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Preschool executive functioning and literacy achievement in Grades 1 and 3 of primary school: A longitudinal study

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Abstract

This longitudinal study examines the extent to which selected components of executive function (EF) measured in preschool children predict several indices of literacy-related achievement during primary school, controlling for general intellectual functioning and maternal education. Six EF measures were assessed in a sample of 5-year-old children (N=175). The literacy achievement (reading/spelling and reading comprehension) of the same children was then tested in Grades 1 and 3. Using previous results obtained from the same sample of children (Usai et al., 2014), two EF components (inhibition and working memory-flexibility) were obtained by means of a confirmatory factor analysis. A full structural equation model was used to test the hypothesis that these two EF components predict literacy achievement in Grades 1 and 3. The results indicate that whereas reading comprehension was uniquely predicted by the WM-flexibility factor in Grade 3, EF did not uniquely predict the reading/spelling factor in either grade.

Preschool executive functioning and literacy achievement in Grades 1 and 3 of primary school: A longitudinal study

1. Introduction

It is generally recognized that early literacy draws upon multiple interrelated variables, including oral language skills and code-related precursors, such as naming letters of the alphabet (Whitehurst & Lonigan, 1998). Although these domain-specific skills are commonly recognized as the foundation for later reading and writing abilities, domain-general skills also play a role in the emergence and early acquisition of literacy. Among these skills, some recent results have highlighted executive function (EF). EFs are commonly defined as a set of cognitive abilities involved in the organization and realization of complex and goal-directed behaviours, such as initiating, planning and organizing one's actions, shifting attention between different tasks and suppressing prepotent responses to reach functional goals (Zelazo & Müller, 2002). EFs are involved in the regulation of more basic cognitive processes and are commonly associated with and predictive of different domains of school achievement (Best, Miller, & Naglieri, 2011; Bull & Scerif, 2001; Monette, Bigras, & Guay, 2011; Viterbori, Usai, Traverso, & De Franchis, 2015; Willoughby, Blair, Wirth, & Greenberg, 2012).

The current study examines the longitudinal relations among EFs measured in the last year of preschool and literacy achievement in primary school children at the ends of Grade 1 and Grade 3. Specifically, literacy achievement included a latent factor representing child performance on academic tests of reading and spelling skills and reading comprehension in a transparent orthographic system, such as the Italian language.

The identification of the cognitive precursors of literacy achievement before school entry can provide guidance to early educators concerning the skills that should be targeted for instruction and help develop specific interventions for children at risk for learning difficulties.

1.1. Executive function in preschoolers

EF skills seem to be present early, possibly in the first year of life, and develop over a long period of time, reaching maturity in adolescence (Lee, Bull, & Ho, 2013). In adults (Miyake et al., 2000) and older children (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003), EFs have been conceptualized as a multicomponent construct comprising primarily working memory (WM), cognitive flexibility (or set-shifting) and inhibition. Nevertheless, the research suggests that the organisation of EF changes in the course of development and that EF is a relatively undifferentiated construct in young children that becomes more modular with age. During the preschool years, a single undifferentiated executive factor was found in younger children (Wiebe et al., 2011), whereas two separate dimensions consisting of WM and inhibition were identified from five years of age (Lee et al., 2013; Miller, Giesbrecht, Mueller, McInerney, & Kerns, 2012; Monette, Bigras, & Lafreniere, 2015; Usai, Viterbori, Traverso, & De Franchis, 2014). Set-shifting or cognitive flexibility emerges later in development, probably over a protracted period ranging from middle childhood (Letho, Juujarvi, Kooistra, & Pulkkinen, 2003) to early adolescence (Lee et al., 2013), and after inhibition and WM abilities have been established.

In the current study, we used the data set employed by Usai et al. (2014) to define the EF latent structure of 5-year-old children. To determine the EF structure, a confirmatory factor approach was used to address the impurity problem. Task impurity refers to the fact that most measures of EF involve non-executive processes that can influence task performance (Miyake et al., 2000). The impurity problem can be addressed by assessing EFs with multiple tasks and then extracting their shared variance with exploratory or confirmatory factor analysis (EFA or CFA; Miller et al., 2012). In Usai et al.'s (2014) study three models representing three different theoretical hypotheses were tested. The examination of fit indices revealed that a two-factor model consisting of inhibition and a mixed WM-flexibility factor provided the best fit to the data. The fit indices were all good: $\chi^2 = 9.481$, $p = .30$, CFI = .983, TLI = .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].

Consequently, in the present study we analyze the contribution of inhibition and of a mixed factor comprising WM and flexibility to explain achievement in the literacy domain. Since the independent contribution of each EF component to achievement can be evaluated only when some differentiation among EFs is apparent, the contribution of shifting as independent dimension to literacy performance will be not considered, because it is not easily assessed in preschoolers.

1.1 Literacy achievement in a shallow orthography

Italian provides a good example of a shallow orthography in which the correspondences between letters and sounds in the writing system are close to one-to-one. In Italian, differently from English, one letter or letter cluster has a single pronunciation, and similarly, a phoneme is almost always spelled the same way. As a consequence, children learning shallow orthographies, such as Italian, show a rapid literacy acquisition compared to children learning deep orthographies: toward the end of Grade 1 Italian children read on average 94% of real words correctly whereas English children show a much lower accuracy (about 40%; Seymour, Aro, & Erskine, 2003). The high consistency in the phoneme-to-grapheme mapping allows obtaining relatively high levels of accuracy throughout the sub-lexical procedure from early grades; as a consequence, decoding and spelling in Italian are usually well developed by the end of Grade 2 (Marinelli, Romani, Burani, & Zoccolotti, 2015).

Reading comprehension is determined by a wide range of component skills and processes (Oakhill & Cain, 2012). According to the Simple View of Reading (Gough & Tunmer, 1986), the skills and processes that determine reading comprehension depend on two broad components: decoding and linguistic comprehension. The relative influence of each component changes during the course of reading development. In the early stages of learning to read, decoding has the greatest influence on reading comprehension, since readers have to learn how their spoken language is represented by their writing system and a great amount of cognitive resources is devoted to this process. Then, when reading decoding becomes more automatic, a greater proportion of these resources can be used for reading comprehension. Nevertheless, for readers of transparent orthographies, linguistic comprehension has a considerable influence on reading comprehension from the very early stages of reading acquisition whereas, in English, decoding influences reading comprehension more strongly and for a longer period of development (Florit & Cain, 2011).

Comprehension continues to develop for many years and it is more influenced by cognitive processes, such as working memory and attention. In older children, in fact, when reading decoding has become more automatic, executive control skills support reading comprehension but are less necessary for decoding (Sesma, Mahone, Levine, Eason, & Cutting, 2009).

Based on the literature that assumes that decoding in reading and spelling relies on shared cognitive systems (Angelelli, Marinelli, & Zoccolotti, 2010; Burt & Tate, 2002; Holmes, & Carruthers, 1998) and are strongly associated to phonological processing, in the present study a latent factor that considers decoding in reading and spelling together was hypothesized at 6 and 8 years of age; reading comprehension was considered as a separate component of literacy.

