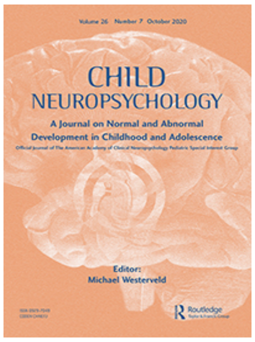

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Executive functions predict literacy and mathematics achievements: The unique contribution of cognitive flexibility in grades 2, 4, and 6

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ABSTRACT
Research has shown that cognitive flexibility plays a critical role in students' learning and academic achievement. However, the unique contribution of cognitive flexibility to academic achievement across schooling is not fully understood. Thus, this study tested whether cognitive flexibility explained a significant amount of variance in academic achievement (i.e., literacy and mathematics outcomes) across Grades 2, 4, and 6, above and beyond fluid intelligence, inhibitory control, working memory, attention, and planning. The sample included 243 second graders, 284 fourth graders, and 203 sixth graders. For Grades 4 and 6, we found that better performance on the flexibility score was associated with better academic outcomes after controlling for fluid intelligence, attention, inhibitory control, working memory, and planning. This effect was not observed for Grade 2. Our findings showed that cognitive flexibility is a key component for school achievement, particularly for older students.

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Executive functions; cognitive flexibility; academic achievements; academic outcomes

Although there are many operational definitions of executive functioning throughout the literature, it is widely agreed that executive functions (EF) are a set of cognitive skills involved in goal-directed activities, which are crucial for the regulation of thoughts and actions (Blair & Peters, 2003; Miller & Cohen, 2001; Miyake et al., 2000). The term EF encompasses at least three separate but related core components (Diamond & Lee, 2011): (a) working memory, the capacity to temporally store, manipulate, and process information while performing a task (Baddeley, 2000); (b) inhibitory control, the ability to inhibit an automatic tendency in a given situation (Thierry et al., 1994); and (c) cognitive flexibility (also referred as shifting, attention switching, or task switching), the capacity to shift between two or more tasks or goals allowing the adaptation of thoughts and actions (Davidson et al., 2006; Miyake et al., 2000). From these three core EF, higher-order EF are built such as planning (Müller & Kerns 2015) and fluid intelligence (e.g., reasoning; Collins et al., 2012; Lunt et al., 2012). Furthermore, EF share a common executive attention component (e.g., Diamond, 2006) that forms a foundation for the development of EF (e.g., Miyake et al., 2000).

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EF are linked to a broad range of skills crucial for daily functioning (Pennington & Ozonoff, 1996; Welsh, 2002). Moreover, several studies have shown that EF are particularly important in school contexts (Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). In particular, it has been argued that cognitive flexibility plays a fundamental role in students' learning and academic achievement (e.g., Bull & Scerif, 2001; Ropovik, 2014; Titz & Karbach, 2014), by enabling them to change perspective, adapt to environmental changes, and think divergently. Although researchers have sought to understand how individual differences in EF are related to children's academic achievement, the unique contribution of cognitive flexibility to academic achievement across schooling is not fully understood. Thus, after controlling for the contribution of working memory, inhibitory control, planning, reasoning, and attention, this study examined the unique contribution of cognitive flexibility to academic achievement in Grades 2, 4, and 6.

Development of cognitive flexibility

In general, research has shown that EF emerge at early infancy and continue to develop into adulthood (Anderson, 2002; Zelazo & Carlson, 2012), and different components of EF develop at different rates during this time (Clark et al., 2013). Specifically, cognitive flexibility develops rapidly in preschool, becomes largely mature by 10 years of age (Blaye et al., 2006; Crone et al., 2004; Dick, 2014; Paniak et al., 1996; Rosselli & Ardila, 1993; Welsh et al., 1991), and continues to improve throughout adolescence and adulthood (Anderson, 2002).

The early development of cognitive flexibility skills is consistently demonstrated by research examining children's categorization and sorting behaviors. For instance, 2-year-olds can judge if an object belongs to a group and consider it as a possible member of another group (e.g., blue blocks in group A, yellow blocks in group B, etc.; Sugarman, 1983). In addition, flexible reclassification of objects (i.e., group objects on the basis of a shared feature and further groupings based on different features) showed important developments across time: the number of children generating two or more groups increased from 37% at 5 years to 67% at 9 years of age (Blaye et al., 2006).

Furthermore, developmental changes on rule-use tasks (i.e., another method to assess cognitive flexibility) also occur since preschool. These tasks typically consist of two phases: (a) the pre-switch phase in which a set is established (e.g., sort cards by color); and (b) the post-switch phase where participants are instructed to shift to a different set (e.g., sort cards by shape) that conflicts with the first set (Garon et al., 2008). The majority of 3-year-olds perform well during the pre-switch phase, but continue to sort according to the pre-switch rules during the post-switch phase. In turn, the majority of 4- and 5-year-olds correctly sort following the post-switch rules (for a review, see Zelazo et al., 2003). Moreover, only about one-fourth of 6-year-olds correctly sort a version of this task requiring shifting between rules that are conditional on contextual cues (i.e., black border vs. no black border; Henning et al., 2011).

Developmental changes on cognitive flexibility skills were also shown by the Flexible Item Selection Task (Blair et al., 2004; Blair & Razza, 2007; Jacques & Zelazo, 2001), in which participants have to sort by a relevant matching dimension and to switch to a new matching dimension. In the standard version of this task, three objects were presented and participants select two objects that match in one way (e.g., Cards 1 and 2 are the same shape and this is different from Card 3). Next, the participants have to flexibly sort and switch to a second dimension (e.g., Cards 2 and 3 are the same color that is different from Card 1). Regarding performance across time, the majority of 3-year-olds showed poor performance on both matching phases, 4-year-olds showed good performance on the first matching phase but had difficulty in switching to the second phase, 5-year-olds flexibly performed better at the second selection than their younger peers, and ceiling performance was not reached until 6 years of age (Yerys et al., 2012).

Maturational changes of cognitive flexibility beyond the preschool were also shown by the Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948). In this test participants sort picture cards by one rule (e.g., shape) and then switch to sort the cards by a different rule that is guessed from experimenter feedback (e.g., color). Six-year-olds have difficulty in performing the WCST, and they fail to perform at adult level until around 10 years of age (Crone et al., 2004; Paniak et al., 1996; Rosselli & Ardila, 1993; Welsh et al., 1991).

Thus, research demonstrated that cognitive flexibility rapidly increases during early and middle childhood and that different paradigms have been developed to assess this skill across ages. Importantly, this EF component is conceptualized as a later developing skill resulting from improvements in working memory and inhibition (Blackwell et al., 2009; Zelazo et al., 2003; Marcovitch et al., 2010). When executing a task requiring cognitive flexibility, an individual needs to, first, develop a strategy for problem-solving in working memory, and, then, shift to a new rule/criterion while inhibiting the previously created rule/criterion (Best & Miller, 2010; Garon et al., 2008).

