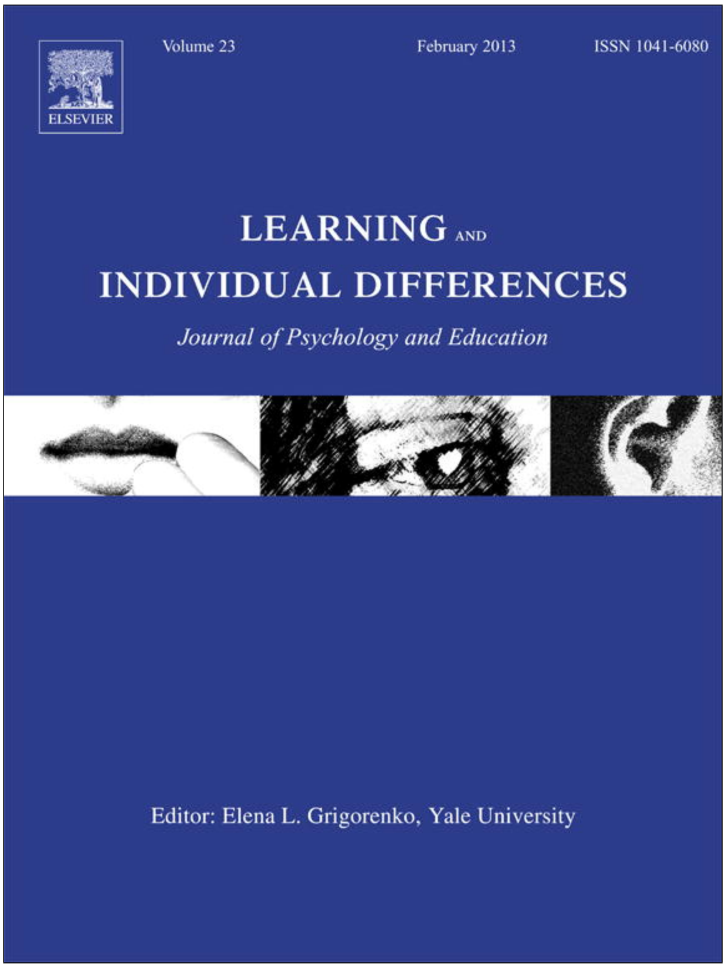
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Shifting ability predicts math and reading performance in children: A meta-analytical study

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ABSTRACT

Empirical evidence on the association between the shifting component of executive functioning and academic performance is equivocal. In two meta-analyses children's shifting ability is examined in relation to their performance in math (k = 18, N = 2330) and reading (k = 16, N = 2266). Shifting ability was significantly and equally associated with performance in both math (r = .26, 95% CI = .15–.35) and reading (r = .21, 95% CI = .11–.31). Intelligence was found to show stronger associations with math and reading performance than shifting ability. We conclude that the links between shifting ability, academic skills, and intelligence are domain-general.

1. Introduction

The ability to shift between conceptual representations is critical for the selection and maintenance of appropriate strategies and disengagement from irrelevant ones, and represents skills that are necessary to successfully perform academic tasks (Best, Miller, & Jones, 2009). It has been argued that this ability is particularly important for performance on complex academic tasks requiring alternation between different aspects of problems or arithmetical strategies (Agostino, Johnson, & Pascual-Leone, 2010; Blair, Knipe, & Gamson, 2008; Van der Sluis, De Jong, & Van der Leij, 2007). This suggests that shifting ability (or cognitive flexibility) would be mainly related to performance in subjects like math, which has indeed been reported in several studies (e.g., Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; Mayes, Calhoun, Bixler, & Zimmerman, 2009), although others have failed to find this association (e.g., Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004; Lee, Ng, & Ng, 2009; Monette, Bigras, & Guay, 2011). Although there is a less strong theoretical case for a link between shifting ability and reading performance, several studies have examined this association, with some reporting significant results (e.g., Latzman, Elkovitch, Young, & Clark, 2010; Van der Sluis et al., 2007), but others showing no link between the two (e.g., Mayes et al., 2009; McLean & Hitch, 1999). In the current study, a set of meta-analyses is performed to investigate whether shifting ability is significantly related to performance in math and reading in children.

1.1. Shifting and academic performance

A growing body of evidence shows that executive function (EF) is a crucial contributor to school achievement (Best et al., 2009; Müller, Liebermann, Frye, & Zelazo, 2008). EF refers to higher-order cognitive processes necessary for goal-directed problem solving in novel situations and planning. The term may encompass at least three separate but related components: inhibition, working memory and shifting (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Broadly speaking, shifting refers to changing the mental set that has been learned to a new one. The first step of shifting is to develop a representation of a rule (i.e., a particular strategy for problem solving) in working memory and the second one is to shift to a new rule, which requires the inhibition of the rule that has been already formed (Best & Miller, 2010; Garon, Bryson, & Smith, 2008). Although there is a substantial amount of research linking EF to academic achievement, most studies have focused on the contribution of working memory (Gathercole & Pickering, 2000; Passolunghi, Mammarella, & Altoe, 2008; Swanson, 2006).

Previous meta-analyses by Carretti, Borella, Cornoldi, and De Beni (2009), Swanson and Jerman (2006) and Swanson, Zheng, and Jerman (2009) found clear evidence for lower working memory capacity of children with math and/or reading disabilities compared to their peers without such disabilities. In addition, a review by Raghubar, Barnes and Hecht (2010) supports the role of working memory in math performance. Regarding inhibition, recent confirmatory factor analyses show that EF

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measures load on two latent factors that might best be called working memory and set-shifting (Huizinga, Dolan, & Van der Molen, 2006). Therefore, we focused on shifting as an important but not yet systematically reviewed component of EF in relation to academic outcomes. In this study, the role of shifting in math and reading achievement is investigated through a set of meta-analyses. Further, possible factors that may influence the association of shifting with these two academic domains are examined via moderator analyses to find out what contributes to the divergence of findings.

