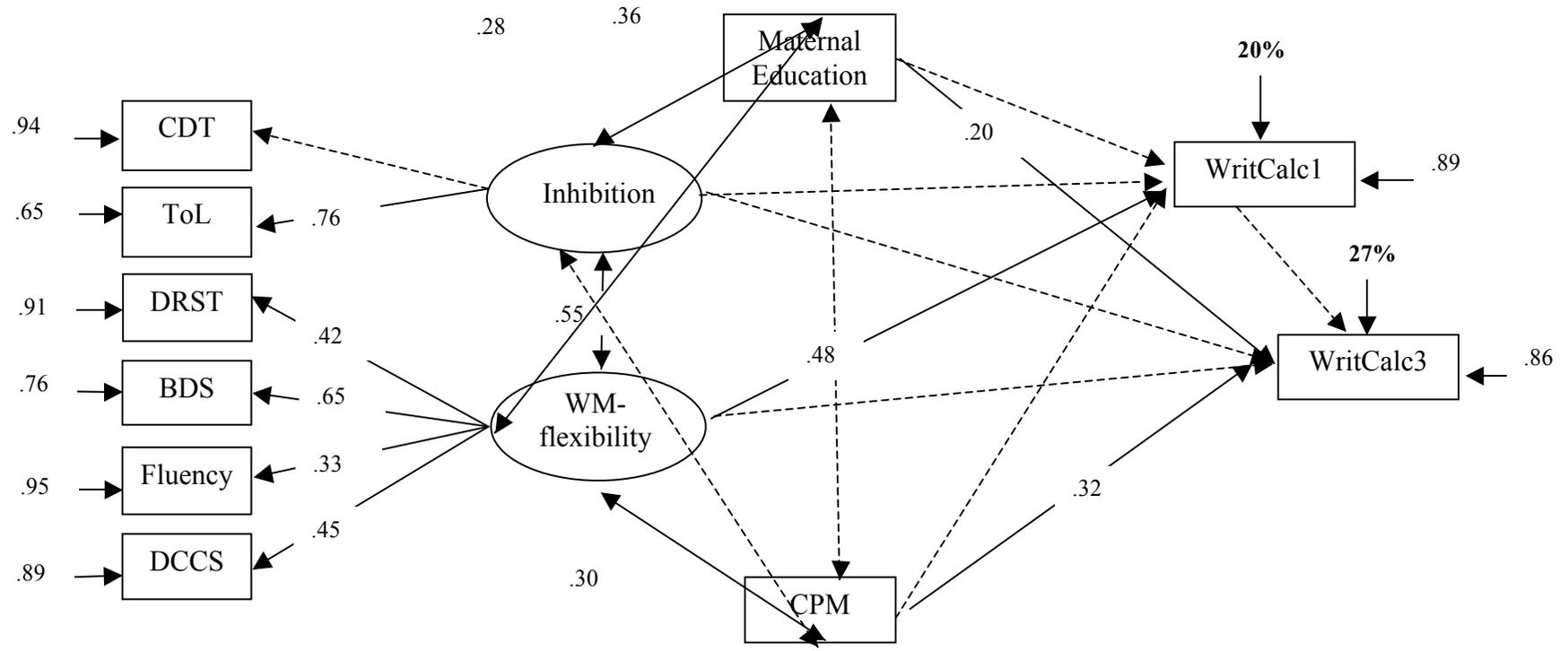


Figure 2. Structural model specifying the relationships among executive functions, control variables and written calculation at grade 1 and at grade 3. Values are standardized estimates. Dashed lines indicate non-significant estimates.

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London in kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS=Backward Digit Span in kindergarten; Fluency=semantic Fluency in kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; Maternal Education: mother's level of education; WritCalc1=correct responses in written calculation in grade 1; WritCalc3=correct responses in written calculation in grade 3.