As cognitive flexibility is closely related to other EF components, controlling for other EF is essential to understand the unique contribution of this component for academic achievement. However, while some studies support that cognitive flexibility is a distinct component of EF, others failed to find this differentiation. (e.g., St Clair-Thompson & Gathercole, 2006). This disparity of results across studies may reflect an important difference in the organization of EF across development. Indeed, some authors suggested that cognitive flexibility may be less differentiated from working memory and inhibition in young children when compared with older participants (e.g., Senn et al., 2004). Though there is increasing evidence that improvements in cognitive flexibility are linked to developments in other EF components (Blackwell et al., 2009; Zelazo et al., 2003; Marcovitch et al., 2010), the nature of these associations remains unclear.

Executive functions and academic achievement

Research has shown that EF predict outcomes in real-world settings, such as school readiness and academic performance (e.g., Blair & Razza, 2007; Bull & Scerif, 2001; Miller & Hinshaw, 2010; Willoughby et al., 2012). Regarding school readiness, links between EF and academic indicators of readiness are strong (e.g., Brock et al., 2009; Kim et al., 2013; Willoughby et al., 2011). For instance, Monette et al. (2011) found that math and reading/writing skills at the end of Grade 1 were associated with kindergarten inhibition, flexibility, and working memory skills. Importantly, in this study working memory contributed uniquely for math skills when all covariates (viz. pre-academic abilities, affective variables, and family variables) were controlled.

Positive associations of performance-based measures of EF with mathematics and literacy performance have been found consistently across different developmental stages (e.g., Blair & Razza, 2007; Bull & Scerif, 2001; Miller & Hinshaw, 2010; Willoughby et al., 2012). Still, most studies have focused on the role of working memory (Gathercole & Pickering, 2000; Passolunghi et al., 2008; Swanson, 2006). For example, three meta-analyses found strong evidence that children with math and/or reading disabilities had lower working memory capacity when compared to typically developing peers (Carretti et al., 2009; Swanson & Jerman, 2006; Swanson et al., 2009). Also, a review supported that working memory is an EF component recruited in math problems (Raghubar et al., 2010).

Though with less consistent evidence, other EF components besides working memory have also been found to be related to academic achievement across schooling. For instance, better inhibition skills were associated with better math and reading performance in preschoolers and first graders (Blair & Razza, 2007; Espy et al., 2004). Significant associations were found between cognitive flexibly, inhibitory control, and mathematical achievement in third graders (Bull & Scerif, 2001). In turn, cognitive flexibility was positively associated with reading achievement, while inhibitory control was positively associated with mathematics achievement in adolescents (Latzman et al., 2010).

In learning and classroom contexts, cognitive flexibility is particularly important. It helps students learn from mistakes and use feedback, select alternative strategies or responses, and process information simultaneously (Anderson, 2002; Deák & Wiseheart, 2015; Diamond, 2013; Ionescu, 2012; Miller & Cohen, 2001). Indeed, a meta-analysis showed that cognitive flexibility predicts math and reading skills in children between the ages of 4 and 13 years (Yeniad et al., 2013). Furthermore, many studies showed that cognitive flexibility training improves children's performance in the classroom (e.g., Titz & Karbach, 2014), supporting that flexibility and achievement performance are related.

Research about the association between cognitive flexibility and math outcomes seems to have more empirical support than the association between cognitive flexibility and literacy skills (Van der Sluis et al., 2004). For instance, studies have found that children with reading disability perform similarly to a control group on flexibility tasks (Klorman et al., 1999; Van der Sluis et al., 2004) suggesting no relation between cognitive flexibility and reading. Overall, studies assessing the relative contribution of cognitive flexibility to school achievement are inconsistent, probably due to changes in the organization of EF components across development and differences in the measurement of EF.

As research provides some evidence that cognitive flexibility, academic achievements, and intelligence are associated (Ardila et al., 2000; Van der Sluis et al., 2004), an important issue is whether the association between flexibility and academic achievements is independent of other variables such as intelligence. On the one hand, research has shown that the relation between flexibility and academic achievements disappears after controlling for verbal intelligence in school-aged children (Bull & Scerif, 2001). Indeed, van der Sluis et al. (2007) also found that cognitive flexibility was related to nonverbal reasoning and reading. On the other hand, others have failed to find this impact of intelligence and showed that cognitive flexibility in preschoolers remains a significant predictor of academic achievements in first grade independent of verbal intelligence (George & Greenfield, 2005). Studies controlling for the potential influence of confounding variables, such as intelligence as well as other EF, are scarce. This raises interpretation problems to the reported associations between cognitive flexibility and academic achievements.

Present study

A limited number of studies have examined the association between cognitive flexibility and academic achievements across schooling. Moreover, the few studies on this topic have focused on a limited age range and/or have failed to understand the unique contribution of this skill, by neglecting likely confounding variables, such as intelligence or other EF components. Thus, the primary goal of this study was to test whether cognitive flexibility would explain a significant amount of variance in academic achievement in Grades 2, 4, and 6, after controlling for fluid intelligence, attention, inhibitory control, working memory, and planning to academic achievement. Based on the previously surveyed research, we anticipated that across the three Grades, fluid intelligence and EF would be associated with academic outcomes, and children with stronger cognitive flexibility would display better academic performance. Analyzing associations between specific EF components and academic performance across development could shed light onto developmental periods during which specific cognitive flexibility is more predictive of academic achievement. This will support educational practitioners and researchers in assessing EF skills and will provide a foundation for research further clarifying components to the development of academic skills and examining opportunities for intervention.

Method

Participants

In this study participated 736 students in Grades 2, 4, and 6 from three public clusters of schools in the North of Portugal. Six participants were excluded from analysis because of missing data mandatory for the computation of the combined scores of NEPSY-II, Development Neuropsychological Assessment (Korkman et al., 2007). The final sample included 243 second graders (M = 7.68 years, SD = 0.34; 111 girls), 284 fourth graders (M = 9.77 years, SD = 0.46; 145 girls), and 203 sixth graders (M = 11.70 years, SD = 0.50; 110 girls). All students were European Portuguese native speakers. The mother's educational level was similar between groups, which was used as a proxy of socio-economic status: in Grade 2, 3% of mothers completed grade 4 or bellow, 28% completed grade 9 or bellow, 32% completed high school, 30% completed college degree, 3% completed a post-graduation course, and 4% have unknown educational level; in Grade 4, 8% of mothers completed grade 4 or bellow, 33% completed grade 9 or bellow, 33% completed high school, 19% completed college degree, 2% completed a post-graduation course, and 5% have unknown educational level, and (c) in Grade 6, 5% of mothers completed grade 4 or bellow, 38% completed grade 9 or bellow, 24% completed high school, 24% completed college degree, 7% completed a post-graduation course, and 2% have unknown educational level.