1.3. Executive functions and literacy

The literature clearly indicates a link between EF and literacy achievement. Nevertheless, the majority of the studies concerning this relationship focus on school-age children, mostly older than 8 years of age. These studies, mainly with English-speaking children, indicate that WM is an important determinant of individual differences in decoding in reading (Christopher et al., 2012; Sesma, Mahone, Levine, Eason, & Cutting, 2009), spelling (Hooper et al., 2011) and reading comprehension (Christopher et al., 2012; De Beni & Palladino, 2000; Sesma et al., 2009). Particularly in reading decoding, WM allows one to access and monitor speech-based information (Swanson, Zheng, & Jerman, 2009): for example, in the early stages of learning to read a child is required to convert each phoneme in the correspondent grapheme and manipulate them together to form the word. In reading comprehension WM is necessary, for example, for the storage and retrieval of multilevel text (Swanson, 1999). Additionally, WM is significantly related to both decoding in reading and reading comprehension when accounting for other cognitive measures, such as naming speed, processing speed (Christopher et al., 2012), reading fluency, vocabulary skills, planning skills (Sesma et al., 2009) and short-term memory (Swanson, 1993).

The role of inhibition in literacy skills is not as clear as for WM. Inhibitory processes have been implicated in decoding in reading (e.g., De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Gernsbacher, 1993) and especially in reading comprehension (Borella, Carretti, & Pelegrina, 2010). In particular, in reading comprehension, inhibition allows individuals to limit and suppress potentially misleading representations caused by ambiguity in either single words or a text passage (e.g., Gernsbacher & Faust, 1991). In some studies, poor comprehenders have been shown to have problems suppressing irrelevant information, suggesting that poor comprehension is related to poor cognitive inhibition in individuals whose comprehension deficits do not arise from underlying problems in decoding (Pimperton & Nation, 2010). In contrast, good and poor decoders have not been found to differ on measures of cognitive inhibition (Chiappe, Hasher, & Siegel, 2000).

Although the literature does not offer a clear explanation for the relation between cognitive flexibility and reading processes, some studies found a significant link between these abilities (e.g., Latzman, Elkovitch, Young, & Clark, 2010; Van der Sluis, De Jong, & Van Der Leij, 2007), whereas others did not (e.g., Mayes, Calhoun, Bixler, & Zimmerman, 2009; McLean & Hitch, 1999). The role of cognitive flexibility in reading comprehension has been explained in several ways (Nouwens, Groen, & Verhoeven, 2016), for example, to allow the reader to simultaneously process phonological and semantic information, to retrieve multiple mental representations or to adjust reading strategies based on the reading goal and task difficulty (Cartwright, 2009).

In summary, the literature on school-age children shows a significant association between single EF components and different domains of literacy, particularly decoding and reading comprehension, while much less is known about spelling ability. In addition to the results obtained with typically developing children, many studies found that children with learning impairments in the domains of decoding, spelling and reading comprehension often show a concurrent EF impairment (Brosnan et al., 2002; Carretti, Cornoldi, De Beni, & Romanò, 2005; Peng, Congying, Beilei, & Sha, 2012).

Regarding pre-schoolers, some studies have identified inhibition as closely linked with performance on pre-reading tasks (Miller, Müller, Giesbrecht, Carpendale, & Kerns, 2013) and involved in the process of acquiring automaticity in letter identification (Blair & Razza, 2007) and early orthographic knowledge skills (Shaul & Schwartz, 2014). Willoughby et al. (2012) found that a latent measure of EF was related to a latent variable measuring academic achievement, as well as to individual standardized measures of phonological awareness and letter-word identification prior to enrolment in kindergarten.

As regards the initial stages of literacy acquisition, Blair, Ursache, Greenberg, & Vernon-Feagans (2015) suggested that emergent reading may rely more on knowledge-based skills, such as knowledge of letters, sounds, and words, and involves EFs to a lesser extent. On the other hand, Cameron et al. (2015) suggested that WM and inhibition contributed to emergent reading through different patterns of influences. Whereas working memory contributed to emergent literacy through an additive pattern, a compensatory pattern of interactions emerged between visuomotor integration and inhibitory control, suggesting that in pre-schoolers one early cognitive skill (either inhibition or visuomotor integration) can compensate for low levels of another skill.

A few studies have longitudinally examined the role of EFs in literacy achievement (Monette et al., 2011; Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010). In particular, Monette et al. (2011), using a mediation analysis, found that WM and inhibition assessed in kindergarten had small but significant indirect effects on reading/writing at the end of Grade 1, in both cases through the mediating effects of socioaffective variables. Welsh et al. (2010) found that a composite measure of EF predicted growth in emergent literacy skills during the pre-kindergarten year; furthermore, growth in EF during the pre-kindergarten year made unique contributions to kindergarten reading. Finally, Röthlisberger et al. (2013) analysed the predictive associations between a composite measure of EF and school achievement and found that EF measured in prekindergarten and kindergarten years was substantially predictive of reading and spelling achievement two years later in Grades 1 and 2. Specifically, EF explained 4 to 12% of the unique variance in spelling and reading tests two years later.

1.4. The role of covariates: mothers' education and general intellectual functioning

As recently pointed out (Blair et al., 2015), a helpful approach to investigate the role of EF in predicting academic outcomes should include other control variables that may play a role in achievement. Because family characteristics and general intellectual functioning are also associated with school achievement, to evaluate the net contribution of EFs to literacy skills, we took such factors into account. Regarding family characteristics, socioeconomic status and parental education were found to be important predictors of children's school achievement in both the literacy and math domains (Davis-Kean, 2005; Magnuson, 2007). Regarding general intellectual functioning, some studies suggested that the key factor underlying the relationship between EFs, 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 achievement compared to IQ (Alloway & Alloway, 2010). Given these findings, children's general intellectual functioning was taken into account in the present study. In particular, according to Gathercole, Pickering, Knight, and Stegman (2004), we decided to assess fluid intelligence because it represents a biologically based ability to acquire skills and knowledge during the lifespan (see Geary, 2007 for a review); it is not knowledge based and is generally less determined by socioeconomic factors and may predict learning across the different contexts of life.

1.5. The current study

As indicated by the literature review, the studies suggesting that preschool EFs are predictive of subsequent literacy are mostly focused on early stages of literacy achievement, mainly kindergarten and Grade 1; moreover, they did not clarify whether all EF processes are equally involved in the acquisition of literacy. Most studies, in fact, assessed the concurrent or predictive role of a single EF dimension, such as WM, on literacy without analysing the net contribution of each EF component while controlling for the others. Alternatively, other studies used a composite EF measure, also without identifying the specific contributions of the various EF processes, such as inhibition versus WM, that are already differentiated in late preschoolers. This study is aimed at contributing to the existing literature, by examining the longitudinal relationship between emerging EF skills prior to school entry and literacy achievement not only in Grade 1 but also at the end of Grade 3. At least in the Italian context, Grade 1 corresponds to the early stage of literacy acquisition, whereas at the end of Grade 3 reading and spelling are expected to be automatized in most children. Furthermore, the study aimed to explore the specific role of inhibition and WM in literacy achievement over time, by using structural equation modelling to analyse the net contribution of each EF component while controlling for the other.

Based on the literature that assumes that decoding in reading and spelling relies on shared cognitive systems (Angelelli et al., 2010; Burt & Tate, 2002; Holmes, & Carruthers, 1998), a latent factor that considers decoding in reading and spelling together was hypothesized at 6 and 8 years of age.