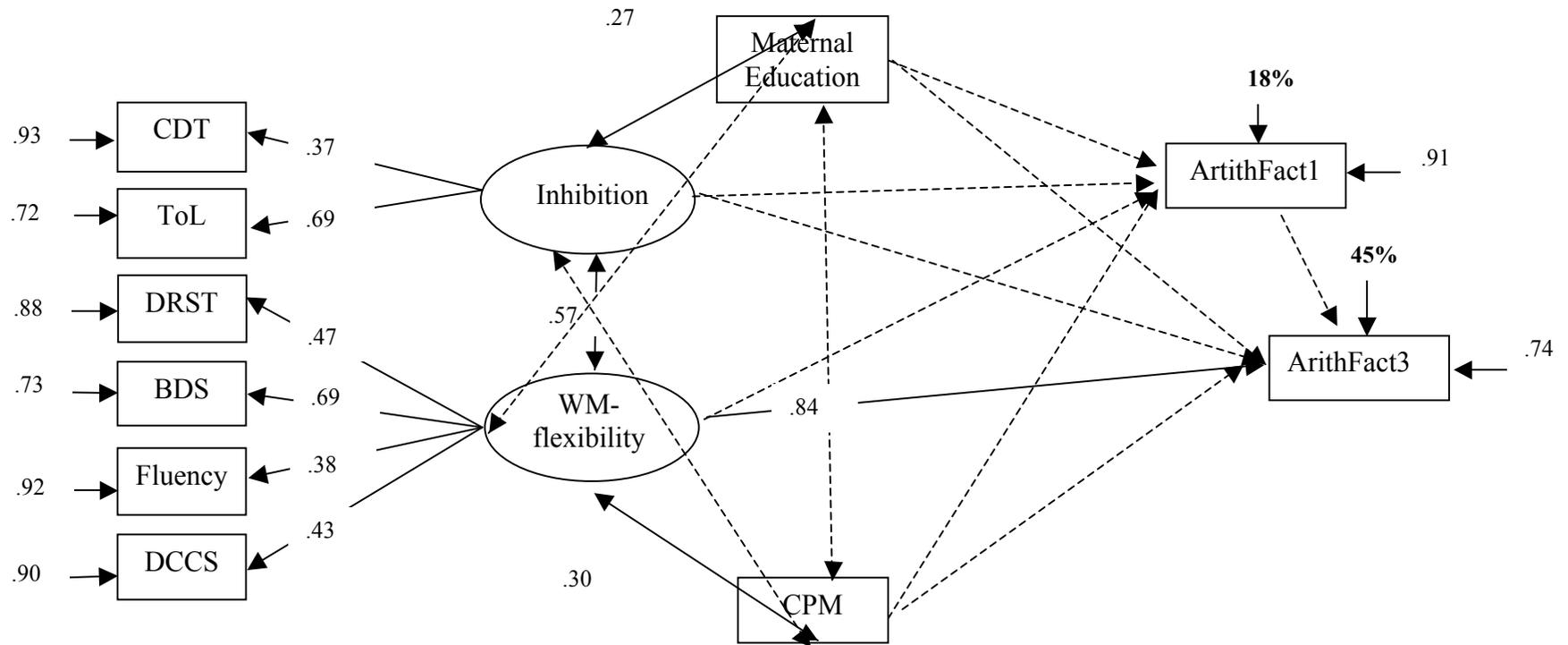


Figure 3. Structural model specifying the relationships among executive functions, control variables and arithmetical facts at grade 1 and at grade 3. Values are standardized estimates. Dashed lines indicate non-significant estimates.

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London in kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS=Backward Digit Span in kindergarten; Fluency=semantic Fluency in kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; Maternal Education: mother's level of education; ArithFacts1=correct responses in arithmetic facts in grade 1; ArithFacts3=correct responses in arithmetic facts in grade 3.