The study was approved by the Ethics Committee of the authors' University and informed consent from all participants' legal guardians and child assent were gathered.

Measures

Fluid intelligence

We used the Raven's Colored Progressive Matrices (Raven et al., 2004; Simões, 2000) as a nonverbal estimate of fluid intelligence. This test is composed of three sets, with 12 items each. Each item requires that participants select from six options the missing element that completes a pattern. The final score was the sum of correct answers, with higher scores corresponding to higher intelligence skills. This test was sensitive to fluctuations in intellectual function, exhibiting good test-retest reliability (*r* =.80; Raven et al., 1998), and good internal consistency (*K–R 20* and Cronbach's alpha average around .85; Cantwell, 1967; Simões, 2000).

Attention

The Cancellation task from the Coimbra Neuropsychological Assessment Battery (BANC; Simões et al., 2016) was used to assess selective and sustained visual attention. This test is an adaptation of the "Test des Deux Barrages" (Zazzo & Stambak, 1960) and of the "Toulouse-Pieron Cancellation Test" (Do Amaral, 1967). Participants are given a sheet with squares arranged in lines and are asked to cross out the squares that are equal to a previously presented model. The tasks last for 10 minutes. The final score was determined through a formula that considers the number of squares correctly crossed, omitted, and incorrectly crossed (Simões et al., 2016). Higher scores indicate higher levels of attention. This test exhibited good test-retest reliability (*r* = .76; Moura et al., 2018) and adequate internal consistency (Cronbach's alpha around .72/.91; Moura et al., 2018).

Inhibitory control

We used the inhibition combined score of the Inhibition subtest of the NEPSY-II, Development Neuropsychological Assessment (Korkman et al., 2007). This test evaluates the ability to quickly inhibit automatic responses in favor of novel responses. Participants are given a sheet with a series of black and white shapes (Part I) or arrows (Part II) and are asked to say the opposite shape (i.e., saying square when circle and vice-versa) or arrow direction (i.e., saying up when pointing down and vice-versa). This task is performed for a maximum of 240 s, and the final score is the combination of completion time with errors (Korkman et al., 2007). Higher combined scores are indicative of better inhibition skills. It exhibited good test-retest reliability (*r* = .81, Brooks et al., 2009) and excellent internal consistency (Cronbach's alpha = .92; Korkman et al., 2007).

Working memory

We assessed verbal working memory through the Backward-digit span task from the Wechsler Intelligence Scale for Children-III (WISC-III; Simões et al., 2003). In this subtest, children are asked to recall sequences of numbers with increasing length in backward order. The final score was the number of sequences successfully recalled, with higher scores indicating higher working memory. This subtest exhibited a good test-retest reliability (*r* = .83; Wechsler, 1981) and an excellent internal consistency (α = .83; Waters & Caplan, 2003).

Planning

The Tower task from BANC (Simões et al., 2016) was used. This kind of task is frequently used to assess planning abilities (Lezak et al., 2004). This task is composed of a tray with three pins with different heights and three colorful balls. Children are asked to reproduce several models presented on cards, which become progressively more demanding. The final score was the number of models correctly completed at the first trial, with higher scores corresponding to better planning skills. It exhibited good test-retest reliability (r = .53 and adequate internal consistency (Cronbach's alpha around .72 and .91; Moura et al., 2018).

Cognitive flexibility

We used the flexibility combined score of the Inhibition subtest of the NEPSY-II (Korkman et al., 2007). This score evaluates the ability to quickly inhibit automatic responses as well as the ability to switch between response types. Participants are provided with the same sheet with black and white shapes or arrows described in described in the Inhibitory Control section. However, in this task, participants' response depends on the color of the shape or arrow. Specifically, they are asked to say the correct shape or arrow direction if it is colored white or to say the opposite shape or arrow direction if it is colored black. This task is performed for a maximum of 240 s, and the final score is the combination of completion time with errors (Korkman et al., 2007). Higher combined scores suggest better flexibility skills. It exhibited good test-retest reliability (r = .82, Brooks et al., 2009) and excellent internal consistency (Cronbach's alpha = .99; Korkman et al., 2007).

Academic achievement

To measure students' academic achievement, we used their marks for two core subjects common to the three targeted grades, namely, Mother Tongue Literacy (i.e., Portuguese) and Mathematics. Marks are assigned by teachers at the end of each term in a scale ranging from 1 (*lowest score*) to 5 (*highest score*). For the present study, we used the marks given at the end of the first term (December), immediately before data collection (January-February).

Procedure

All students were evaluated in two 40-min individual testing sessions during the second term of the Portuguese academic year (January-February). All measures were administered in a quiet room by highly-trained research assistants with a graduate degree in Psychology. Students performed the following tasks: Raven's Colored Progressive Matrices, Backward-digit span task, and Inhibition tasks from NEPSY-II in one session; and Tower and Canceling tasks from BANC in another session. Sessions order was counterbalanced, but tasks order within sessions was held constant.

Results

Table 1 displays descriptive statistics for all variables across the three grades. Skewness and kurtosis values were below |3| and |10|, respectively, suggesting no severe deviations from the normal distribution (Kline, 2005). The inspection of the correlation matrices presented in Tables 2–3 showed that all EF-related variables were moderately-to-strongly correlated with each other as well as with academic achievement.

To examine the effects of EF on academic achievement and the unique contribution of cognitive flexibility, we conducted a two-step regression analysis for each Grade (see Tables 4 and 5 for the results of the regression models for Literacy and Mathematics

Table 1. Descriptive statistics for all measures in the study.

	Grade 2		Grade 4		Grade 6	
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*
Reasoning	24.27	5.00	28.45	4.72	31.41	3.45
Attention	6.69	2.55	9.67	3.10	13.61	4.10
Inhibitory control	11.10	3.07	9.83	3.42	9.34	3.50
Working memory	3.63	1.31	4.24	1.37	5.06	1.58
Planning	9.05	1.70	9.98	1.73	10.00	1.79
Cognitive flexibility	9.67	3.40	9.13	3.22	9.72	3.36
Literacy achievement	3.86	0.92	3.62	0.74	3.41	0.63
Math achievement	3.84	0.90	3.60	0.87	3.49	0.97

Table 2. Bivariate correlations between all measures in the study for grade 2 (below the diagonal) and grade 4 (above the diagonal).

	1	2	3	4	5	6	7	8
1. Reasoning		.36***	.37***	.37***	.16**	.33***	.34***	.42***
2. Attention	.27***		.33***	.20**	.11	.30***	.21***	.28***
3. Inhibitory control	.32***	.23***		.27***	.06	.51***	.35***	.32***
4. Working memory	.34***	.21**	.38***		.16**	.27***	.33***	.36***
5. Planning	.20**	.14*	.14*	.06		.13*	.15*	.23***
6. Cognitive flexibility	.36***	.25***	.40***	.28***	.08		.34***	.33***
7. Literacy achievement	.42***	.23***	.32***	.29***	.14*	.29***		.72***
8. Math achievement	.49***	.33***	.38***	.30***	.21**	.30***	.74***	

* *p* <.05. ** *p* <.01. *** *p* <.001.