The specific aims of the study were as follows:

1. To describe the relationships between emerging EF at age 5 and literacy achievement at age 6 (Grade 1) and age 8 (Grade 3) using a latent factor approach.
2. To analyse the specific contributions of different EF components at age 5 to reading-spelling processes at age 6 (Grade 1) and both reading-spelling and reading comprehension at age 8 (Grade 3).

3. To examine the extent to which associations between preschool EF abilities and later literacy achievement persist when the contributions of other concurrent predictors, such as general intellectual functioning and maternal education, are taken into account.

Based on previous research, we expected to find an association between preschool EF and literacy achievement in Grades 1 and 3. In particular, we hypothesized that WM could be related to both reading-spelling processes and reading comprehension, given the concurrent and predictive associations between WM and literacy found with older children. Moreover, in accordance with an additive pattern of influences, we hypothesized that this relationship may be higher for children in Grade 3 than in Grade 1.

We also hypothesized a lower effect of inhibition on both reading-spelling ability and reading comprehension, as suggested by the hypothesis according to which inhibition may interact with other abilities (Cameron et al., 2015). This expectation could be particularly true for reading-spelling ability, considering that it may involve knowledge-based skills more than reading comprehension (Blair et al., 2015).

In summary, differently from previous studies, we analysed the predictive role of EF assessed before formal instruction across school years, not only in an early stage of literacy acquisition (Grade 1) but also when literacy processes have been automatized (Grade 3); we used CFA to limit task impurity in EF assessment and structural equation modelling (SEM) to analyse the net contribution of each EF component while controlling for the others; we included in the model general intellectual functioning and maternal education, which are two significant predictors of early attainment; and finally, we considered different aspects of literacy (reading-spelling processes and reading comprehension).

2. Methods

2.1. Participants

Participants were recruited by contacting the families of children who had attended the prior school year at 23 public preschools located in the main town in a northwestern region of Italy. In Italy, preschool education encompasses children aged 3 to 5 years, whereas primary school provides education for children aged 6 to 10 years. Normally, in Grade 1, Italian children become familiar with the alphabet and the letter-sound correspondences, and during Grade 3, reading decoding and spelling become automatized. In every preschool, both teachers and parents were informed about the aims of the study. Parents who decided to participate in the study were asked to complete a questionnaire with some information about their family and an informed consent form, according to the ethical standard established by The National Psychology Association for Research (for further detail see http://www.aipass.org/node/26).

The eligibility criteria for the children included the following: (a) attended the last year of preschool; (b) spoke Italian as a first language; and (c) had no history of any neurological, psychiatric, or developmental disorders. The families of 206 typically developing children agreed to participate in the study; 31 children were excluded 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 Coloured Progressive Matrices Test ($n = 23$). The final sample characteristics are shown in Table 1. The highest rate of dropout observed between wave 1 and wave 2 occurred mainly because 46 children could not be located after they moved from preschool to different primary schools. Nevertheless, no differences emerged in preschool EF measures, general intellectual functioning and maternal education levels (all $p > .05$) between the children who continued the study and those who dropped out.

The mothers' highest level of academic achievement was recorded. Of the 165 mothers who provided this information at time 1, 13% had a middle school education, 45% had a high school education and 42% had a university degree.

(Table 1 about here)

2.2. Procedure

Every child was tested three different times: in the spring of their final year of preschool (at 5 years of age) 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 general intellectual functioning and EF. In Grade 1 and Grade 3, the children's literacy 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 should be used for the investigation of individual differences (see Wiebe et al., 2011).

2.3. Measures

2.3.1. Executive Function tasks

Circle Drawing Task. The Circle Drawing Task (Bachorowski & Newman, 1985) is a measure of inhibition of an ongoing response (Marzocchi et al., 2008). The task consists of a circle 17 cm in diameter drawn on paper with the words "start" and "stop" indicating the starting and finishing points of the tracing. The child must trace the circle with his finger from the start to the end point. The task is administered twice: first with neutral instructions ("trace the circle") and then with inhibition instructions ("trace the circle again, but this time as slowly as you can"). The greater the inhibition time is, the better a participant is able to inhibit (slow down) a continuous tracing response. The test-retest reliability coefficient was calculated on a sample of 43 children of five years, that were assessed twice (a month later) in a previous study by Traverso, Viterbori, and Usai, (2015). The Pearson correlation coefficient was .57. The time in seconds was recorded for each trial. Scores were calculated as the proportion of the slowdown in relation to the total time using the formula (T2-T1)/(T2+T1), where T1 and T2 were the times recorded for the first and second trials, respectively.

Tower of London (ToL). The Tower of London test is a complex task used to assess 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). 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's alpha was .46, and the test-retest correlation was .57 (Fancello, Vio, & Cianchetti, 2006). The Cronbach's alpha calculated in our sample was .33. The apparatus includes two wooden boards with three pegs of different sizes; for each wooden board, there are three wooden balls of different colours (red, green, and blue). Each ball has a hole through the middle so that it 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 is given one of the two wooden boards with its balls, while the examiner keeps the other board. 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 given 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 a child violates a rule or does not respect the limit on the number of movements, then 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 for a perfect solution 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 within which 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 working memory test that requires the child to recall a sequence of spoken digits in reverse order. 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 of age (Alloway, Gathercole, & Pickering, 2006). The Cronbach's alpha calculated in our sample was .67. The score is calculated as the maximum list length at which two sequences are correctly recalled (Bisiacchi, Cendron, Gugliotta, Tressoldi, & Vio, 2005), and one point is granted for a length of 1 (Morra, Camba, Calvini, & Bracco, 2013).

Dual Request Selective Task (DRST). The Dual Request Selective Task (Re, De Franchis, & Cornoldi, 2010) is a visual-spatial working memory 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 years (Lanfranchi, Cornoldi, & Vianello, 2004; Re & Cornoldi, 2007). Task reliability was explored in a sample of 509 children between 4 and 6 years of age; both Cronbach's alpha (.81) and the split half (.80) revealed good reliability (Lanfranchi & Vianello, 2008). The Cronbach's alpha calculated in our sample was .72.

This task is suitable for assessing the participants' ability to maintain information in WM while performing a concurrent task. The child is required to control the given information in working memory 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 then must 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 of the pathways include a step in the red square. Each child completes 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 is 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 (Miyake et al., 2000). The research literature has shown that two main processes are activated by this task, in both adults and children (Kavé, Kigel, & Kochva, 2008): clustering, which is temporally mediated, and switching, which is a frontally mediated executive process (see, e.g., Unsworth, Spillers, & Brewer, 2011). The test-retest reliability for the same task administration procedure used in the present study is .85 (Bisiacchi et al., 2005). The Cronbach's alpha calculated in our sample was .53. The children have a total of four minutes to state how many different words they know for each of four separate categories in the following order: colours, animals, fruits, and cities. They are given 60 seconds for each category. Repeated words are not considered in the final score, which includes only the total number of correct words.

Dimensional Change Card Sort (DCCS). The Dimensional Change Card Sort (Zelazo, 2006; Traverso, & De Franchis, 2014) 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 Cronbach's 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., colour) and then according to another dimension (e.g., shape). Target cards (a blue rabbit and a red boat) are affixed to the fronts of two boxes. The experimenter presents a series of cards (red rabbits and blue boats) and introduces the child to the "colour 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 of six trials, the experimenter announces that they will stop playing the colour 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, then it should be sorted according to the colour, 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 of six trials in the first two sessions. The score is the proportion of total correct trials (of 24 trials).