1.2. Moderators

Divergent findings regarding shifting and academic achievement may result from heterogeneity of (1) shifting tasks, (2) shifting task scoring, (3) sample characteristics, and (4) whether the impact of intelligence is controlled for in statistical analyses. One of the sources of heterogeneity in shifting tasks is variation in their level of complexity. Clark et al. (2010) for instance found that the Flexible Item Selection Task showed robust correlations with later achievement scores whereas the Shape School-Switch Condition demonstrated no association with achievement in preschool children after controlling for verbal intelligence, working memory and inhibition. The researchers explained the mixed results with academic achievement by pointing out the difference in the level of linguistic complexity between these two shifting tasks. Like other EF measures, shifting tasks may also differ in terms of the cognitive processes operating in addition to shifting, which may affect the relations with academic scores. Furthermore, shifting tasks differ in terms of rule presentation. On some tasks, the rule is explicitly presented to the child (e.g., trail making), whereas the sorting criterion is not explicitly revealed in most of the card sorting tasks (see Dimensional Change Card Sorting for exception) in which the rule should be deduced from the feedback on the trials. The distinction in rule presentation may change the load of nonexecutive processes (e.g., language and intelligence) or other executive components (working memory or inhibition), which may in turn moderate the relation of shifting with academic outcomes.

A second potential explanation for the heterogeneity of findings is the type of scoring of shifting tasks. Different tasks provide different scores such as reaction time, accuracy, or efficiency. In addition, some tasks provide difference scores (e.g., RT difference between the Parts A and B of Trail Making Task) whereas others give raw scores (e.g., total RT to complete the task). Despite a wealth of research on EF tasks, it is unclear whether different scores measure the same construct and whether tasks with multiple scores differ from those with a single score in terms of measuring shifting. Davidson, Amso, Anderson, and Diamond (2006) provided striking evidence that score type matters for different age groups. In their study with 4- to 13-year-olds and young adults, accuracy was found to be a more sensitive measure for young children than reaction time. Children were more impulsive than adults, so their reaction time resisted changing with an accuracy cost on difficult trials whereas adults tended to slow down (increasing their reaction time) to be able to give accurate responses. Scoring type of shifting tasks may thus moderate the relation between shifting and academic achievement.

Third, diverging outcomes may also result from the variation in age, gender, and SES of the samples in different studies. Shifting shows a long developmental progression, as even 13-year-old children do not reach the adult level (Davidson et al., 2006). It is unclear whether the relation between shifting and academic achievement differs across age. On the one hand, it has been found that shifting in preschool does not contribute to math skills at the age of 6 when the effect of age is controlled for (Espy et al., 2004). On the other hand, in another study with third and fourth graders, Trail Making Task, which is a commonly used shifting measure, showed significant correlations with math and reading scores, controlling for age (Andersson, 2008). It is possible that the relation between shifting and academic outcomes changes for preschoolers and school-aged children partly because of the changing structure of EF with development. Some studies, for instance support the unitary structure of EF in preschool years (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011) as opposed to the fractionated nature of the same construct in school-aged children (Huizinga et al., 2006; Lehto et al., 2003). Gender has been reported to have no effect on the relation between executive functions in general and academic domains (e.g., Bull, Espy, & Wiebe, 2008; Clark et al., 2010). However, to our knowledge, there are no studies that specifically focus on the potential moderating effect of gender on the relation between shifting and academic achievement. There is also evidence that SES is related to both shifting ability and academic achievement, with children from low SES backgrounds performing less well than children from higher SES backgrounds (Alexander, Entwisle, & Dauber, 1993; Ardila, Rosselli, Matute, & Guajardo, 2005; Davis-Kean, 2005; Noble, McCandliss, & Farah, 2007). Whether the relation of shifting with academic outcomes differs for children coming from low-income families compared to their socio-economically more advantageous peers has not yet been explored.

1.3. The impact of intelligence

The fourth and last methodological issue is related to the question whether the association between shifting ability and academic performance is independent from the impact of intelligence on academic achievement. The literature provides some evidence that shifting and intelligence are associated in children (Ardila, Pineda, & Rosselli, 2000; Van der Sluis et al., 2007). Further, some studies have shown that the relation between shifting and academic achievement disappears after controlling for verbal intelligence in preschoolers (Espy et al., 2004) and school-aged children (Bull & Scerif, 2001). On the other hand, there has been research showing that shifting measured in kindergarten remains a significant predictor of academic performance in the first grade independent of covariates such as verbal intelligence, social skills and current academic achievement (George & Greenfield, 2005). An analysis of shifting ability in relation to academic achievement will thus have to take into account the potential confounding influence of intelligence.