Table 3. Bivariate correlations between all measures in the study for grade 6.

	1	2	3	4	5	6	7	8
1. Reasoning								
2. Attention	.25***							
3. Inhibitory control	.30***	.33***						
4. Working memory	.31***	.19**	.21**					
5. Planning	.25***	.20**	.15*	.17*				
6. Cognitive flexibility	.29***	.37***	.39***	.28***	.20**			
7. Literacy achievement	.28***	.31***	.32***	.28***	.22**	.41***		
8. Math achievement	.42***	.29***	.33***	.40***	.29***	.48***	.67***	

* *p* <.05. ** *p* <.01. *** *p* <.001.

achievement, respectively). In the first step, we introduced fluid intelligence, attention, inhibitory control, working memory, and planning as predictors. In the second step, we added cognitive flexibility to the model. In all analyses, the inspection of the Variance Inflation Factor (VIF) showed no evidence of multicollinearity (VIF < 2).

Effects of EF on academic achievement in grade 2

Literacy

Step 1 of the regression analysis was significant, $R^2 = .24$, $F(5, 237) = 14.57$, $p < .001$. Fluid intelligence ($b = .31$) and inhibitory control ($b = .15$) were found to predict literacy achievement. The inclusion of cognitive flexibility on Step 2 did not increase the amount of explained variance in literacy achievement, $F_{\text{change}} < 1$.

Table 4. Parameter estimates for the regression models predicting literacy achievement in grades 2, 4, and 6.

	Grade 2			Grade 4			Grade 6		
Predictors	*B*	*b*	*t*	*B*	*b*	*t*	*B*	*b*	*t*
Step 1									
Reasoning	0.06	.31	4.85***	0.02	.16	2.52*	0.02	.10	1.48
Attention	0.03	.08	1.35	0.01	.03	0.48	0.03	.17	2.46*
Inhibitory control	0.05	.15	2.43*	0.05	.22	3.77***	0.03	.18	2.60**
Working memory	0.08	.11	1.73	0.11	.20	3.36***	0.07	.17	2.44*
Planning	0.02	.03	0.57	0.04	.08	1.50	0.04	.10	1.51
Step 2									
Reasoning	0.05	.29	4.45***	0.02	.14	2.30*	0.02	.08	1.16
Attention	0.03	.08	1.17	0.003	.01	0.21	0.02	.12	1.67
Inhibitory control	0.04	.13	1.97*	0.04	.16	2.56*	0.02	.12	1.75
Working memory	0.08	.10	1.62	0.10	.18	3.14**	0.05	.13	1.97*
Planning	0.02	.04	0.61	0.03	.07	1.32	0.03	.08	1.29
Cognitive flexibility	0.02	.09	1.39	0.03	.15	2.36*	0.04	.24	3.30***

* p <.05. ** p <.01. *** p <.001.

Table 5. Parameter estimates for the regression models predicting math achievement in grades 2, 4, and 6.

	Grade 2			Grade 4			Grade 6		
Predictors	*B*	*b*	*t*	*B*	*b*	*t*	*B*	*b*	*t*
Step 1									
Reasoning	0.06	.35	5.83***	0.05	.25	4.16***	0.07	.24	3.65***
Attention	0.06	.16	2.85**	0.03	.09	1.62	0.03	.11	1.67
Inhibitory control	0.06	.20	3.32***	0.04	.14	2.40*	0.04	.14	2.23*
Working memory	0.05	.08	1.29	0.12	.19	3.31***	0.16	.25	4.06***
Planning	0.05	.09	1.58	0.08	.15	2.86**	0.08	.15	2.39*
Step 2									
Reasoning	0.06	.34	5.54***	0.04	.24	3.98***	0.06	.21	3.33***
Attention	0.05	.16	2.74**	0.02	.08	1.40	0.01	.04	0.64
Inhibitory control	0.05	.19	3.01**	0.02	.09	1.50	0.02	.07	1.14
Working memory	0.05	.07	1.23	0.11	.18	3.11**	0.13	.21	3.53***
Planning	0.05	.09	1.60	0.07	.14	2.71**	0.07	.13	2.16*
Cognitive flexibility	0.01	.04	0.67	0.03	.12	1.93*	0.09	.29	4.51***

* p <.05. ** p <.01. *** p <.001.

Mathematics

Step 1 of the regression analysis was significant, $R^2 = .34$, $F(5, 237) = 24.32$, $p < .001$. Fluid intelligence ($b = .35$), attention ($b = .16$), and inhibitory control ($b = .20$) were significant predictors of academic achievement. When cognitive flexibility was entered on Step 2, there was no significant increase in the amount of explained variance in mathematics achievement, $F_{change} < 1$.

Effects of EF on academic achievement in grade 4

Literacy

Step 1 of the regression analysis was significant, $R^2 = .21$, $F(5, 278) = 15.16$, $p < .001$. Fluid intelligence ($b = .16$), inhibitory control ($b = .22$), and working memory ($b = .20$) were significant predictors of literacy achievement. When cognitive flexibility was entered on Step 2, there was a significant increase in the amount of explained variance in academic achievement, $\Delta R^2 = .02$, $F_{change}(1, 277) = 5.56$, $p = .02$. Cognitive flexibility was found to be a significant and unique predictor, above and beyond the other EF ($b = .15$).

Mathematics

Step 1 of the regression analysis was significant, $R^2 = .28$, $F(5, 278) = 21.11$, $p < .001$. Fluid intelligence ($b = .25$), inhibitory control ($b = .14$), working memory ($b = .19$), and planning ($b = .15$) were significant predictors of mathematics achievement. When cognitive flexibility was entered on Step 2, there was a significant increase in the amount of explained variance in mathematics achievement, $\Delta R^2 = .01$, $F_{change}(1, 277) = 3.72$, $p = .05$. Cognitive flexibility was found to be a significant and unique predictor, above and beyond the other EF ($b = .12$).

Effects of EF on academic achievement in grade 6

Literacy

Step 1 of the regression analysis was significant $R^2 = .31$, $F(5, 197) = 10.27$, $p < .001$. Attention ($b = .17$), inhibitory control ($b = .18$), and working memory ($b = .17$) had a significant contribution to literacy achievement. As in Grade 4, the introduction of cognitive flexibility on Step 2 resulted in significant increase in the amount of explained variance in literacy achievement, $\Delta R^2 = .04$, $F_{change}(1, 196) = 10.88$, $p = .001$. Again, cognitive flexibility was found to have a significant and unique contribution to literacy achievement, above and beyond the other EF ($b = .24$).