2.3.2. General intellectual functioning

Coloured Progressive Matrices Test (CPM). The Coloured Progressive Matrices Test (Raven, 1947) is a non-verbal measure of general intellectual functioning that consists of 36 items. Each item contains a figure with a missing piece. Below the figure are six alternative pieces to complete it, only one of which is correct. Children are presented with a demonstration trial and are then instructed on successive trials to point to the piece that best completes the pattern. The total number of correct responses is used for analyses.

2.3.3. Literacy

Battery for the assessment of reading decoding and text comprehension in primary school
Reading decoding and reading comprehension abilities were examined using different standardized curriculum-based school achievement tests from the Italian “Battery for the assessment of reading and reading comprehension in primary school” (Cornoldi & Colpo, 2011). The reliability for reading decoding was obtained by calculating the Cronbach’s alpha coefficient, which was .75 for accuracy and .64 for speed, whereas the reliability for text comprehension was measured with the Cronbach’s alpha and ranged from .61 to .77 (Cornoldi & Colpo, 2011). The Cronbach’s alpha in our sample was .59. In the reading task, children are asked to read aloud a text passage within 4 minutes. The battery scoring norms was followed and the total number of reading errors was used for the analyses as a

measure of lack of accuracy in reading decoding in Grades 1 and 3 (Reading Errors 1; Reading Errors 3).

To assess reading comprehension ability, in Grade 1, children were asked to answer ten multiple-choice questions after listening to the examiner read a text; in Grade 3, children had to read the text silently by themselves and then answer ten multiple-choice questions. The texts differed between Grades 1 and 3. Considering the influence of immaturity in reading processes at the beginning of primary school, the examiner read the text aloud only for the first graders; in both grades (Grades 1 and 3), the text was available for the children to read or consult while answering the questions. This procedure limits the influence of memory on performance. The total number of correct answers was used for analyses as a measure of accuracy in text comprehension in Grades 1 and 3 (Comprehension Accuracy 1; Comprehension Accuracy 3).

Battery for the assessment of spelling

Spelling ability was assessed by administering a dictation from the Battery for the Assessment of Writing Skills (Tressoldi & Cornoldi, 2000). The test-retest reliability of the battery was r = .78 for phonological errors, r = .59 for non-phonological errors, r = .48 for other errors and r = .83 for speed. The passage was read collectively in the classroom to all the children, who then had to write it down. The total number of incorrectly written words (errors) was used as a measure of lack of accuracy in spelling in Grades 1 and 3 (Spelling Errors 1; Spelling Errors 3).

2.4. Statistical analyses

Descriptive analyses, zero-order (Pearson) and partial (controlling for age at 5 years) correlations among measures, and ANOVAs in which the CPM, EF and literacy measures were treated as dependent variables and gender and mothers' level of education as independent variables were performed.

Based on the two-step approach recommended by Anderson & Gerbin (1988), two types of latent variable techniques were used: CFA and full structural equation modelling (SEM; Bollen, 1989). Regarding CFA, as the same data set in Usai et al. (2014) was used, we employed the two-factor CFA model resulted with the best fit in this previous study. Then, a first structural equation model (SEM) was used to test the hypothesis that the scores in reading decoding and in spelling tasks might constitute a single latent factor in both Grade 1 (Reading-Spelling 1) and Grade 3 (Reading-Spelling 3); moreover, we added a predictive path from Reading-Spelling 1 to Reading-Spelling 3 and from Reading-Spelling 1 to the reading comprehension observed variable in Grade 3 (Comprehension Accuracy 3). Finally, we combined the CFA and the first SEM model in a full structural equation model to test the hypothesis that the reading-spelling latent variables in Grades 1 (Reading-Spelling 1) and 3 (Reading-Spelling 3) and the reading comprehension scores in Grade 3 (Comprehension Accuracy 3) could be explained by the two EF components. These analyses were conducted using MPlus 7.4 software (Muthen & Muthen, 1998) and were based on the raw data. The optimal Full Information Maximum Likelihood approach was used to estimate missing data (Collins, Schafer & Kam, 2001). The fit of each model to the data was evaluated by examining multiple fit indices (Schermelleh-Engel, Moosbrugger, & Műller, 2003): the χ^2 statistic, the root mean square error of approximation (RMSEA), the standardized root mean squared residual (SRMR), Bentler's comparative fit index (CFI), the Tucker-Lewis fit index (TLI) and the Akaike Information Criterion (AIC).

The χ^2 test was used to evaluate the appropriateness of the CFA model; non-significant values indicated a minor difference between the covariance matrix generated by the model and the observed matrix, and thus, the model had an acceptable fit. The RMSEA is a measure of approximate fit in the population; it measures how closely the covariances predicted by the model match the actual covariances. RMSEA values ≤ .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 > .10 are not acceptable (Browne & Cudeck, 1993). The SRMR is the square root of the averaged squared residuals (i.e., the differences between the observed and predicted covariances). SRMR values < .10 are acceptable; however, values < .05 represent a good fit (Schermelleh-Engel et al., 2003). CFI compares the covariance matrix predicted by the model with the observed covariance matrix and compares the null model with the observed covariance matrix. TLI reflects the proportion by which the researcher's model improves fit compared to the null model, while controlling for the degrees of freedom. CFI and TLI values > .97 are indicative of a good fit, whereas values > .95 may be interpreted as acceptable (Schermelleh-Engel et al., 2003).

(Table 2 about here)

3. Results

Descriptive statistics for the six EF measures, general intellectual functioning (CPM) and achievement measures are shown in Table 2. Skewness and kurtosis coefficients were relatively low, except for those for the switch task (DCCS); therefore, these scores were transformed using an arcsin transformation that converts proportions into scores that are more centred than raw percentage. The transformed descriptive statistics for DCCS were as follows: M = .86, S.D. = .25, skewness = -.27, and kurtosis = 2.54.

Inspection of the descriptive statistics shows that the children performed all of the tasks without any floor or ceiling effect, with the only exception being reading comprehension in Grade 1: in this task, the mean value and the standard deviation reveal that the children mostly reached the ceiling effect. A possible explanation can be found in the fact that several teachers reported that they used the same material that we used to assess the comprehension level in their classes; another possible explanation can be found in the procedure used to assess this competence, which could have made it very easy for the majority of the children to perform this task. As a result, reading comprehension in Grade 1 was excluded from the subsequent analyses.

No differences were found between males and females in general intellectual functioning and EFs. No gender differences were found in spelling errors in either Grade 1 or 3. Regarding reading decoding and reading comprehension, no difference was found between males and females in Grade 1, whereas in Grade 3, females performed slightly better than males: females showed fewer errors in reading decoding task $F(1, 114) = 4.41$, $p < 0.04$, $\eta^2 = 0.05$ ($M_{Females} = 1.44$, S.D. = 1.58 *vs* $M_{Males} = 2.11$, S.D. = 1.18) and had more correct answers in the reading comprehension task, $F(1, 110) = 6{,}07$, $p < 0.05$, $\eta^2 = 0.05$ ($M_{Females} = 9.00$, S.D. = 1.43 *vs* $M_{Males} = 8.26$, S.D. = 1.64).