1.4. Current study

In sum, empirical evidence on the association between shifting and academic achievement is equivocal. In this study we investigate shifting in relation to math and reading achievement in two meta-analyses. The association between shifting and math seems to have empirical support, whereas there is a less strong case for the association between shifting and reading. Some studies also reported that children with reading disability perform similarly to a control group on shifting measures (Klorman et al., 1999; Van der Sluis, De Jong, & Van der Leij, 2004), which supports the idea that there may be no relation between shifting and reading. Therefore, we hypothesize that shifting is positively associated with math performance, but not associated with reading. We also search for explanations of the mixed findings by testing the effects of procedural moderators, including rule presentation (whether the rule is explicitly revealed versus kept implicit to be deduced by the participant), scoring type of the shifting task (accuracy, reaction time, efficiency, or combined), study design (longitudinal versus concurrent), and time period between the assessment of shifting and academic skills, as well as sample moderators, including age, grade level (preschool versus primary/secondary school), gender ratio, and socio-economic status (SES). To evaluate the effect sizes obtained in the first analyses in light of the associations of our main variables with intelligence, we will also present the results of four additional meta-analyses to assess the associations of intelligence with math and reading, the associations between shifting and intelligence, and between math and reading.

2. Method

2.1. Literature search

Three search methods were used to identify relevant studies. First, we searched the electronic database Web of Science by using the keywords "*executive funct**", *shift**, "*set shift**" "*task switch**", "*cognitive flexib**", "*mental flexib**"combined with *academ** and *school*. Second, we searched online dissertations via the database ProQuest Dissertations and Theses with the same keywords. The search was finalized in August 2011. Third, the reference lists of the collected articles and dissertations and of the book chapter by Müller et al. (2008) were checked for relevant studies. Studies were included if they reported on the relation between shifting ability and any type of academic achievement. Five additional inclusion criteria were used. (1) We included studies with shifting tasks, which require changing the mental set to a newer one that conflicts with the first; (2) shifting was analyzed as a predictor of an academic outcome, or both constructs were measured concurrently. If the academic assessment was conducted prior to the measurement of shifting ability, the study was excluded; (3) the sample consisted of children from the general population. When information about the screening procedure was not provided, the study was included; (4) both for shifting and academic performance, only the studies with performance-based tasks were included. We excluded studies using only questionnaires and studies using only observations; (5) we focused on math and reading as academic outcomes since there were no sufficient results relating shifting to other types of academic skills such as writing.

We found 20 studies with 34 outcomes that met our search criteria with sample sizes ranging from 36 to 255 (see Table 2). Fourteen of the studies provided separate outcomes for math and reading. Four studies provided only math outcomes and two studies provided only reading outcomes. Thus, 18 studies reported on shifting and math ($N=2330$) and 16 studies reported on shifting and reading ($N=2266$). The coding system for sample characteristics and study methods is presented in Table 1. To assess intercoder reliability, all studies were coded by two coders. Cohen's kappa was computed for categorical variables, and intraclass correlations were computed for continuous variables. The average agreement was .74 (86%) across the categorical variables and .94 for the continuous variables. The coders discussed disagreements in order to reach a consensus.

2.2. Moderators

We coded two types of moderators: sample and procedural characteristics.

Sample moderators included *age of the children* as a continuous variable and as a categorical variable (recoded into three categories by using the 33rd and 67th percentile scores as "younger than 6", "between 6 and 10 years" and "older than 10 years"); *grade level* (recoded into two categories as preschool/kindergarten vs. primary/secondary school); *gender ratio* (% of girls), and *socio-economic status* (recoded into three categories as low, middle and high). The predominant SES category of the sample was coded. Age of the children, grade level and gender ratio were estimated for studies that do not provide information for these moderators. Grade level was estimated based on the mean age of the children. Similarly, age of children was estimated based on the grade (e.g., 9 years for children in the grades 3 to 5). Gender ratio of girls was estimated as 50%. Procedural moderators included *study design* (longitudinal vs. cross-sectional), *time period* between shifting assessment and academic testing, *rule presentation* (explicit versus implicit), and *scoring type of the shifting task* (accuracy, reaction time, efficiency, or combined).

Table 1
Coding system for studies on shifting and academic achievement.

Variable	Coding system
Academic outcome	1 = math 2 = reading 3 = other 4 = aggregate
Sample	
Mean age at T1	Continuous
Mean age at T2	Continuous
Grade level	1 = preschool/kindergarten 2 = primary/secondary
Gender ratio (% girls)	Continuous
Socio-economic status	1 = high 2 = middle 3 = low 4 = not reported or mixed
Procedure	
Research design	1 = concurrent 2 = longitudinal
Time period between the measurement of shifting and of academic achievement	Continuous
Rule presentation in the shifting task	1 = explicit 2 = implicit (rule deduction by the participant)
The type of shifting scoring I	1 = accuracy or errors 2 = reaction time 3 = efficiency 4 = combined
The type of shifting scoring II	1 = raw 2 = difference/cost
Covariates used in the statistical analyses?	1 = yes (partial correlations) 2 = no (zero-order correlations)
Sample size	Continuous

We coded the shifting tasks based on rule presentation. For instance, the cards on the Wisconsin Card Sorting Test are sorted by color, shape, or number of the objects. However, the sorting rule is not revealed and remains implicit. The child has to deduce the correct sorting principle by using the feedback (right or wrong) after each trial. However, on most other shifting tasks the rule to sort and/or switch is given explicitly. Thus, we coded the tasks as having either explicit or hidden rules. One of the studies (Monette et al., 2011) was coded as mixed since it included two tasks; one coded as explicit and the other as implicit (hidden).