Mathematics

Step 1 of the regression analysis was significant $R^2 = .32$, $F(5, 197) = 18.85$, $p < .001$. Fluid intelligence ($b = .24$), inhibitory control ($b = .14$), working memory ($b = .25$), and planning ($b = .15$) had a significant contribution to mathematics achievement. As in Grade 4, the introduction of cognitive flexibility on Step 2 resulted in significant increase in the amount of explained variance in mathematics achievement, $\Delta R^2 = .06$, $F_{change}(1, 196) = 20.32$, $p < .001$. Again, cognitive flexibility was found to have a significant and unique contribution to mathematics achievement, above and beyond the other EF ($b = .29$).

Discussion

This study aimed to increase our understanding of EF in general and cognitive flexibility in particular involved in children's academic performance. For that, we tested whether cognitive flexibility would explain a significant amount of variance in academic outcomes of Grades 2, 4, and 6, above and beyond other EF (viz., fluid intelligence, attention, inhibitory control, working memory, and planning). Overall, for Grades 4 and 6, we found that better performance on the flexibility combined score of the Inhibition subtest predicted better Literacy and Mathematics outcomes after controlling for the Raven's Colored Progressive Matrices (fluid intelligence), Cancellation task (attention), Inhibition subtest (inhibitory control), Backward-Digit Span task (working memory), and Tower task (planning). This effect was not observed for Grade 2.

As expected, this study showed that EF continues to develop through school-age years (e.g., Anderson, 2002; Zelazo & Carlson, 2012). Interestingly, results disclosed the specific contribution of EF components to academic achievements across Grades. In Grade 2, fluid intelligence and inhibitory control predicted literacy achievements, while fluid intelligence, attention, and inhibitory control predicted mathematics outcomes.

In this Grade, the inclusion of cognitive flexibility did not increase the amount of explained variance in academic achievements. In Grade 4, fluid intelligence, inhibitory control, and working memory predicted literacy outcomes, and fluid intelligence, inhibitory control, working memory, and planning were significant predictors of mathematics achievement. Importantly, in this Grade cognitive flexibility was found to be a significant and unique predictor of academic achievement, above and beyond control variables. In Grade 6, attention, inhibitory control, and working memory predicted literacy achievement, whereas fluid intelligence, inhibitory control, working memory, and planning had a significant contribution to mathematics achievement. As for Grade 4, for Grade 6, the inclusion of cognitive flexibility increased the amount of explained variance.

The association of EF with students' academic achievement across schooling seems to be cumulative in the sense that as students get older there is an increasing contribution of EF. In line with this pattern, the unique contribution of cognitive flexibility to students' marks was only evident in Grades 4 and 6, but no in Grade 2. Indeed, as suggested by previous research, cognitive flexibility may be more critical for more complex problems assessed in later school than in simple tasks assessed in younger ages (e.g., Bull et al., 2008). Several studies have shown that specific EF could be indistinguishable from each other up to 9 years of age (Brydges et al., 2012; Shing et al., 2010; Willoughby et al., 2012), but they are differentiable by the age of 10–11 years (Duan et al., 2010; Lehto et al., 2003; Wu et al., 2011). Our findings seem to confirm this general trend by providing evidence for the specific differentiation of cognitive flexibility across development and by showing that cognitive flexibility has a differentiable and unique value in Grade 4 and 6. This differentiable value was not observed in Grade 2. Moreover, our results show an additional evidence for the increasing importance of cognitive flexibility across development, since the magnitude of the effect is larger in Grade 6 than in Grade 4. Importantly, these findings may reflect either a developmental differentiation of cognitive flexibility and/or that cognitive flexibility is critical for more complex tasks assessed in later school.

Although a large body of literature underscores the importance of working memory skills for academic outcomes (Gathercole & Pickering, 2000; Passolunghi et al., 2008; Swanson, 2006), our findings highlight the important role that cognitive flexibility plays in predicting academic outcomes across development, above and beyond the other EF components. Though cognitive flexibility only explains a small percentage of the variation in our outcomes, this is a significant result showing that this particular skill explains part of the variability of academic achievement after controlling for another EF.

Literature provides little evidence on the specific contributions of cognitive flexibility for academic achievements controlling for confounding variables such as intelligence. Some studies have suggested that this association with intelligence disappears when controlling for other EF components (Duan et al., 2010; Friedman et al., 2006). In particular, several studies have shown that fluid intelligence impairments are responsible for the deficits observed in executive tests for different neurological conditions (e.g., frontal lobe lesions, Roca et al., 2010; Parkinson's disease, 2012; frontotemporal dementia, 2013). This raised the question of how well executive impairments are explained by a fluid intelligence deficit. However, our results suggest a unique contribution of cognitive flexibility after controlling for a nonverbal estimate of fluid intelligence. Part of these apparent discrepant findings between studies could be explained to differences in the kind of tasks used to assess cognitive flexibility. In the flexibility subtest of NEPSY-II participants have to perform multitasking task as they have to switch between two tasks. A multitasking task may reflect anterior prefrontal impairments and not the dorsolateral deficits associated with fluid intelligence deficits (Roca et al., 2010). Our findings support the unique contribution of cognitive flexibility to academic outcomes independent of fluid intelligence and other components of EF. Still, it remains unclear whether flexibility predicts academic outcomes when controlling for other variables such as intelligence in general and verbal intelligence in particular.

Although there is less evidence for the association between cognitive flexibility and language achievements than for the link between cognitive flexibility and math outcomes (e.g., Van der Sluis et al., 2004), the present study supports the literature suggesting that cognitive flexibility is necessary for both literacy and mathematics achievements (Yeniad et al., 2013). It seems that children with a higher capacity to change perspective and adapt to environmental changes show better mathematical and literacy performance. However, the disparity found between studies could result from limitations associated with the paradigms used for the assessment of cognitive flexibility skills (see Emerson & Miyake, 2003; Rogers & Monsell, 1995).

The investigation about specific associations between EF components and academic outcomes through development shed some light on the timing during which specific EF components are more predictive of academic performance. The current study indicates that cognitive flexibility skills may be particularly important for older students, and it hints at the possibility that fourth grade may be an important period for promoting flexibility skills. These results support practitioners and researchers in assessing EF skills in general and cognitive flexibility in particular, since cognitive flexibility might be critical for assessing children's potential for academic performance. This also provides a foundation for research clarifying cognitive components to the development of academic skills and also for examining opportunities for intervention.

Limitations and future directions

Three limitations of the present study, along with possible avenues to overcome them in future research, are worth considering. First, because data were obtained at a single time point and because this study is correlational in nature, causality inferences should be avoided. Further longitudinal research is needed to replicate reported results. It would be particularly insightful to examine the role of EF in academic achievement throughout schooling.