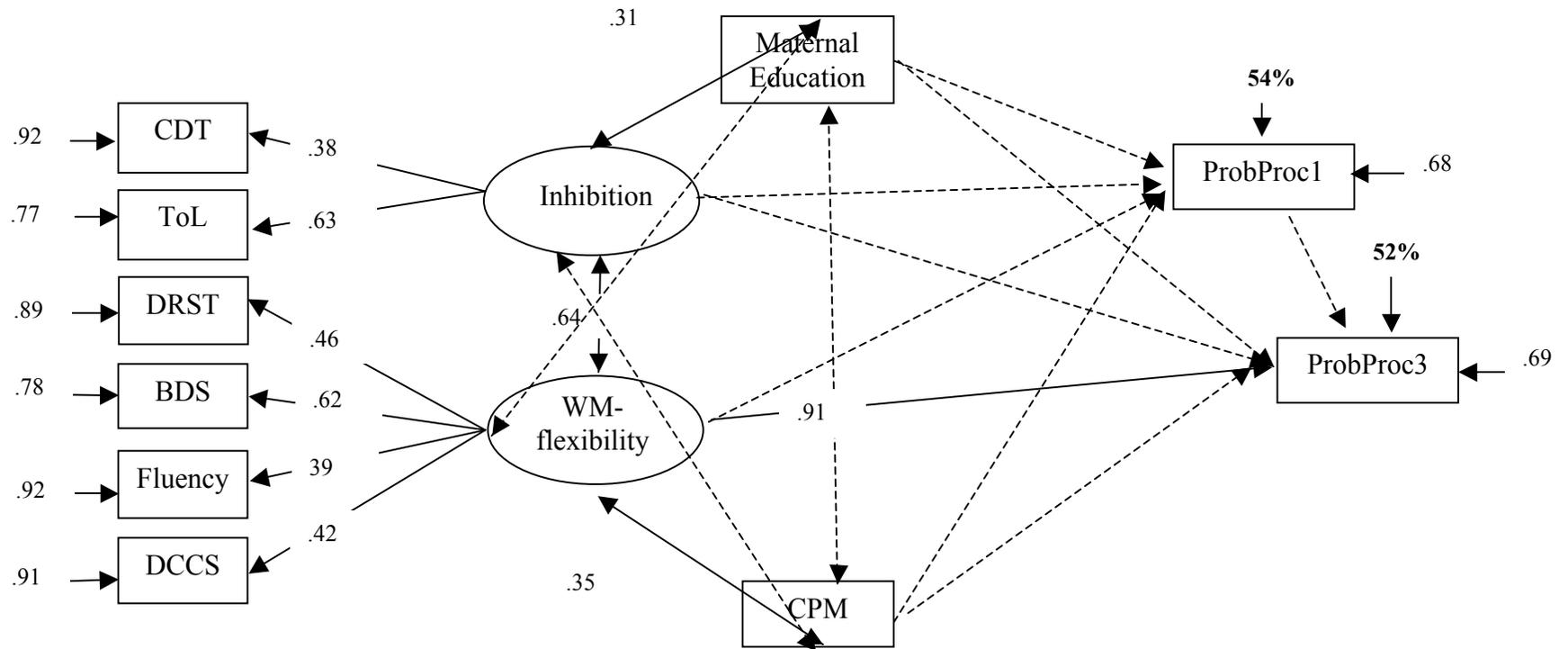


Figure 4. Structural model specifying the relationships among executive functions, control variables and problem solving at grade 1 and at grade 3. Values are standardized estimates. Dashed lines indicate non-significant estimates.

Note. CDT=Circle Drawing Task in kindergarten; ToL=Tower of London at kindergarten; DRST=Dual Request Selective Task in kindergarten; BDS=Backward Digit Span in kindergarten; Fluency=semantic Fluency in kindergarten; DCCS=Dimensional Change Sort Task in kindergarten; CPM=Colored Progressive Matrices Test in kindergarten; Maternal Education: mother's level of education; ProbProc1=correct answers in problem solving procedure in grade 1; ProbProc3=correct answers in problem solving procedure in grade 3.

Discussion

This study adds to the growing body of research that confirms the role of EF skills in fostering the acquisition of early math abilities. In particular, the present study assessed whether select EF components support specific aspects of math learning (written calculation, arithmetical facts and problem solving) and contributes to the literature by applying CFA to model EF functioning and using a longitudinal design to more clearly specify the predictive associations between EF skills measured in kindergarten and subsequent math achievement in grades 1 and 3.

Overall, the results indicate that EF levels in kindergarten have significant predictive power for mathematical achievement in grade 3 and, to a lesser extent, in grade 1. Interestingly, both general cognitive functioning and maternal education had a minor influence on math performance. In agreement with the literature, maternal education was positively associated with both EF factors (see, e.g., Hackman & Farah, 2009; Noble, Norman, & Farah, 2005; Noble, McCandliss, & Farah, 2007), but its contribution to math performance was not significant except for written calculation in grade 3. However, it should be noted that our sample was quite homogeneous in terms of mothers' education level: 87% of mothers received a high school or college education, that means about 13 to 18 years of formal education, and the remaining 13% had a middle school degree. General intellectual functioning was positively associated with only the WM-shifting factor and again with written calculation in grade 3; this result is consistent with that of Friedman et al. (2006) who found intelligence to be more correlated with updating, rather than with inhibition tasks.