The shifting tasks also showed a great deal of variety in terms of scoring. Some studies used reaction time and others calculated the number of correct responses as measures of performance. Likewise, some used difference or costs between the versions of the task (e.g., RT difference between the Parts A and B of Trail Making Task) whereas others provided only raw score. The task scoring is crucial to decide whether the effect is in the hypothesized direction or not. We categorized the shifting scores as reaction time, accuracy or errors, efficiency (number of correct responses divided by reaction time) or combined (when the task provided two or more different scores or when multiple shifting tasks with a single score were used). When the task score was reaction time or errors, the effect sign was reversed (i.e., higher shifting scores in these cases would be expected to relate to lower academic achievement). We coded the type of scoring also for raw versus difference categorization. In the case of multiple correlation coefficients (e.g., when there were multiple shifting scores and/or multiple academic scores), these were averaged. If the averaged shifting scores were combinations of various shifting indices (like accuracy and efficiency), then the scoring type was coded as "combined". In three studies, shifting was measured by the Wisconsin Card Sorting Test (WCST), which simultaneously assesses multiple cognitive processes related to shifting. We averaged the WCST scores in order to obtain one single effect size for the

Table 2
Studies included in meta-analyses.

Study	Effect sizes for[a] Math	Effect sizes for[a] Reading	Shifting task[b]	Shifting scoring I[c]	Shifting scoring II	Shifting rule	Sample size[b]	Mean age (mo) T1	Mean age (mo) T2	% girls	Grade[d]	Time period (mo)	Concurrent vs longitudinal	SES	IQ measure
Andersson (2007)	.59***	.41***	Trail Making	Reaction time	Difference	Explicit	69	119.5		48	2, 3 and 4	0	C	No info	Raven's
Andersson (2008)	.61***	.42***	Trail Making	Reaction time	Difference	Explicit	141	124		59	3 and 4	0	C	Middle	Raven's
Andersson (2010)[f]		.33**	Trail Making	Reaction time	Difference	Explicit	95	125	141	65	3 and 4	16	L	No info	Raven's
Bull, Johnston, and Roy (1999)[j]	.17		Wisconsin	Combined†	Raw	Implicit	44	87		41	3	0	C	Low	
Bull and Scerif (2001)	.21*		Wisconsin†	Combined	Raw	Implicit	93	88		46	3	0	C	No info	Wechsler Block Design and Vocabulary
Mayes et al. (2009)	.02	.00	Wisconsin†	Combined	Raw	Implicit	214	103.2		53	K-5	0	C	No info	WASI
Blair and Razza (2007)	.26**	.19*	Flexible Item Selection	Accuracy	Raw	Explicit	141	61	74.4	47	Preschool	13	L	Low	Raven's and PPVT
Turner (2010)	.35***	.14	Flexible Item Selection	Accuracy	Raw	Explicit	138	60		53	Preschool[i]	0	C	High	Expressive Vocabulary
Mazzocco and Kover (2007)[h]	.13	.12	Contingency Naming†	Combined	Raw	Explicit	177	80.4		52	Primary school	0	C	No info	Wechsler Abbreviated
Latzman et al. (2010)	.48***	.55***	D-KEFS	Combined	Raw	Implicit	151	163.68		0	Middle school[i]	0	C	High	KBIT-2 Verbal and Nonverbal
Bull et al. (2008)[g]	.29**	.29**	Shape School, Switch	Efficiency	Raw	Explicit	82/83	54	92.52	52	Preschool	38	L	Middle	
Vitiello (2009)	.29***	.17*	Something's the same	Accuracy	Raw	Explicit	179	51.4	52.4	50	Preschool	1	L	Low	PPVT
Altemeier, Jones, Abbott, and Berninger (2006)		.00	Wolf Rapid Automatized	Reaction time	Raw	Explicit	228	108[i]		55	3 and 5	0	C	High	
Clark et al. (2010) [i]	.32**	.25*	Flexible Item Selection and Shape School, Switch	Combined	Raw	Explicit	102	48	72	50	Preschool	24	L	Middle	WPPSI-R
Lee et al. (2009)[k]	−.11	−.09	Number Letter and Plus Minus	Reaction time	Difference	Explicit	255	134.4		48	5	0	C	Low	Wechsler Vocabulary
Espy et al. (2004)	−.08		Spatial Reversal (SR) and SR Irrelevant cues	Combined†	Raw	Implicit	96	50		57	Preschool	0	C	High	WJ Picture Vocabulary
Agostino et al. (2010)[e]	.31***		Trail Making and Contingency naming	Combined	Both	Explicit	155	122.1		56	3–6	0	C	No info	
McLean and Hitch (1999)	.23	−.06	Trails Written, Verbal, Color and Crossing Out	Reaction time	Raw	Explicit	36	108.96		58	3 and 4	0	C	No info	
Monette et al. (2011)	.06	.13	Trails-P and Card sorting	Accuracy†	Raw	Mixed	85	70	82	54	Preschool	12	L	High	
Van der Sluis et al. (2007)	.24**	.38***	Trails making, Object-S, Symbol-S, and Place-S	Efficiency	Raw	Explicit	172	128.08		51	4 and 5	0	C	No info	Raven's and RAKIT Verbal Analogies

*$p<.05$, **$p<.01$, ***$p<.001$.
Notes for Table 2.
[a] Academic outcomes were grouped as M = Math, R = Reading.
[b] Shifting tasks and sample size as included in meta analyses. Those with † refer to the tasks, for which scores were aggregated in order to obtain one single effect size for the association between shifting and academic outcome. When the correlation between a single score and the academic outcome was reported as nonsignificant, it was estimated as zero.
[c] Coding of the shifting task scores is described in detail in the text. Those with † refer to the latent factors.
[d] For longitudinal studies, the reported grade refers to the grade in which children were assessed for the first time.
[e] In the study by Agostino et al. (2010), academic outcome was based on the total sample and one attribute part of Contingency Naming Task.
[f] In the study by Andersson (2010), reading performance on both foreign and native language tests was used.
[g] In the study by Bull et al. (2008), the sample size is 83 for reading and 82 for math due to one missing case. The correlations of shifting with the 3rd wave academic scores were included.
[h] In the study by Mazzocco and Kover (2007), the research design is longitudinal but the concurrent associations between the CNT and the academic scores were used.
[i] Gender ratio was estimated (see Method section).
[j] In the study by Bull et al. (1999), IQ was assessed, but the correlations of intelligence with academic scores and with shifting are not reported.
[k] In the study by Lee et al. (2009), Block Design and Vocabulary subtests of WISC-III were used. However, only the correlations of Vocabulary with the variables of interest were reported.