The level of maternal education did not significantly influence general intellectual functioning, EFs or literacy performance, except for spelling errors in both levels of primary school, $F(2, 122) = 10.08$, $p < 0.001$, $\eta^2 = .14$ and $F(2, 102) = 4.09$, $p < 0.05$, $\eta^2 = .08$ for Grades 1 and 3, respectively. Children whose mothers had the lowest level of education performed worse than children whose mothers had a high school or a university degree, in both Grade 1 (M = 22.44, S.D. = 17.92 *vs* M = 11.21, S.D. = 10.43 and M = 9.60, S.D. = 6.23; Tukey post-hoc $p < 0.05$) and Grade 3 (M = 11.54, S.D. = 15.42 *vs* M = 5.02, S.D. = 5.51 and M = 6.14, S.D. = 7.59; Tukey post-hoc $p < 0.05$).

3.1. Correlations between EF and literacy measures

Reading decoding and spelling in Grades 1 and 3 and reading comprehension in Grade 3 showed a pattern of significant association with executive measures at Time 1 (Table 3). The correlations were generally low to moderate: in Grade 1, Reading Errors 1 showed a significant negative correlation with the CDT, TOL, and BDS measures assessed in the last year of preschool (Time 1). In Grade 3, Reading Errors showed a significant negative correlation with BDS.

Spelling Errors negatively correlated with TOL, DRST, and BDS in Grade 1 and with TOL in Grade 3. Comprehension Accuracy positively correlated with TOL, BDS, and DCCS in Grade 3. General intellectual functioning (CPM) was negatively associated with Spelling Errors in both grades and with Reading Errors in third graders. Maternal education was negatively associated with Spelling Errors in Grade 1 and positively with Comprehension Accuracy in Grade 3. Controlling for age differences at age 5 did not change substantially this pattern of results. In conclusion, the achievement measures were moderately to highly associated with each other in both Grades 1 and 3.

(Table 3 about here)

3.2. CFA and SEM analyses

3.2.1. Modelling the literacy achievement

The SEM included the observed reading decoding (Reading Errors), spelling (Spelling Errors) and reading comprehension variables (Comprehension Accuracy) from assessments in Grades 1 and 3. Two latent factors representing the reading-spelling processes together, separately for Grades 1 (Reading-Spelling 1) and 3 (Reading-Spelling 3), were included; we also included a path from Reading-Spelling latent variable at Grade 1 to Reading-Spelling latent variable and Comprehension Accuracy at Grade 3.

In SEM modelling, 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 works as a complex multiple regression analysis, loadings should be interpreted as suggesting that changes in the independent variables co-occur with changes in the dependent variables. In a longitudinal design, with independent variables observed prior to the subsequent dependent variables, we may interpret these loadings as estimates of how much change in the independent variable (after controlling for the other factors it is correlated with) predicts change in the dependent variable. These standardized parameters estimated correspond to the standardized linear regression coefficients (i.e. Beta coefficients).

The factorial fit indices show that the model fits well with the data: $\chi^2 = 5.507$, p = .14, CFI = .98, TLI = .94, SRMR = .03, RMSEA = .08, and 90% CI = [.00, .19]. The factor loadings were significant (t values > 2), and the proportion of variance in the individual task scores explained by the latent variables varied across tasks. The R^2 values were .56 and .75 for reading and spelling errors, respectively, in Grade 1; .34 for reading errors in Grade 3; .54 for spelling errors in Grade 3; and .25 for correct text comprehension answers in Grade 3.

3.2.2. Modelling the executive predictors of literacy achievement

The CFA model employed in the present study is the same obtained in Usai et al. (2014), as the same data set was used. The full SEM combines the CFA and SEM models described above and includes the latent factors established there (inhibition, WM-flexibility factors, Reading-Spelling 1 and Reading-Spelling 3); moreover, it includes the following observed variables: Comprehension Accuracy in Grade 3 and the two control variables, general intellectual functioning and mother's education level, measured at the same time as the EF variables. We added structural paths such that each executive factor and control variable predicted each achievement variable (Figure 1).

The full factorial fit indices show that the model fit well with the data: $\chi^2 = 46.460$, degrees of freedom = 47, p = .50, CFI = 1.000, TLI = 1.004, SRMR = .045, RMSEA = .000, and 90% CI = [.000, .049]. As Table 4 shows, all the predictors were significantly associated among each other, except for the general intellectual functioning measure with the mother's education level. The model identified a latent variable representing reading-spelling processes in reading and writing tasks for each grade. The factor loadings were significant (t values > 2), and the proportion of variance in the individual task scores explained by the latent variables varied across tasks. The R^2 values were .48 for reading errors in Grade 1, .43 for spelling errors in Grade 1, .39 for reading errors in Grade 3, and .43 for spelling errors in Grade 3. Figure 1 shows the standardized significant parameters of the final model.

None of the predictors at 5 years of age uniquely contributed to the variability in the Reading-Spelling factors; however, the entire model accounted for a large portion of these outcome variables' variance: 21% and 67% for the latent variables representing the reading decoding and spelling processes in Grades 1 and 3, respectively. The Reading-Spelling latent variable at Grade 1 predicted the Reading-Spelling latent variable and the Comprehension Accuracy in Grade 3 (p value < .05). Notably for the aim of this study, the mixed executive factor measured at 5 years of age significantly predicted Comprehension Accuracy in Grade 3. The model accounted for 47% of variance in third graders' Comprehension Accuracy.

4. Discussion

This longitudinal study supports the role of early EF abilities in promoting the acquisition of literacy during the early grades of primary school. In particular, the present study contributes to the current literature by applying CFA and SEM to model EF functioning measured before school entry and by analysing longitudinally the predictive associations between preschool EF components and subsequent literacy skills.

Overall, the results indicate that the WM-flexibility latent factor found in pre-schoolers strongly predicts reading comprehension in Grade 3 but not reading decoding and spelling processes at either age level. Contrary to expectations, inhibition assessed at 5 years of age did not affect literacy achievement in Grade 1 or Grade 3.

As expected based on the literature, the WM and flexibility mixed latent factor longitudinally influences reading comprehension (Christopher et al., 2012; De Beni & Palladino, 2000; Sesma et al., 2009), indicating that there is a uniquely predictive role for this latent EF dimension, even after controlling for general intellectual functioning (see also Alloway, Gathercole, Kirkwood, & Eliott, 2009). The longitudinal relationship between this EF latent factor measured before school entrance and reading comprehension in Grade 3 is compatible with an additive pattern of influences and may be explained considering the cumulative effect of poor WM across development. Alloway, Gathercole, Kirkwood, and Eliott (2009), investigating the cognitive and behavioural profiles of children who showed low performance on WM tasks at 5-6 and then at 9-10 years of age, found that older children performed significantly worse than younger children did on learning measures. According to the authors, the effect of poor WM is cumulative across development, resulting in greater decrements in learning as children grow. This decrement is not necessarily connected to a decrease in WM ability, which, on the contrary, appears relatively stable throughout this period (Alloway, 2009); it is instead a consequence of a change in school activities and tasks, which involve progressively higher WM demands (i.e., more items to consider, hold and manipulate mentally): children with poor WM more frequently lose crucial information during lessons due to WM overload, especially when tasks require memorization of lengthy instructions or coping with simultaneous processing and storage demands. Additionally, according to Alloway et al. (2009), older children do not develop efficient strategies independently or spontaneously use them on their own. Our results are in line with the hypothesis that a low level of WM-flexibility abilities affects achievement more at a later stage than in earlier grades, partly because children progressively face more higher-level cognitive tasks that rely heavily on WM processes.