Previous studies (Bull et al., 2008; Miller et al., 2013; Passolunghi et al., 2008; Passolunghi & Lanfranchi, 2012) found that WM was more predictive of math performance than inhibition. Accordingly, in this study, only the WM-flexibility factor was a significant predictor of both the composite scores at each grade level and the single components of math abilities, even though with some differences depending on grade level. In fact, when the

single math ability scores were used as outcome measures, the WM-flexibility component predicted only written calculation in grade 1. In grade 3, both problem-solving performance and arithmetical facts performance were predicted by the WM-flexibility component, whereas written calculation was found to be associated with only general cognitive functioning and maternal education.

These findings support the hypothesis that the contribution of EF subcomponents varies across math components (see Cragg & Gilmore, 2014) and grade levels. Within the literature based on Baddeley's theoretical model of WM (Baddeley, 1986), a frequently posed hypothesis is that mathematical performance becomes more dependent on updating capacity with age (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). In line with this body of research, our results indicate that early EF measures are more predictive of math performance in older children than in younger children. In early grades math achievement would be more strongly associated with domain-specific competencies, such as the ability to immediately apprehend the value of small quantities, make judgments about numbers and their magnitudes and understand counting principles (Jordan, Glutting, & Ramineni, 2010; Jordan, Kaplan, Ramineni, & Locuniak, 2009). Nevertheless, since in our sample we did not evaluate domain-specific abilities at first assessment, we could not compare the different role of EF and domain-specific skills in short and long term prediction of math performance.

The analysis of the relationships between the EF subcomponents and math skills showed that in grade 3, both problem-solving performance and arithmetical facts performance were predicted by the WM-flexibility component, and written calculation performance was only associated with general cognitive functioning.

Inconsistent relationships between EF and math performance were also found by Best et al. (2011) in their large cross-sectional study, in which they observed that EF was a stronger correlate of problem solving than of calculation, as in the present study. To explain

these results, they proposed that problem solving is more strongly dependent on strategy formulation and implementation and self-monitoring, which are critical components of EF, than calculation (Best et al., 2011). This explanation appears to be more useful to illustrate the concurrent, rather than the longitudinal, relationship between EF and math skills. The longitudinal link between WM and problem solving can be better framed within the literature that explored how WM can affect learning processes over the course of time. Alloway, Gathercole, Kirkwood, and Elliott (2009), for example, suggest that children with poor WM frequently fail in tasks that require remembering lengthy instructions or coping with simultaneous processing and storage demands; as a consequence, they lose crucial information due to WM overload, which in turn affects their learning outcome. In this view, the effect of poor WM is cumulative across development and results in poorer learning outcomes as a child gets older, especially in tasks such as math word problems that impose high demands on a child's WM as they involve a complex interplay of processes (language comprehension, problem representation, selection and execution of calculation operations). Gathercole et al. (2008), analyzing the profiles of children with poor WM at different age levels, found in fact that older children performed significantly more poorly than younger children on learning measures.

In addition, WM was found to be associated with strategy use. For example, in the study by Geary, Hoard, Byrd-Craven, and De Soto (2004), strong performance on the WM measures was associated with the use of more sophisticated strategies in solving simple and complex additions in primary school children. Similarly, Van der Ven, Boom, Kroesbergen and Leseman (2012) found that WM was related to both the maturity of strategy choice and the probability of making procedural mistakes. This suggests that children with lower WM abilities might show more difficulties in developing efficient strategies to control their learning processes, as well as making more mistakes in executing the strategies they choose.

In the arithmetical fact task, the children were required to retrieve the correct answer within 5 seconds. Though arithmetic fact retrieval is influenced by the strength of fact representation in long-term memory, it has been suggested that this process also depends on WM (Lemaire, 1996). In a study with third and fourth graders, Barrouillet and Lépine (2005), for example, found that children's WM resources affected both the frequency and the efficiency of the retrieval strategy in simple arithmetic problem solving. They suggest that these results are in line with Siegler's (1996) theoretical framework, which predicts that individual differences in WM capacity should affect the use of retrieval at two different levels: the construction of associations and their subsequent use. As regards the associative process, low WM resources should lead to weaker associations between the arithmetic problem and the correct answer. Secondly, low WM capacity would be associated with a reduced amount of attentional resources available to activate knowledge from long-term memory, thus resulting in slower and less efficient retrieval processes (Barrouillet, Bernardin, & Camos, 2004). Finally, the transition between the use of algorithmic computing and direct retrieval in simple arithmetic problems takes place across the third and fourth grades (Cooney, Swanson, & Ladd, 1988; Widaman, Little, Geary, & Cormier, 1992). This suggests that during this developmental stage, factors such as WM capacity should still have an impact because children do not completely rely on retrieval strategies.