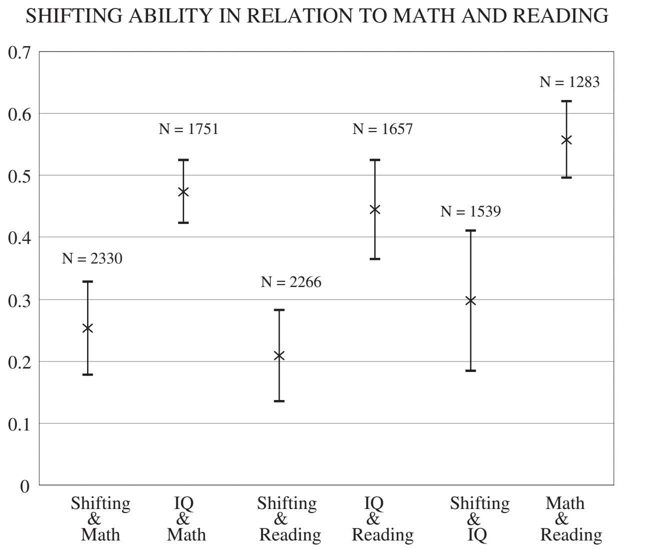

Fig. 1. Comparison of the 85% confidence intervals of the meta-analyses regarding shifting and intelligence (IQ) in relation to math and reading. *Note*. The combined effect size (correlation) is shown with 'x'.

association between shifting and academic outcome (excluding "failure to maintain set", because this is considered to be independent of cognitive flexibility, see Greve, Love, Sherwin, Mathias, Ramzinski, & Levy, 2002; Greve, Stickle, Love, Bianchini, & Stanford, 2005).

2.3. Intelligence

Intelligence was measured only by a verbal (e.g., Peabody Picture Vocabulary) or a nonverbal (e.g., Raven's Matrices) test in some studies, whereas in other studies, a single quotient was estimated based on multiple subtests of a battery to indicate general intelligence. We coded different types of intelligence, but due to the lack of studies tapping each type of intelligence we were unable to use this moderator in the analyses.

2.4. Statistical analyses

First, two meta-analyses were carried out, namely, one for the relation between shifting and math, and one for the relation between shifting and reading. Second, we conducted two additional sets of meta-analyses to investigate the relation between intelligence and the two academic domains within the selected publications, which provided outcomes regarding the association of intelligence with math and/or reading. Third, we meta-analyzed the associations between shifting and intelligence, and between math and reading within the set of selected studies. The meta-analyses were performed using the Comprehensive Meta-Analysis (CMA) program (Borenstein, Rothstein, & Cohen, 2005). For each outcome, an effect size (correlation) was calculated.

Effects in the hypothesized direction (i.e., a positive association between cognitive flexibility and academic achievement) were given a positive sign. Effects indicating an association opposite to the hypothesized direction were given a negative sign. Studies reporting no exact statistics but reported a non-significant finding were assigned a conservative non-significant zero effect size (included using the study's sample size and $p = .50$) (Mullen, 1989).

Using CMA, combined effect sizes were computed. Significance tests and moderator analyses were performed through random effects models as the preferred mode of analysis (Borenstein, Hedges, & Rothstein, 2007). Random effects models allow for the possibility that there are random differences between studies that are associated with variations in procedures, measures, settings, that go beyond subject-level sampling error, and thus point to different study populations (Lipsey & Wilson, 2001). To test the homogeneity of the sets of effect sizes, we computed Q-statistics (Borenstein et al., 2005). In addition, we computed 95% confidence intervals (CIs) around the point estimate of each set of effect sizes. Q-statistics and p-values were also computed to assess differences between combined effect sizes for specific subsets of study effect sizes grouped by moderators. Contrasts were only tested when at least two of the subsets consisted of at least four studies (Bakermans-Kranenburg, Van IJzendoorn, & Juffer, 2003).

Funnel plots for both sets of studies were examined in order to detect possible publication bias. A funnel plot is a plot of each study's effect size against its standard error (usually plotted as 1/SE, or precision). It is expected that this plot has the shape of a funnel, because studies with smaller sample sizes (larger standard errors) have increasingly large variation in estimates of their effect size as random variation becomes increasingly influential, whereas studies with larger sample sizes have smaller variation in effect sizes (Duval & Tweedie, 2000b; Sutton, Duval, Tweedie, Abrams, & Jones, 2000). However, smaller studies with nonsignificant results or with effect sizes in the nonhypothesized direction are less likely to be published. Therefore, a funnel plot may be asymmetrical around its base. The degree of asymmetry in the funnel plot was examined by estimating the number of studies, which have no symmetric counterpart on the other side of the funnel. The "trim and fill" method was used to test the influence of possible adjustments of the sets of studies for publication bias (Duval & Tweedie, 2000a,b).