Regarding the role of cognitive flexibility, it should be noted that it might not be distinguished from other EF abilities until 9 or 10 years of age (see Monette et al., 2015); however, we cannot exclude the possibility that emerging flexibility abilities may contribute to predict learning in the literacy domain. Indeed, Colé, Duncan, and Blaye (2014) recently found cognitive flexibility to be predictive of reading acquisition also in a relatively transparent orthographic system (French language); according to the authors, reading skills require manipulating different types of information contained in print and therefore necessitate flexibly managing the orthographic, phonological, and semantic codes.

Although the model contributes to the explanation of the 21% and 67% literacy latent variable variance in first and third graders, respectively, the WM-flexibility latent factor does not uniquely predict reading decoding and spelling. This finding is in line with the idea that WM is more crucial for reading comprehension than for word reading decoding because successful comprehension depends upon the ability to remember and integrate information across the text to build appropriate representations of the contents (Swanson et al., 2009; but Christopher et al., 2012). Furthermore, this finding is in accordance with the hypothesis that reading decoding and spelling may rely more on knowledge-based skills and involves EFs less than it is required by reading comprehension (Blair et al., 2015).

Our results do not support the hypothesis that inhibition uniquely predicts reading decoding and spelling or reading comprehension (see also Christopher et al., 2012). The role of WM but not of inhibition in predicting early literacy was also found by Miller et al. (2013) using a latent variable approach in a cross-sectional study with 3- to 5-year-old pre-schoolers. It should be noted that in our study, the inhibition component that was better represented by the measures that we used to assess inhibitory processes was response inhibition, which was, in fact, found to be predictive of literacy in those studies that investigated preschool EF and early achievement (i.e., Miller et al., 2013). Nevertheless, some studies with school-age children suggest that the ability to filter out irrelevant information (interference monitoring and suppression) – and not response inhibition – might be more associated with reading skills, particularly reading comprehension. Borella et al. (2010), for example, found that poor comprehenders were selectively impaired in the inhibition-related measure indexing resistance to proactive interference but not in measures of response inhibition. Similarly, van der Sluis, de Jong and van der Leij (2004) demonstrated that learning-disabled children were not impaired in suppressing exogenous, external irrelevant information but rather in inhibiting endogenous irrelevant information.

Furthermore, it should be noted that most previous studies were conducted in the English language. In English, the correspondence between letters or groups of letters and pronunciation is not regular, and children must manage the conflict between lexical and sublexical strategies. For example, when reading the word “mint”, they can use both a sublexical or lexical approach with a correct outcome in both cases, whereas when they read “pint”, they must inhibit the tendency to use a grapheme-phoneme correspondence in favour of a whole-word strategy (Monsell, Patterson, Graham, Hughes, & Milroy, 1992). The Italian language is, in contrast, highly regular, and children can read and write words relying on sublexical strategies and phoneme-grapheme correspondence rules. Indeed, the literature indicates that Italian children experience less difficulty in acquiring reading and spelling skills compared to English children (see, e.g., Cossu, Shankweiler, Liberman, Katz, & Tola, 1988).

An alternative explanation comes from a recent study (Cameron et al., 2015) that found as lower inhibition abilities may be compensated by the presence of higher levels of other abilities, such as visuomotor integration. On the base of this hypothesis, different task demands, such as inhibition or motor requirements, compete for the same cognitive resources. Children with either strong inhibition or strong visuomotor integration may succeed in the tasks used to assess literacy that could require both types of skills.

Remarkably, as already found for math achievement (Viterbori et al., 2015), both general intellectual functioning and maternal education have minor influences on literacy. Consistent with the literature, maternal education was positively associated with both EF factors (see, e.g., Hackman & Farah, 2009) but did not predict the reading-spelling processes and reading comprehension in primary school. When considering reading decoding and spelling skills separately, children at the highest level of the maternal education group performed better in spelling than children at the lowest level of the maternal education group at both levels of primary school. However, the homogeneous composition of our sample in terms of mothers’ education level (87% of the mothers had a high school or college education) may have reduced the variability, which, in turn, affected the relationship between maternal education and literacy.

Regarding the relation between general intellectual functioning and EF, our results show that both executive latent factors were associated with general intellectual functioning (Friedman et al., 2006; for a discussion about the relationship between general intellectual functioning and WM during development, see Demetriou et al., 2014). The SEM model reveals that although general intellectual functioning is associated with the EF, the WM-shifting factor contributes independently to explain performance in the literacy domain (see also Christopher et al., 2012).

Our results support the associations between EF subcomponents and literacy found in previous studies, suggesting that early EF skills are predictors of later attainment in the verbal domain. Moreover, the combined use of CFA and SEM techniques addressed the task impurity problem of EF measures and allowed the evaluation of the influence of the latent EF dimensions on academic learning while accounting for other influencing variables, such as general intellectual functioning and cultural differences.

However, this study presents some limitations that should be noted. First, we did not evaluate children's pre-literacy domain-specific competence and vocabulary knowledge at 5 years of age. In this study the question of independent contribution of EF after controlling for these skills remains unanswered although there are some longitudinal studies that have found that cognitive antecedents such as emergent literacy (letter recognition, phonemic awareness, rapid naming, spelling etc.) had a predictive power for the respective domains and there are some evidence of a significant longitudinal relationships between pre-literacy vocabulary knowledge and subsequent reading (e.g. Duff, Reen, Plunkett, & Nation, 2015). Second, due to the ceiling effect of comprehension performance in first graders, we could not test a reliable comprehensive model in which the two EF components could be related to all the linguistic measures. Third, only a component of inhibition has been assessed, i.e., response inhibition, and consequently, the influence of the ability to filter out irrelevant information on literacy skills was not assessed.

It is important to highlight that the unidirectional arrows from the WM-flexibility latent factor to reading comprehension do not express a causal relation. As in multiple regression analyses, the SEM significant loadings reflect how performance on reading comprehension changes depending upon performance on a cognitive factor. Nevertheless, it should be considered that this relation is longitudinal, suggesting that a causal relationship may be plausible.

Notably, for knowledge about how literacy processes are organized, the SEM models support the hypothesis that reading and spelling rely on a common orthographic lexicon (Angelelli et al., 2010; Burt & Tate, 2002; Holmes & Carruthers, 1998), although the performance in the two tasks appears only moderately associated, especially in Grade 3. According to the developmental model proposed by Fitzgerald and Shanahan (2000), reading and writing underlining processes play different roles at different stages of development, suggesting that at ages 8-12, complex skills, such as knowledge of morphology, syntax, and text organization, are more important than grapho-phonic knowledge, phonological awareness, and grapheme awareness to the ability to read and write.