Unexpectedly, inhibitory processes were not predictive of later math performance. One possible explanation is that the measures we used to assess inhibitory processes were tapping one particular aspect of inhibition, which is response inhibition. Several authors (Nigg, 2000) have suggested that inhibitory processes may be better conceptualized as a set of functions than as a unitary construct, even in early infancy (Gandolfi, Viterbori, Traverso, & Usai, 2014). According to this observation, the capacity to suppress prepotent but inappropriate responses (response inhibition) and the ability to filter out irrelevant

information (interference monitoring and suppression) could affect math skills differently. In the case of our study, the inhibition component better represented response inhibition, whereas research findings indicate that the suppression of irrelevant information, which is interference monitoring and suppression, is more related to math skills (Passolunghi & Siegel, 2001).

Our results support the associations between EF subcomponents and math skills found in previous studies, suggesting that early EF skills are important predictors of later math achievement. However, some limitations of this study need mentioning. First, we did not evaluate the children's early number competence in kindergarten. To develop a comprehensive model for early math development, both number-specific and domain-general cognitive abilities should be considered to evaluate the contribution of both knowledge-based skills (e.g., number sense, counting, number recognition) and cognitive skills (e.g., EF). Several authors (Hornung, Schiltz, Brunner, & Martin, 2014) have suggested, for example, that both nonverbal number sense and WM capacity contribute to early number competence in kindergarten, which in turn predicts math achievement in grade 1. Second, due to power consideration, we could not test a comprehensive model in which the two EF components could be related to all the math measures at the same time, in order to take their covariance into account.

Nevertheless, the present findings have implications for assessment and educational practices. First, they suggest that early measures of EF may be useful in identifying children who may experience difficulty learning mathematical skills and concepts. They also indicate that supporting executive skills might enhance early childhood mathematics education, even though for now there is little evidence of the generalization of WM and EF training to other skills for both typically and atypically developing children (Melby-Lervåg & Hulme, 2013; Rapport, Orban, Kofler, & Friedman, 2013). The development of EF interventions that are

more integrated with learning goals and interwoven within curricula could help generalizing the EF gains to other competencies (Traverso, Viterbori & Usai, 2015). Finally, the results suggest that adequate teaching strategies should be developed for children with lower WM capacity to prevent or reduce task failure which in turn could help these children reducing the long term effects of poor WM

References

- Agostino, A., Johnson, J., & Pascual-Leone, J. (2010). Executive functions underlying multiplicative reasoning: Problem type matters. *Journal of Experimental Child Psychology*, 105, 286-305. doi: 10.1016/j.jecp.2009.09.006
- Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, 106, 20-29. doi:10.1016/j.jecp.2009.11.003
- Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable? *Child Development*, 77, 1698-1716.
- Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development*, 80, 606-621. doi: 10.1111/j.1467-8624.2009.01282.x
- Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin*, 103, 411-423. doi: 10.1037/0033-2909.103.3.411
- Baddeley, A. D. (1986). *Working memory*. Oxford, UK: Oxford University Press.
- Barrouillet, P., & L epine, R. (2005). Working memory and children's use of retrieval to solve addition problems. *Journal of Experimental Child Psychology*, 91, 183-204. doi: 10.1016/j.jecp.2005.03.002
- Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General*, 133, 83. doi: 10.1037/0096-3445.133.1.83

- Barrouillet, P., Fayol, M., & Lathuliere, E. (1997). Selecting between competitors in multiplication tasks: an explanation of errors produced by adolescents with learning difficulties. *International Journal of Behavioral Development*, 21; 253–275
- Bentler, P. M. (2006). *EQS 6 structural equations program manual*. Encino, CA: Multivariate Software, inc.
- Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, 21, 327-336. doi: 10.1016/j.lindif.2011.01.007
- Bisiacchi, P. S., Cendron, M., Gugliotta, M., Tressoldi, P. E., & Vio, C. (2005). *BVN 5-11. Batteria di valutazione neuropsicologica per l'età evolutiva*. Trento: Erickson.
- Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, 78, 647–663. doi: 10.1111/j.1467–8624.2007.01019.x 17381795
- Bollen, K. A. (1989). *Structural Equations with Latent Variables*. New York: Wiley.
- Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen, & J. S. Long (Eds.), *Testing Structural Equation Models* (pp. 136–162). Beverly Hills, CA: Sage.
- Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives*, 8, 36-41. doi: 10.1111/cdep.12059
- Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, 33, 205-228. doi: 10.1080/87565640801982312
- Bull, R., Espy, K. A., Wiebe, S. A., Sheffield, T. D., & Nelson, J. M. (2011). Using confirmatory factor analysis to understand executive control in preschool children:

- Sources of variation in emergent mathematic achievement. *Developmental Science*, 14, 679-692. doi: 10.1111/j.1467-7687.2010.01012.x
- Clark, C. A., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*, 46, 1176. doi: 10.1037/a0019672
- Conway, A. R., & Engle, R. W. (1994). Working memory and retrieval: a resource-dependent inhibition model. *Journal of Experimental Psychology: General*, 123, 354.
- Cooney, J. B., Swanson, H. L., & Ladd, S. F. (1988). Acquisition of mental multiplication skill: Evidence for the transition between counting and retrieval strategies. *Cognition and Instruction*, 5, 323-345. doi: 10.1207/s1532690xci0504_5
- Cornoldi, C., Lucangeli, D., & Bellina, M. (2002). *AC-MT. Test di valutazione delle abilità di calcolo*. Trento: Erickson.
- Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, 3, 63-68. doi: 10.1016/j.tine.2013.12.001
- Deschuyteneer, M., & Vandierendonck, A. (2005). The role of response selection and input monitoring in solving simple arithmetical products. *Memory & Cognition*, 33, 1472-1483.
- Duncan, G. J., Brooks-Gunn, J., & Klebanov, P. K. (1994). Economic deprivation and early childhood development. *Child Development*, 65, 296-318.
- Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology*, 26, 465-486. doi: 10.1207/s15326942dn2601_6

- Fancello, G. S., Vio, C., & Cianchetti, C. (2006). *TOL. Torre di Londra. Test di valutazione delle funzioni esecutive (pianificazione e problem solving)*. Trento: Erickson.
- Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, 17(2), 172-179. doi: 10.1111/j.1467-9280.2006.01681.x
- Friso-van den Bos, I., van der Ven, S. H., Kroesbergen, E. H., & van Luit, J. E. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, 10, 29-44. doi: 10.1016/j.edurev.2013.05.003
- Gandolfi, E., Viterbori, P., Traverso, L., & Usai, M. C. (2014). Inhibitory processes in toddlers: A latent-variable approach. *Frontiers in Psychology*, 5, 381. doi: 10.3389/fpsyg.2014.00381
- Gathercole, S. E., Durling, E., Evans, M., Jeffcock, S., & Stone, S. (2008). Working memory abilities and children's performance in laboratory analogues of classroom activities. *Applied Cognitive Psychology*, 22, 1019-1037. doi: 10.1002/acp.1407
- Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology*, 88, 121-151. doi:10.1016/j.jecp.2004.03.002
- Geurts, H.M., Verté, S., Oosterlaan, J., Roeyers, H., & Sergeant, J.A. (2005). ADHD subtypes: Do they differ in their executive functioning profile? *Archives of Clinical Neuropsychology*, 20, 457-477. doi: 10.1016/j.acn.2004.11.001
- Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences*, 13, 65-73. doi: 10.1016/j.tics.2008.11.003