Second, as evident from the data-analytic strategy adopted, all EF were measured through single indicators. Although the measures used are proposed as sound indicators of the respective constructs (Diamond, 2013), it is advisable to cross-validate the results using a multiple-indicator approach. To increase our theoretical and empirical knowledge about the link between EF and school achievements and eventually about the processes underlying this link, researchers may consider to use structural equation modeling to test complex models with several indicators per latent construct. Such analysis may increase the reliability of the constructs being measured and be more appropriate to grasp the complexity of EF, which may be overlooked by single indicators approaches. The understanding of the specific time of EF development would require longitudinal data and should include several measures per EF component. More studies are needed to understand the precise timing of differentiation of EF components and the implications on academic outcomes.

Finally, we restricted the assessment of EF to cognitive aspects activated during the resolution of abstract and decontextualized problems (i.e., cool EF). Recent definitions of EF also include affective aspects (hot EF), which are critical in situations that are emotionally and motivationally relevant (Zelazo et al., 2005). For instance, studies with preschoolers (Howse et al., 2003) and kindergartners (Graziano et al., 2007; Trentacosta & Izard, 2007) showed that ratings of hot EF abilities were linked to achievement outcomes. For a more comprehensive study of the relationship between EF and academic achievement, researchers should target cool and hot EF together.

Conclusion

Previous research has shown that EF components (particularly, working memory) and intelligence are important contributors to academic outcomes. Our results found that cognitive flexibility is another key component for school achievement, likely in older students. Furthermore, our findings provide an insight into the unique contribution of cognitive flexibility to academic outcomes controlling for fluid intelligence, attention, inhibitory control, and working memory. By analyzing the relationship between these variables, the current study supports the importance of taking into account cognitive flexibility skills when exploring the contribution of EF components to academic achievements.

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References

Anderson, P. (2002). Assessment and development of Executive Function (EF) during childhood. *Child Neuropsychology*, *8*(2), 71–82. https://doi.org/10.1076/chin.8.2.71.8724

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology*, *15*(1), 31–36. https://doi.org/10.1093/arclin/15.1.31

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*(11), 417–423. https://doi.org/10.1016/S1364-6613(00)01538-2

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *The Journal of General Psychology*, *39*(1), 15–22. https://doi.org/10.1080/00221309.1948.9918159

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blackwell, K. A., Cepeda, N. J., & Munakata, Y. (2009). When simple things are meaningful: Working memory strength predicts children's cognitive flexibility. *Journal of Experimental Child Psychology*, *103*(2), 241–249. https://doi.org/10.1016/j.jecp.2009.01.002

Blair, C., & Peters, R. (2003). Physiological and neurocognitive correlates of adaptive behavior in preschool among children in head start. *Developmental Neuropsychology*, *24*(1), 479–497. https://doi.org/org/10.1207/S15326942DN2401_04

Blair, C., Peters, R., & Granger, D. (2004). Physiological and neuropsychological correlates of approach/withdrawal tendencies in preschool: Further examination of the behavioral inhibition system/behavioral activation system scales for young children. *Developmental Psychobiology*, *45*(3), 113–124. https://doi.org/10.1002/dev.20022

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*(2), 647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Blaye, A., Bernard-Peyron, V., Paour, J., & Bonthoux, F. (2006). Categorical flexibility in children: Distinguishing response flexibility from conceptual flexibility; the protracted development of taxonomic representations. *European Journal of Developmental Psychology*, *3*(2), 163–188. https://doi.org/10.1080/17405620500412267

Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., & Grimm, K. J. (2009). The contributions of "hot" and "cool" executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly*, *24*(3), 337–349. https://doi.org/10.1016/j.ecresq.2009.06.001

Brooks, B. L., Sherman, E. M. S., & Strauss, E. (2009). NEPSY-II: A developmental neuropsychological assessment, second edition. *Child Neuropsychology*, *16*(1), 80–101. https://doi.org/10.1080/09297040903146966

Brydges, C. R., Reid, C. L., Fox, A. M., & Anderson, M. (2012). A unitary executive function predicts intelligence in children. *Intelligence*, *40*(5), 458–469. https://doi.org/10.1016/j.intell.2012.05.006

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*(3), 205–228. https://doi.org/10.1080/87565640801982312

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*(3), 273–293. https://doi.org/10.1207/S15326942DN1903_3

Cantwell, Z. M. (1967). The performance of american pupils on the coloured progressive matrices. *British Journal of Educational Psychology*, *37*(3), 389–390. https://doi.org/10.1111/j.2044-8279.1967.tb01959.x

Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining the performance of individuals with specific reading comprehension difficulties: A meta-analysis. *Learning and Individual Differences*, *19*(2), 246–251. https://doi.org/10.1016/j.lindif.2008.10.002

Clark, C. A. C., Sheffield, T. D., Chevalier, N., Nelson, J. M., Wiebe, S. A., & Espy, K. A. (2013). Charting early trajectories of executive control with the shape school. *Developmental Psychology*, *49*(8), 1481–1493. https://doi.org/10.1037/a0030578

Collins, A., Koechlin, E., & O'Doherty, J. P. (2012). Reasoning, learning, and creativity: Frontal lobe function and human decision-making. *PLoS Biology*, *10*(3), 1–16. https://doi.org/10.1371/journal.pbio.1001293

Crone, E. A., Ridderinkhof, K. R., Worm, M., Somsen, R. J. M., & van der Molen, M. W. (2004). Switching between spatial stimulus-response mappings: A developmental study of cognitive flexibility. *Developmental Science*, *7*(4), 443–455. https://doi.org/10.1111/j.1467-7687.2004.00365.x

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037–2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Deák, G. O., & Wiseheart, M. (2015). Cognitive flexibility in young children: General or task-specific capacity? *Journal of Experimental Child Psychology*, *138*, 31–53. https://doi.org/10.1016/j.jecp.2015.04.003

Diamond, A. (2006). The early development of executive functions. In E. Bialystok & F. I. M. Craik, (Eds..), *Lifespan cognition: Mechanisms of change* (pp. 70–95). New York, NY: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195169539.003.0006.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Dick, A. S. (2014). The development of cognitive flexibility beyond the preschool period: An investigation using a modified flexible item selection task. *Journal of Experimental Child Psychology*, *125*, 13–34. https://doi.org/10.1016/j.jecp.2014.01.021

Do Amaral, J. R. (1967). *O teste da barragem de Toulouse e Piéron: Elementos de aferição para a população portuguesa*. Fundação Calouste Gulbenkian.