In conclusion, the present study indicates that EF at 5 years of age contributes to the acquisition of specific aspects of literacy achievement in 6- to 8-year-old children: in particular WM-flexibility contributes to reading comprehension at Grade 3. Consequently, the present findings have implications for both assessment and educational practices. First, they suggest that early measures of EF may be useful in identifying children who may experience more difficulty in literacy acquisition, especially in reading comprehension. Second, they also suggest that supporting executive skills may enhance early childhood literacy education. Traditionally, most efforts to promote school readiness have focused on improving knowledge-based skills (e.g., letter identification, phonemic awareness, number recognition) that are strong predictors of later achievement. Although these strategies have proven useful, especially for disadvantaged children who may have had inadequate learning opportunities (see, for example, Starkey, Klein, & Wakeley, 2004), they may be less effective in the long term than programmes that foster the development of the mental systems that support learning (Blair, 2002). In other words, supporting the development of EF during the preschool period might allow children to enhance the cognitive processes that will enable them to learn more effectively.

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GRADE	N	Males	Females	Age	
				M	DS
Preschool (5 years of age)	175	101	74	68.4	3.4
Grade 1 (6 years of age)	129	73	56	80	3.58
Grade 3 (8 years of age)	118	69	49	104	3.36

Table 1 Sample characteristics

		N	Minimum	Maximum	Mean	Std. Dev.	Skewness	Kurtosis
EF at preschool (5 years of age)	CDT	175	-0.08	0.91	0.55	0.23	-0.67	-0.04
	ToL	175	8	33	22.98	4.35	-0.57	0.82
	DRST	175	0	10	4.63	2.71	0.08	-1.08
	BDS	175	0	4	1.89	0.89	-1.03	0.78
	Fluency	175	10	46	27.91	6.49	0.21	0,27
	DCCS	175	6	24	17.63	3.80	-1.58	3.51
	Gen. Intel. F.	175	13	30	17.68	3.39	0.97	0.74
Literacy in Grade 1 (6 years of age)	Reading-Er1	127	0	27.50	4.93	4.60	2.50	8.50
	Spelling-Er1	125	0	64	11.90	10.84	2.45	8.05
	Comp. Acc. 1	129	5	10	9.09	1.08	-1.86	4.47
Literacy in Grade 3 (8 years of age)	Reading-Er3	116	0	7.50	1.83	1.73	1.25	1.28
	Spelling-Er3	106	0	52	6.25	7.78	2.70	11.10
	Comp. Acc..3	111	4	10	8.56	1.59	-1.28	1.12

Table 2 Descriptive statistics of preschool EF measures and literacy measures from Grades 1 and 3.

Note: CDT, Circle Drawing Task at 5 years of age; ToL, Tower of London at 5 years of age; DRST, Dual Request Selective Task at 5 years of age; BDS, Backward Digit Span at 5 years of age; Fluency, Semantic Fluency at 5 years of age; DCCS, Dimensional Change Card Sort at 5 years of age; Gen. Intel. F., Colored Progressive Matrices test score at 5 years of age; Reading-Er1, number of errors in decoding in reading a text passage in Grade 1; Spelling-Er1, number of words, incorrectly written in a dictation in Grade 1; Comp. Acc. 1, total number of correct answers in multiple-choice questions after listening the examiner that read a text in Grade 1; Reading-Er3, number of errors in decoding in reading a text passage in Grade 3; Spelling-Er3, number of words, incorrectly written in a dictation in Grade 3; Com. Acc. 3, total number of correct answers in multiple-choice questions after reading a text in Grade 3.

		1st Grade		3th Grade		
	Age	Reading-Er1	Spelling-Er1	Reading-Er3	Spelling-Er3	Comp. Acc. 3
CDT	.02	-.23** (-.23**)	-.08 (-.08)	-.11 (-.11)	-.06 (-.06)	.07 (.07)
ToL	-.02	-.24** (-.25**)	-.25** (-.26*)	-.18 (-.19*)	-.20* (-.20*)	.22* (.22*)
DRST	.15	-.15 (-.12)	-.18* (-.16)	-.07 (-.03)	-.15 (-.15)	.17 (.15)
BDS	.03	-.23* (-.22*)	-.35** (-.36**)	-.19* (-.18)	-.10 (-.10)	.47** (.47**)
Fluency	.19*	-.03 (.00)	-.14 (-.11)	-.07 (-.02)	-.11 (-.11)	.14 (.11)
DCCS	.08	-.10 (-.09)	-.18* (-.17)	-.17 (-.16)	-.15 (-.15)	.24* (.23*)
Gen. Intel. F.	.13	-.08 (-.06)	-.20* (-.18*)	-.21* (-.19*)	-.23* (-.23*)	.14 (.13)
Maternal education	-.07	-.16 (-.18*)	-.32** (-.34**)	-.17 (-.03)	-.17 (-.17)	.20* (.21*)
Reading-Er1	-.19*	-				
Spelling-Er1	-.19*	.60** (.59**)	-			
Reading-Er3	-.23*	.41** (.38**)	.27** (.24*)	-		
Spelling-Er3	-.02	.39** (.40**)	.45** (.45**)	.41** (.42**)	-	
Comp. Acc. 3	.16	-.24* (-.22*)	-.41** (-.39**)	-.32** (-.30**)	-.37** (-.37**)	-

*p<0.05; **p<0.01

Table 3 Zero-order correlations (partial correlation with control of age at the first wave of assessment) between achievement measures and executive and general intellectual functioning tasks. In the lower section of the table zero-order correlations across achievement measures are reported.

Note. Reading-Er1, number of errors in decoding in reading a text passage in Grade 1; Spelling-Er1, number of words, incorrectly written in a dictation in Grade 1; Reading-Er3, number of errors in decoding in reading a text passage in Grade 3; Spelling-Er3, number of words, incorrectly written in a dictation in Grade 3; Com. Acc. 3, total number of correct answers in multiple-choice questions after reading a text in Grade 3; CDT, Circle drawing Task at 5 years of age; ToL, Tower of London at 5 years of age; DRST, Dual Request Selective Task at 5 years of age; BDS, Backward Digit Span at 5 years of age; Fluency, semantic Fluency at 5 years of age; DCCS, Dimensional Change Card Sort Task at 5 years of age; Gen. Intel. F., Coloured Progressive Matrices Test score at 5 years of age.

		Estimate	S.E.	Est./S.E.	P-Value
Inhibition BY	ToL	1.000	0.000	999.000	999.000
	CDT	0.032	0.010	3.130	0.002
WM-flexibility BY	BDS	1.000	0.000	999.000	999.000
	DRST	1.479	0.409	3.617	0.000
	Fluency	2.604	0.943	2.762	0.006
	DCCS	0.190	0.037	5.101	0.000
Reading Spelling 1 BY	Spelling-Er1	1.000	0.000	999.000	999.000
	Reading-Er1	0.451	0.098	4.625	0.000
Reading Spelling 3 BY	Spelling-Er3	2.390	1.044	2.288	0.022
	Reading-Er3	0.614	0.235	2.619	0.009
Reading Spelling 1 ON	Inhibition	-0.831	0.612	-1.358	0.175
	WM-flexibility	-0.233	2.461	-0.095	0.925
Reading Spelling 3 ON	Reading Spelling 1	0.212	0.122	1.740	0.082
	Inhibition	0.065	0.169	0.382	0.702
	WM-flexibility	0.093	0.638	0.145	0.885
Reading Spelling 1 ON	Maternal education	-1.780	1.236	-1.440	0.150
	Gen. Intel. F.	-0.041	0.232	-0.176	0.861
Reading Spelling 3 ON	Maternal education	0.213	0.340	0.625	0.532
	Gen. Intel. F.	-0.091	0.072	-1.275	0.202
Comp. Acc. 3 ON	Reading Spelling 1	-0.088	0.044	-1.990	0.047
	Inhibition	-0.158	0.160	-0.993	0.321
	WM-flexibility	1.640	0.632	2.594	0.009
	Maternal education	-0.013	0.247	-0.053	0.958
	Gen. Intel. F.	-0.043	0.048	-0.909	0.364
Inhibition WITH	WM-flexibility	1.251	0.290	4.308	0.000
	Maternal education	0.549	0.228	2.412	0.016
	Gen. Intel. F.	2.482	1.082	2.294	0.022
WM-flexibility WITH	Maternal education	0.105	0.047	2.237	0.025
	Gen. Intel. F.	0.878	0.224	3.925	0.000
Comp. Acc. 3 WITH	Reading Spelling 3	-0.379	0.368	-1.029	0.303
Maternal education WITH	Gen. Intel. F.	-0.002	0.176	-0.009	0.993