- Hirshorn, E. A., & Thompson-Schill, S. L. (2006). Role of the left inferior frontal gyrus in covert word retrieval: Neural correlates of switching during verbal fluency. *Neuropsychologia*, 44, 2547–2557. doi: 10.1016/j.neuropsychologia.2006.03.035
- Hornung, C., Schiltz, C., Brunner, M., & Martin, R. (2014). Predicting first-grade mathematics achievement: the contributions of domain-general cognitive abilities, nonverbal number sense, and early number competence. *Frontiers in psychology*, 5, 272. doi: 10.3389/fpsyg.2014.00272
- Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: A latent variable approach. *Developmental Neuropsychology*, 35, 20-36. doi:10.1080/87565640903325691
- Jordan, N. C., Glutting, J., & Ramineni, C. (2010). The importance of number sense to mathematics achievement in first and third grades. *Learning and Individual Differences*, 20, 82-88. doi: 10.1016/j.lindif.2009.07.004
- Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: kindergarten number competence and later mathematics outcomes. *Developmental Psychology*, 45, 850-867. doi:10.1037/a0014939
- Kavé, G., Kigel, S., & Kochva, R. (2008). Switching and clustering in verbal fluency tasks throughout childhood. *Journal of Clinical and Experimental Neuropsychology*, 30, 349–359. doi:10.1080/13803390701416197
- Kroesbergen, E. H., Van Luit, J. E. H., Van Lieshout, E. C. D. M., Van Loosbroek, E., & Van de Rijt, B. A. M. (2009). Individual differences in early numeracy the role of executive functions and subitizing. *Journal of Psychoeducational Assessment*, 27, 226-236. doi: 10.1177/0734282908330586
- Lan, X., Legare, C. H., Ponitz, C. C., Li, S., & Morrison, F. J. (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-

- cultural analysis of Chinese and American preschoolers. *Journal of Experimental Child Psychology*, 108, 677-692. doi: 10.1016/j.jecp.2010.11.001
- Lanfranchi S. & Vianello R. (2008) A battery for assessing short-term and working memory in preschoolers: preliminary results. In N. B. Johansen (Ed) *New Research on Short-Term Memory* (pp.207-222). New York: Nova Science Publishers. ISBN: 9781604565485.
- LeBlanc M.D., & Weber-Russell S. (1996). Text integration and mathematics connections: A computer model of arithmetic work problem-solving. *Cognitive Science*, 20, 357–407. doi: 10.1207/s15516709cog2003_2
- Lee, K., Bull, R., & Ho, R. M. H. (2013). Developmental changes in executive functioning. *Child Development*, 84, 1933-1953. doi: 10.1111/cdev.12096
- Lehto, J. E., Juujarvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, 21, 59–80. doi: 10.1348/026151003321164627
- Lemaire, P. (1996). The role of working memory resources in simple cognitive arithmetic. *European Journal of Cognitive Psychology*, 8(1), 73-104.
- Lemaire, P., Abdi, H., & Fayol, M. (1996). The role of working memory resources in simple cognitive arithmetic. *European Journal of Cognitive Psychology*, 8, 73-103. doi: 10.1080/095414496383211
- Lucangeli, D., Tressoldi, P.E., & Cendron, M. (1998). *SPM. Soluzione Problemi di Matematica*. Trento: Erickson.
- Marzocchi, G .M., Oosterlaan, J., Zuddas, A., Cavolina, P., Geurts, H., Redigolo, D., Vio, C., & Sergeant, J. A. (2008). Contrasting deficits on executive functions between ADHD and reading disabled children. *Journal of Child Psychology and Psychiatry*, 49, 543–552. doi: 10.1111/j.1469-7610.2007.01859.x

- Mazzocco, M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*, 13, 18-45. doi:10.1080/09297040600611346
- McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, 43, 947-959. doi: 10.1037/0012-1649.43.4.947
- Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, 49, 270-291. doi: 10.1037/a0028228
- Miller, M. R., Giesbrecht, G. F., Müller, U., McInerney, R. J., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. *Journal of Cognitive Development*, 13, 395-423. doi: 10.1080/15248372.2011.585478
- Miller, M. R., Müller, U., Giesbrecht, G. F., Carpendale, J. I., & Kerns, K. A. (2013). The contribution of executive function and social understanding to preschoolers' letter and math skills. *Cognitive Development*, 28, 331-349. doi: 10.1016/j.cogdev.2012.10.005
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49-100. doi: 10.1006/cogp.1999.0734
- Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology*, 73, 139-158.