For each study, Fisher's Z scores were computed as equivalents for correlations. Fisher's Z scores have better distribution characteristics than correlations, in particular better estimates of the standard error (Lipsey & Wilson, 2001; Mullen, 1989). All Fisher z transformed effect sizes and all sample sizes were examined for outliers (defined as standardized z-values exceeding $+/-3.29$) (Tabachnick & Fidell, 2001). No outliers were detected.

Further, the 85% CIs were compared to explore whether the combined effect sizes of six different sets of effect sizes were significantly different (Van IJzendoorn, Juffer, & Poelhuis, 2005). The sets of effect sizes were partly based on the same subjects and therefore direct statistical tests were not warranted. The absence of overlap between 85% CIs indicates a statistically significant difference since producing 85% confidence intervals guarantees that if the confidence intervals around the combined effect sizes of the two sets of meta-analyses do not overlap then the level of statistical significance between the two groups would be 5% or lower (Goldstein & Healy, 1995; Julious, 2004; Payton, Greenstone, & Schenker, 2003). So, we used the 85% CI around the point estimate as a conservative way of testing whether the difference in effect sizes for the two comparison groups (intelligence versus shifting as the predictor) for each of the academic skills (math and reading) was significant (see Fig. 1). Using 95% CIs did not change our findings and conclusions.

3. Results

3.1. Shifting and academic outcomes

The meta-analysis concerning the relation between shifting and math included 18 studies, with a total sample of 2330 children. The results of the meta-analyses for math and reading are presented in Table 3. The combined effect size for the relation between shifting and math was substantial and significant ($r = .26$, 95% CI $= .15$–$.35$, $p < .01$) in a heterogeneous set of studies ($Q = 113.31$, $p < .01$). Overall, higher levels of performance on shifting tasks were related to higher levels of performance on math tests. Using the trim and fill method (Duval & Tweedie, 2000a,b), we did not find evidence for publication bias. The fail-safe number for this set of studies was 614, i.e., it would take 614 null results to cancel out this significant combined effect size.

The meta-analysis concerning the relation between shifting and reading included 16 studies with a total of 2266 children. The

Table 3
Meta-analytic results of studies relating shifting with math and with reading.

	Math						Reading					
	k	*n*	*r*	95% CI	Q[a]	*p*	*k*	*n*	*r*	95% CI	Q[a]	*p*
Total set	18	2330	.26	[.15, .35]	113.31	.00	16	2266	.21	[.11, .31]	90.85	.00
Sample characteristics												
Age					.66	.72					3.30	.19
Youngest	7	823	.22*	[.04, .39]	12.88*		6	728	.20*	[.03, .35]	2.02	
Medium	6	633	.23**	[.03, .42]	23.03**		5	724	.09	[−.09, .28]	12.01*	
Oldest	5	874	.32**	[.12, .50]	73.23**		5	814	.32**	[.15, .47]	59.10**	
Grade					.23	.63					.04	.84
Preschool/K	7	823	.22*	[.05, .38]	12.88*		6	728	.20*	[.02, .36]	2.02	
Primary/secondary	11	1507	.27**	[.13, .40]	100.26**		10	1538	.22**	[.08, .34]	88.78**	
SES[b]					1.26	.26						
High/middle	7	795	.32**	[.14, .47]	29.92**		7	928				
Low	4	619	.15	[−.09, .38]	24.41**		3	575				
Procedure characteristics												
Study design					.00	.92					.07	.79
Concurrent	13	1682	.26**	[.16, .41]	108.00**		10	1581	.20**	[.07, .33]	86.39**	
Longitudinal	5	648	.25*	[.04, .43]	4.14		6	685	.23*	[.06, .38]	3.08	
Rule presentation[c]					1.72	.42						
Explicit	12	1647	.30**	[.17, ..42]	80.51**		13	1816				
Implicit	5	598	.18	[−.04, .38]	27.32**		2	365				
Shifting scoring I					.98	.61					.92	.63
Accuracy/errors	4	543	.25*	[.01, .46]	4.96		4	543	.16	[−.05, .36]	.33	
Reaction time	4	501	.36**	[.12, .56]	74.51**		6	824	.18	[−.00, .34]	42.08**	
Efficiency/combined	10	1286	.22*	[.06, .36]	32.96**		6	899	.27**	[.11, .43]	39.78**	
Shifting scoring II											.33	.56
Difference/costs	3	465					4	560	.26*	[.05, .45]	35.88**	
Raw	14	1710					12	1706	.19*	[..07, .31]	54.94**	

Note: *$p<.05$, **$p<.01$.
[a] Q statistic for moderator stands for effect of contrasts (df = number of subgroups − 1), Q statistic for subgroup stands for homogeneity (df = $k-1$).
[b] The studies that do not report SES information were excluded.
[c] The study by Monette et al. (2011) was excluded.

combined effect size for the relation between shifting and reading was moderate and significant ($r = .21$, 95% CI = .11–.31, $p < .01$) in a heterogeneous set of studies ($Q = 90.85$, $p < .01$). Overall, higher levels of performance on shifting tasks were related to higher levels of performance on reading tests. Using the trim and fill method (Duval & Tweedie, 2000a,b), no asymmetry was found in the funnel plot; therefore evidence for publication bias was absent. The fail-safe number for this set of studies was 344.