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12-year- old children. *Psychological Test and Assessment Modeling*, *52* (4), 419–431. Retrieved from https://psycnet.apa.org/record/2011-02815-005

Emerson, M. J., & Miyake, A. (2003). The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language*, *48*(1), 148–168. https://doi.org/10.1016/S0749-596X(02)00511-9

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*(1), 465–486. https://doi.org/10.1207/s15326942dn2601_6

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. https://doi.org/10.1111/j.1467-9280.2006.01681.x

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, *70*(2), 177–194. https://doi.org/10.1348/000709900158047

George, J., & Greenfield, D. B. (2005). Examination of a structured problem-solving flexibility task for assessing approaches to learning in young children: Relation to teacher ratings and children's achievement. *Journal of Applied Developmental Psychology*, *26*(1), 69–84. https://doi.org/10.1016/j.appdev.2004.10.006

Grant, D. A., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology*, *38*(4), 404–411. https://doi.org/10.1037/h0059831

Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, S. D. (2007). The role of emotion regulation in children's early academic success. *Journal of School Psychology*, *45*(1), 3–19. https://doi.org/10.1016/j.jsp.2006.09.002

Henning, A., Spinath, F. M., & Aschersleben, G. (2011). The link between preschoolers' executive function and theory of mind and the role of epistemic states. *Journal of Experimental Child Psychology*, *108*(3), 513–531. https://doi.org/10.1016/j.jecp.2010.10.006

Howse, R. B., Calkins, S. D., Anastopoulos, A. D., Keane, S. P., & Shelton, T. L. (2003). Regulatory contributors to children's kindergarten achievement. *Early Education & Development*, *14*(1), 101–120. https://doi.org/10.1207/s15566935eed1401_7

Ionescu, T. (2012). Exploring the nature of cognitive flexibility. *New Ideas in Psychology*, *30*(2), 190–200. https://doi.org/10.1016/j.newideapsych.2011.11.001

Jacques, S., & Zelazo, P. D. (2001). The Flexible Item Selection Task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*(3), 573–591. https://doi.org/10.1207/S15326942DN2003_2

Kim, S., Nordling, J. K., Yoon, J. E., Boldt, L. J., & Kochanska, G. (2013). Effortful control in "hot" and "cool" tasks differentially predicts children's behavior problems and academic performance. *Journal of Abnormal Child Psychology*, *41*(1), 43–56. https://doi.org/10.1007/s10802-012-9661-4

Kline, R. B. (2005). *Principles and practice of structural equation modeling* (2nd edn ed.). The Guilford Press.

Klorman, R., Hazel-Fernandez, L. A., Shaywitz, S. E., Fletcher, J. M., Marchione, K. E., Holahan, J. M., Shaywitz, S. E., Stuebing, K. K., & Shaywitz, B. A. (1999). Executive functioning deficits in attention-deficit/hyperactivity disorder are independent of oppositional defiant or reading disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *38*(9), 1148–1155. https://doi.org/10.1097/00004583-199909000-00020

Korkman, M., Kirk, U., & Kemp, S. (2007). *NEPSY II: Administration manual*. Harcourt Assessment.

Latzman, R. D., Elkovitch, N., Young, J., & Clark, L. A. (2010). The contribution of executive functioning to academic achievement among male adolescents. *Journal of Clinical and Experimental Neuropsychology*, *32*(5), 455–462. https://doi.org/10.1080/13803390903164363

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, *21*(1), 59–80. https://doi.org/10.1348/026151003321164627

Lezak, M., Howieson, D., Loring, D., Hannay, J., & Fischer, J. (2004). *Neuropsychological assessment*. Oxford University Press.

Lunt, L., Bramham, J., Morris, R. G., Bullock, P. R., Selway, R. P., Xenitidis, K., & David, A. S. (2012). Prefrontal cortex dysfunction and 'jumping to conclusions': Bias or deficit? *Journal of Neuropsychology*, *6*(1), 65–78. https://doi.org/10.1111/j.1748-6653.2011.02005.x

Marcovitch, S., Boseovski, J. J., Knapp, R. J., & Kane, M. J. (2010). Goal neglect and working memory capacity in 4- to 6-year-old children. *Child Development*, *81*(6), 1687–1695. https://doi.org/10.1111/j.1467-8624.2010.01503.x

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Miller, M., & Hinshaw, S. P. (2010). Does childhood executive function predict adolescent functional outcomes in girls with ADHD? *Journal of Abnormal Child Psychology*, *38*(3), 315–326. https://doi.org/10.1007/s10802-009-9369-2

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*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Monette, S., Bigras, M., & Guay, M.-C. (2011). The role of the executive functions in school achievement at the end of grade 1. *Journal of Experimental Child Psychology*, *109*(2), 158–173. https://doi.org/10.1016/j.jecp.2011.01.008

Moura, O., Albuquerque, C. P., Pinho, M. S., Vilar, M., Lopes, A. F., Alberto, I., Pereira, M., Santos, M. J. S., & Simões, M. R. (2018). Factor structure and measurement invariance of the Coimbra neuropsychological Assessment Battery (BANC). *Archives of Clinical Neuropsychology*, *33*(1), 66–78. https://doi.org/10.1093/arclin/acx052

Müller, U., & Kerns, K. (2015). The development of executive function. In R. M. Lerner, L. S. Liben, & U. Mueller, (Eds..), *Handbook of child psychology and developmental science - Volume 2* (pp. 571–612). New Jersey: John Wiley & Sons. https://doi.org/10.1002/9781118963418.childpsy214.