- Nigg, J.T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, 126, 220–246. doi:10.1037/0033-2909.126.2.220
- Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science*, 10, 464-480. doi: 10.1111/j.1467-7687.2007.00600.x
- Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, 8, 74-87. doi: 10.1111/j.1467-7687.2005.00394.x
- Passolunghi M.C., Cornoldi C., & De Liberto S. (1999). Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. *Memory and Cognition*, 27, 779–790.
- Passolunghi M.C., Siegel L.S. (2001). Short-term memory, working memory, and inhibitory control in children with specific arithmetic learning disabilities. *Journal of Experimental Child Psychology*, 80, 44–57. doi:10.1006/jecp.2000.2626
- Passolunghi, M. C., & Lanfranchi, S. (2012). Domain-specific and domain-general precursors of mathematical achievement: A longitudinal study from kindergarten to first grade. *British Journal of Educational Psychology*, 82, 42-63. doi: 10.1111/j.2044-8279.2011.02039.x
- Passolunghi, M. C., & Pazzaglia, F. (2005). A comparison of updating processes in children good or poor in arithmetic word problem-solving. *Learning and Individual Differences*, 15, 257-269.
- Passolunghi, M. C., Mammarella, I. C., & Altoè, G. (2008). Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. *Developmental Neuropsychology*, 33, 229-250. doi: 10.1080/87565640801982320

- Rappaport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review, 33*, 1237-1252. doi: 10.1016/j.cpr.2013.08.005
- Raven, J. C. (1947). *Progressive matrices. Set A, Ab, B, Board and book form*. London: H.K.
- Re, A. M., & Cornoldi, C. (2007). ADHD at five: A diagnosis-intervention program. *Advances in Learning and Behavioral Disabilities, 20*, 223–240. doi: 10.1016/S0735-004X(07)20009-6
- Re, A.M., De Franchis, V., & Cornoldi, C. (2010). A working memory control deficit in kindergarten ADHD children. *Child Neuropsychology, 16*, 134-144. doi: 10.1080/09297040903373404
- Röthlisberger, M., Neuenschwander, R., Cimeli, P., & Roebbers, C. M. (2013). Executive functions in 5-to 8-year olds: Developmental changes and relationship to academic achievement. *Journal of Educational & Developmental Psychology, 3*, 153-167. doi: 10.5539/jedp.v3n2p153
- Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of Psychological Research, 8*, 23-74.
- Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences, 298*, 199-209. doi: doi:10.1098/rstb.1982.0082
- Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology, 96*, 471-491. doi: 10.1037/0022-0663.96.3.471

- Swanson, H. L., & Sachse-Lee, C. (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. *Journal of Experimental Child Psychology*, 79, 294-321. doi:10.1006/jecp.2000.2587
- Traverso, L., Viterbori, P., & Usai, M. C. (2015). Improving executive function in childhood: evaluation of a training intervention for 5-year-old children. *Frontiers in Psychology*, 6, 525. doi: 10.3389/fpsyg.2015.00525
- Unsworth, N., Spillers, G. J., & Brewer, G. A. (2011). Variation in verbal fluency: A latent variable analysis of clustering, switching, and overall performance. *The Quarterly Journal of Experimental Psychology*, 64, 447-466. doi: 10.1080/17470218.2010.505292
- Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in 5 to and 6 year old children: A longitudinal study. *European Journal of Developmental Psychology*, 11, 447-462. doi: 10.1080/17405629.2013.840578
- Van der Ven, S. H., Kroesbergen, E. H., Boom, J., & Leseman, P. P. (2012). The development of executive functions and early mathematics: A dynamic relationship. *British Journal of Educational Psychology*, 82, 100-119. doi:10.1111/j.2044-8279.2011.02035.x
- Van der Ven, S. H., Boom, J., Kroesbergen, E. H., & Leseman, P. P. (2012). Microgenetic patterns of children's multiplication learning: Confirming the overlapping waves model by latent growth modeling. *Journal Of Experimental Child Psychology*, 113, 1-19. doi:10.1016/j.jecp.2012.02.001
- Weintraub, S. et al. (2013). Cognition assessment using the NIH Toolbox. *Neurology*, 80, S54-S64. doi: 10.1212/WNL.0b013e3182872ded

- Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, 102, 43-53. doi: 10.1037/a0016738
- Widaman, K. F., Little, T. D., Geary, D. C., & Cormier, P. (1992). Individual differences in the development of skill in mental addition: Internal and external validation of chronometric models. *Learning and Individual Differences*, 4, 167-213.
- Wiebe, S., Espy, K., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, 44, 575-587. doi:10.1037/0012-1649.44.2.575
- Wiebe, S., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*, 108, 436-452. doi:10.1016/j.jecp.2010.08.008
- Zelazo, P. D. & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445-469). Oxford: Blackwell.
- Zelazo, P. D. (2006). The dimensional change card sort (DCCS): A method of assessing executive function in children. *Nature Protocols*, 1, 297-330. doi:10.1038/nprot.2006.46