We examined the papers included in our meta-analyses for reliability estimates. We used the Spearman's (1904) correction for attenuation formula based on the reliabilities of the measures. The mean reliabilities were as follows: .74 for the shifting measures ($k = 4$), .82 for the math measures ($k = 4$), and .86 for the reading measures ($k = 2$). We found "true" population effect sizes for the association between shifting ability and math performance of .33 and for the association between shifting ability and reading performance of .26. Since a very small number of studies reported reliability estimates of the measures on the sample involved, the results based on this correction should be interpreted tentatively.

3.2. Moderators

We tested whether moderators regarding sample characteristics (age, grade level, gender ratio and socio-economic status) and procedure (study design, time period between shifting and academic testing, rule presentation and scoring type in shifting tasks) were associated with effect size separately for math and reading (Table 3). For exploring the effect of a continuous variable, weighted regression models were used. None of the sample characteristics and none of the procedural moderators showed significant effects on the association between shifting and math or reading performance. However, the lack of moderation effects is tentative due to the small number of studies in particular subsets. The moderating effects of SES ($k = 3$ low SES for reading), rule presentation ($k = 2$ implicit for reading), shifting scoring as difference versus raw ($k = 3$ difference for math) and a covariate used in the statistical analyses ($k = 3$ partial correlations for both math and reading) could not be tested due to an insufficient number of studies per subset i.e., less than four (Bakermans-Kranenburg et al., 2003).

3.3. Intelligence, shifting and academic outcomes

The meta-analysis concerning the relation between intelligence and math that included 12 studies with a total sample of 1751 children showed a significant and large combined effect size ($r = .47$, 85% CI = .41–.52) in a heterogeneous set of studies ($Q = 40.86$, $p < .01$). The CI around the point estimate for the relation between intelligence and math did not overlap with the CI for the relation between shifting and math ($r = .26$, 85% CI = .18–.33), which means that the relation between intelligence and math was significantly stronger than between shifting and math. The meta-analysis concerning the relation between intelligence and reading, which included 11 studies with a total of 1657 children showed a significant and large combined effect size ($r = .43$, 85% CI = .37–.49, $p < .01$) in a heterogeneous set of studies ($Q = 46.27$, $p < .01$). The absence of overlapping 85% CI with the CI for the relation between shifting and reading ($r = .21$, 85% CI = .14–.28) suggested that the relation between intelligence and reading was significantly stronger than that between shifting and reading.

The relation between shifting and intelligence was reported in 11 studies with a total sample of 1539 children. The combined effect size for the relation between intelligence and shifting was significant and substantial ($r = .30$, 85% CI = .18–.41, $p < .01$) in a heterogeneous set of studies ($Q = 107.54$, $p < .01$). Last, we conducted a meta-analysis with 10 studies that provided results for the association between math and reading. The combined effect size within a total of 1283 children was significant and large ($r = .56$, 85% CI = .50–.62, $p < .01$) in a heterogeneous set of studies ($Q = 22.24$, $p < .001$). Comparison of the 85% confidence intervals of the meta-analyses regarding shifting and intelligence in relation to math and reading is presented in Fig. 1.

4. Discussion

4.1. Discussion of the findings

Our meta-analyses showed that the association between shifting ability and math as well as the association between shifting ability and reading performance were substantial and significant. The variation in effect sizes between studies for the association between shifting and academic achievement was not related to differences in rule presentation or type of scoring on the shifting task, or to differences in research design, time period between the measurement of shifting and academic outcomes, children's age, grade level, SES or gender. Intelligence was found to be a stronger contributor to academic performance than shifting, and shifting was substantially associated with intelligence. Lower reliabilities of shifting measures compared to IQ assessments were not responsible for the weaker contribution of EF to school achievement compared to IQ. Even after correction for attenuation combined effect sizes for shifting were considerably smaller than those found for IQ.

First of all, the results of our main meta-analyses indicate that children with a higher capacity to switch a conceptual representation (i.e., goals, rules or strategies for problem solving) to a newer one show better performance on math and reading. The combined effect sizes of the associations of shifting with math and with reading were quite similar. This is contrary to our hypothesis that shifting would be related to math but not to reading. Whereas shifting is considered to be necessary for alternating between different strategies in complex mathematical problem solving (Agostino et al., 2010; Bull et al., 2008; Mayes et al., 2009; Van der Sluis et al., 2007), the literature does not offer a clear explanation for the relation between shifting and reading. Given the results of our meta-analysis of the association between math and reading skills, it is likely that our results are due to the substantial shared variance between the two constructs. Apparently, competence in both math and reading taps into a common more general cognitive ability. This is confirmed by our finding that the associations of math and reading skills with intelligence are very similar in size. These results all point to a domain-general interpretation of the links between shifting ability, academic skills, and intelligence. According to a new framework proposed by Miyake and Friedman (2012), each EF component involves a common (across all three EFs) and a specific part (unique to that particular ability). Taken this new conceptualization of the EFs into account, it might be possible that common EF may enable children to maintain the goal of a task, whereas shifting-specific abilities may contribute to particular domains of achievement (e.g., alternate between different arithmetical strategies in complex math tasks). Since in the included studies shifting ability was not decomposed as it is proposed by Miyake and Friedman (2012), the question of how the common and specific parts of shifting ability are related to achievement remains unanswered.