Paniak, C., Miller, H. B., Murphy, D., Patterson, L., & Keizer, J. (1996). Canadian developmental norms for 9 to 14 year-olds on the Wisconsin Card Sorting Test. *Canadian Journal of Rehabilitation*, *9*(4), 233–237.
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*(3), 229–250. https://doi.org/10.1080/87565640801982320
Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*(1), 51–87. https://doi.org/10.1111/j.1469-7610.1996.tb01380.x
Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*(2), 110–122. https://doi.org/10.1016/j.lindif.2009.10.005
Raven, J., Raven, J. C., & Court, J. (2004). *Manual for Raven's progressive matrices and vocabulary scales*. Harcourt Assessment.
Raven, J., Raven, J. C., & Court, J. H. (1998). Manual for Raven's progressive matrices and vocabulary scales. In *Section 2: Coloured progressive matrices*. Oxford, UK: Oxford Psychologists Press.
Roca, M., Manes, F., Chade, A., Gleichgerrcht, E., Gershanik, O., Arévalo, G. G., Torralva, T., & Duncan, J. (2012). The relationship between executive functions and fluid intelligence in Parkinson's disease. *Psychological Medicine*, *42*(11), 2445–2452. https://doi.org/10.1017/S0033291712000451
Roca, M., Manes, F., Gleichgerrcht, E., Watson, P., Ibáñez, A., Thompson, R., Torralva, T., & Duncan, J. (2013). Intelligence and executive functions in frontotemporal dementia. *Neuropsychologia*, *51*(4), 725–730. https://doi.org/10.1016/j.neuropsychologia.2013.01.008
Roca, M., Parr, A., Thompson, R., Woolgar, A., Torralva, T., Antoun, N., Manes, F., & Duncan, J. (2010). Executive function and fluid intelligence after frontal lobe lesions. *Brain*, *133*(1), 234–247. https://doi.org/10.1093/brain/awp269
Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*(2), 207–231. https://doi.org/10.1037/0096-3445.124.2.207
Ropovik, I. (2014). Do executive functions predict the ability to learn problem-solving principles? *Intelligence*, *44*(1), 64–74. https://doi.org/10.1016/j.intell.2014.03.002
Rosselli, M., & Ardila, A. (1993). Developmental norms for the Wisconsin Card Sorting Test in 5-to 12-year-old children. *Clinical Neuropsychologist*, *7*(2), 145–154. https://doi.org/10.1080/13854049308401516
Senn, T. E., Espy, K. A., & Kaufmann, P. M. (2004). Using path analysis to understand executive function organization in preschool children. *Developmental Neuropsychology*, *26*(1), 445–464. https://doi.org/10.1207/s15326942dn2601_5
Shing, Y. L., Lindenberger, U., Diamond, A., Li, S.-C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. *Developmental Neuropsychology*, *35*(6), 679–697. https://doi.org/10.1080/87565641.2010.508546
Simões, M., Albuquerque, C., Pinho, M., Vilar, M., Pereira, M., Seabra-Santos, M., … Moura, O. (2016). *Bateria de Avaliação Neuropsicológica de Coimbra (BANC)*. CEGOC-TEA.
Simões, M., Rocha, A., & Ferreira, C. (2003). *Manual da Escala de Inteligência da Wechsler para Crianças - 3ª Edição (WISC-III)*. CEGOC-TEA.
Simões, M. M. R. (2000). *Investigações no âmbito da aferição nacional do teste das Matrizes Progressivas Coloridas de Raven (M.P.C.R)*. Lisboa: Fundação Calouste Gulbenkian & Fundação para a Ciência e Tecnologia.
Simões, M. M. R. (2000). Um estudo exploratorio com o Teste das Matrices Progressivas de Raven para Crianças (CPM/PM47). *Psychology and Psychologists Today Congress*.
St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology*, *59*(4), 745–759. https://doi.org/10.1080/17470210500162854

Sugarman, S. (1983). *Children's early thought: Developments in classifications*. Cambridge University Press.
Swanson, H. L. (2006). Cross-sectional and incremental changes in working memory and mathematical problem solving. *Journal of Educational Psychology*, *98*(2), 265–281. https://doi.org/10.1037/0022-0663.98.2.265
Swanson, H. L., & Jerman, O. (2006). Math disabilities: A selective meta-analysis of the literature. *Review of Educational Research*, *76*(2), 249–274. https://doi.org/10.3102/00346543076002249
Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities. *Journal of Learning Disabilities*, *42*(3), 260–287. https://doi.org/10.1177/0022219409331958
Thierry, A. M., Glowinski, J., Goldman-Rakic, P. S., & Christen, Y. (Eds.). (1994). *Motor and cognitive functions of the prefrontal cortex*. Springer-Verlag.
Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research*, *78*(6), 852–868. https://doi.org/10.1007/s00426-013-0537-1
Trentacosta, C. J., & Izard, C. E. (2007). Kindergarten children's emotion competence as a predictor of their academic competence in first grade. *Emotion*, *7*(1), 77–88. https://doi.org/10.1037/1528-3542.7.1.77
van der Sluis, S., de Jong, P. F., & van der Leij, A. (2004). Inhibition and shifting in children with learning deficits in arithmetic and reading. *Journal of Experimental Child Psychology*, *87*(3), 239–266. https://doi.org/10.1016/j.jecp.2003.12.002
van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, *35*, 427–449. https://doi.org/10.1016/j.intell.2006.09.001
Waters, G. S., & Caplan, D. (2003). The reliability and stability of verbal working memory measures. *Behavior Research Methods, Instruments, & Computers*, *35*(4), 550–564. https://doi.org/10.3758/BF03195534
Wechsler, D. (1981). The psychometric tradition: Developing the Wechsler adult intelligence scale. *Contemporary Educational Psychology*, *6*(2), 82–85. https://doi.org/10.1016/0361-476X(81)90035-7
Welsh, M. C. (2002). Developmental and clinical variations in executive functions. In D. L. Molfese & V. J. Molfese (Eds.), *Developmental variations in learning: Applications to social, executive function, language, and reading skills* (pp. 139–185). Lawrence Erlbaum Associates Publishers.
Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology*, *7*(2), 131–149. https://doi.org/10.1080/87565649109540483
Willoughby, M., Kupersmidt, J., Voegler-Lee, M., & Bryant, D. (2011). Contributions of hot and cool self-regulation to preschool disruptive behavior and academic achievement. *Developmental Neuropsychology*, *36*(2), 162–180. https://doi.org/10.1080/87565641.2010.549980
Willoughby, M. T., Wirth, R. J., & Blair, C. B. (2012). Executive function in early childhood: Longitudinal measurement invariance and developmental change. *Psychological Assessment*, *24*(2), 418–431. https://doi.org/10.1037/a0025779
Wu, K. K., Chan, S. K., Leung, P. W. L., Liu, W.-S., Leung, F. L. T., & Ng, R. (2011). Components and developmental differences of executive functioning for school-aged children. *Developmental Neuropsychology*, *36*(3), 319–337. https://doi.org/10.1080/87565641.2010.549979
Yeniad, N., Malda, M., Mesman, J., van IJzendoorn, M. H., & Pieper, S. (2013). Shifting ability predicts math and reading performance in children: A meta-analytical study. *Learning and Individual Differences*, *23*(1), 1–9. https://doi.org/10.1016/j.lindif.2012.10.004
Yerys, B. E., Wolff, B. C., Moody, E., Pennington, B. F., & Hepburn, S. L. (2012). Brief report: Impaired Flexible Item Selection Task (FIST) in school-age children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *42*(9), 2013–2020. https://doi.org/10.1007/s10803-012-1443-x

Zazzo, R., & Stambak, M. (1960). *Le Test des Deux Barrages: Une épreuve de pointillage. Neuchatel.* Delachaux et Niestlé.
Zelazo, P., Qu, L., & Müller, U. (2005). Hot and cool aspects of executive function: Relations in early development. In W. Schneider, R. Schumann-Hengsteler, & B. Sodian (Eds.), *Young children's cognitive development: Interrelationships among executive functioning, working memory, verbal ability, and theory of mind* (pp. 71–93). Lawrence Erlbaum Associates, Inc.
Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*(4), 354–360. https://doi.org/10.1111/j.1750-8606.2012.00246.x
Zelazo, P. D., Muller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood: VI. The development of executive function: Cognitive complexity and control –Revised. *Monographs of the Society for Research in Child Development*, *68*(3), 93–119. https://doi.org/10.1111/j.0037-976X.2003.00266.x