Table 4 SEM results (standardized parameters are showed in Figure 1). Uppercase words in the first column refer to the M-Plus sintax: BY relates latent factors with their observed variables; ON means that a variable is predicted from one or more others latent or observed variables; WITH indicates a correlation between variables.

Note. Inhibition and WM-flexibility, EF latent factors at 5 years of age. Reading Spelling 1 and Reading Spelling 3, literacy latent factors in Grade 1 and 3. Reading-Er1, number of errors in decoding in reading a text passage in Grade 1; Spelling-Er1, number of words, incorrectly written in a dictation in Grade 1; Reading-Er3, number of errors in decoding in reading a text passage in Grade 3; Spelling-Er3, number of words, incorrectly written in a dictation in Grade 3; Com. Acc. 3, total number of correct answers in multiple-choice questions after reading a text in Grade 3; CDT, Circle drawing Task at 5 years of age; ToL, Tower of London at 5 years of age;

DRST, Dual Request Selective Task at 5 years of age; BDS, Backward Digit Span at 5 years of age; Fluency, semantic Fluency at 5 years of age; DCCS, Dimensional Change Card Sort Task at 5 years of age; Gen. Intel. F., Coloured Progressive Matrices Test score at 5 years of age.

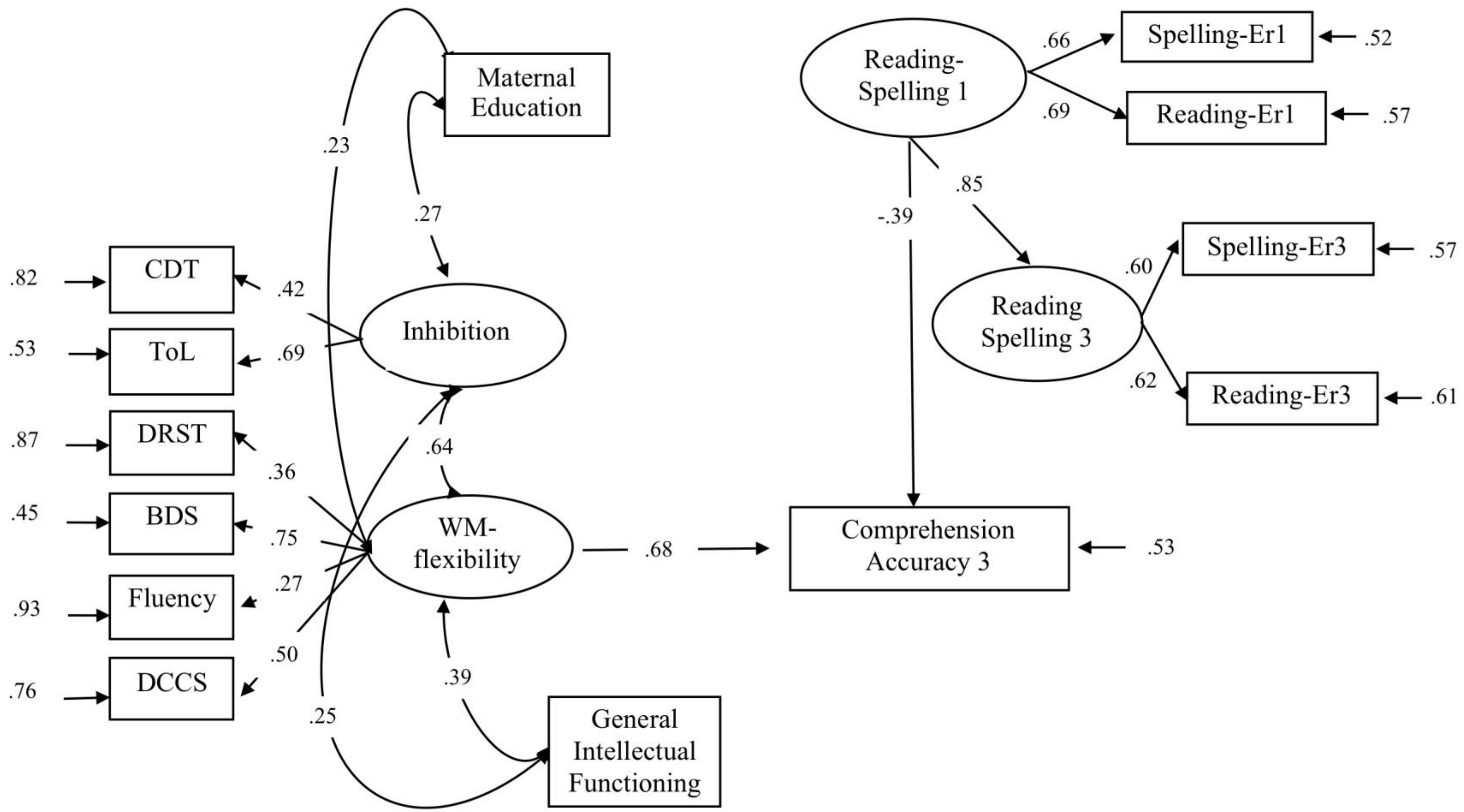

Figure 1. Structural model specifying the relationships among executive functions, control variables and reading-spelling factors at grade 1 and 3 and comprehension score at grade 3. Values are standardized estimates. The standardized parameters estimated correspond to the standardized linear regression coefficients (i.e. Beta coefficients). Non-significant parameters estimated are not shown.

Note. CDT=Circle Drawing Task at 5 years of age; ToL=Tower of London at 5 years of age; DRST=Dual Request Selective Task at 5 years of age; BDS=Backward Digit Span at 5 years of age; Fluency=semantic Fluency at 5 years of age; DCCS=Dimensional Change Sort Task at 5 years of age; General Intellectual Functioning: Colored Progressive Matrices Test score at 5 years of age; Maternal Education: mother's level of education; Reading-Er1, number of errors in decoding in reading a text passage in Grade 1; Spelling-Er1, number of words, incorrectly written in a dictation in Grade 1; Reading-Er3, number of errors in decoding in reading a text passage in Grade 3; Spelling-Er3, number of words, incorrectly written in a dictation in Grade 3; Com. Acc. 3, total number of correct answers in multiple-choice questions after reading a text in Grade 3