Second, the results of the moderator analyses did not support the hypothesis that the diverging outcomes regarding the relation between shifting and academic achievement may result from the heterogeneity of procedural or sample characteristics in different studies. It is important to note however, that the lack of moderation effects may be due to the small number of studies in particular subsets. The reasons for including most of these moderators (e.g., rule presentation and scoring type on the shifting task) were based on theoretical considerations rather than on empirical evidence, because the effect of these variables on the association between shifting and academic performance has never been investigated before. For a moderator like child age there has been some empirical work, but with contradicting results. Our meta-analyses therefore provide a much-needed clarification of the (lack of) effects of these moderators. However, we could not test the effects of all possible interfering variables for the association between shifting and academic performance in this study. For instance, it is important to note that the substantial variety in shifting tasks remains a methodological challenge mostly due to task impurity (Miyake et al., 2000). Shifting tasks, like other EF measures, differ in terms of complexity as a result of different amount of loadings on other executive (inhibition and working memory) and nonexecutive processes (e.g., linguistic skills). Unfortunately, the literature does not provide a well-defined framework to categorize shifting tasks by taking into account these levels of complexity. Instead, it has been proposed that the relatively pure EF components can be extracted by confirmatory factor analysis (Lehto et al., 2003; Miyake et al., 2000) and the nonexecutive processes operated by EF tasks should be accounted for by using control tasks, which are quite similar to their EF correspondents except that they do not require the operation of the given EF component (Van der Sluis et al., 2007). It is important to note that conclusions regarding the specific role of EF components in academic achievement without controlling for the common executive and nonexecutive (e.g., intelligence) variance are limited. Future studies that employ these kinds of methods may be more promising to overcome task impurity, and therefore allow for more straightforward conclusions regarding the unique relations of EF components with academic performance.

Because to the best of our knowledge only one study reports on the association between shifting and academic outcomes correcting for IQ (Mayes et al., 2009), the literature did not provide enough evidence to disentangle the contributions of shifting and intelligence to academic outcomes. To gain at least some insight into the role of intelligence, we analyzed the associations of intelligence with math and reading using the publications selected for the main meta-analyses. Our results showed that the relations of intelligence with math and reading were significantly stronger than the relations of shifting with these academic outcomes. The large combined effect size between intelligence and the academic outcomes seems to support previous findings reporting high correlations between intelligence and achievement tests (Psychological Corporation, 2002). The similarity in the combined effect sizes for the associations of intelligence with math and reading supports the fact that intelligence is a higher-order, domain-free contributor to school achievement much like shifting ability. What remains unclear however, is whether shifting ability predicts achievement beyond the effect of intelligence. In most of the previous studies, the association between academic and executive functions has been explored without controlling for intelligence. One study showed that the WCST perseverative responses score, a measure of the inability to shift, was one of the very few scores that predicted math (but not reading) beyond intelligence, which led the researchers to conclude that switching ability is necessary for math performance (Mayes et al., 2009). Consequently, the unique contribution of shifting to math independent of intelligence has some support, but needs replication. It remains to be seen whether shifting predicts reading in a similar fashion, when controlling for intelligence in general and verbal intelligence in particular.

Our findings showed a significant and substantial association between shifting and intelligence consistent with previous research (e.g., Ardila et al., 2000). In contrast, some studies have reported that the association of shifting with intelligence disappears when the intercorrelations among the three EF components are controlled for (Duan, Wei, Wang, & Shi, 2010; Friedman et al., 2006). In these studies, working memory was the only EF component that remained significantly correlated with intelligence after controlling for the other components. In the present study, it was impossible to remove the variance of other EF components from the relation between shifting and intelligence. Nevertheless, our findings support the growing evidence reporting moderate to high correlations between EF components and intelligence scores (e.g., Blair & Razza, 2007; George & Greenfield, 2005; Latzman et al., 2010).

4.2. Limitations

It is important to note some limitations of this study. First, due to the small number of studies in particular subsets (e.g., implicit subset of rule presentation), we had to merge different subcategories into one subset in statistical analyses (e.g., efficiency and combined scoring of shifting tasks), which may have reduced the clarity of the results regarding the moderator effects. For the same reason, we were unable to test the moderating effects of SES (for reading), rule presentation (for reading), and covariates (for both math and reading). Second, due to the lack of studies including partial correlations controlling for intelligence (only the study by Mayes et al., 2009), we could not investigate whether shifting is associated with academic achievement beyond the influence of intelligence. Some studies reported regression analyses controlling for intelligence in addition to the effects of several other covariates such as age, maternal education or effortful control in predicting academic outcomes by EF components (e.g., Blair & Razza, 2007; Espy et al., 2004), thus making it more difficult to estimate the influence of intelligence on the association between shifting and academic outcome.

4.3. Implications

On a theoretical level, our results provide evidence that shifting ability is a domain-general cognitive process for predicting academic performance, as is the case for intelligence. However, more research is needed to explore the nonshared variance of these higher-order cognitive processes to determine whether they are unique predictors of achievement. There is an ongoing debate about the nature of shifting ability (Chavelier & Blaye, 2008). Based on the new unity and diversity framework (Miyake & Friedman, 2012), future studies decomposing shifting ability into common and specific parts and examining the associations of these parts with academic performance could provide a better understanding of the role of shifting in achievement. From a practical point of view, identifying the potential contributors to school success is necessary to improve the effectiveness of assessment at educational settings. Selecting assessment tools, which tap domain-general abilities contributing to achievement, may help practitioners and educators to evaluate children's competencies at the time of school entry that are important for later success. In this sense, measuring shifting ability may provide crucial information to target at-risk children, who may experience difficulties on reading or math performance. In addition, the knowledge about the contribution of shifting ability to achievement combined with evidence showing positive effects of some training programs on EF performance (Diamond, Barnett, Thomas, & Munro, 2007; Dowsett & Livesey, 2000; Karbach & Kray, 2009) suggests that it is worthwhile to further investigate the potential effects of experimentally enhanced shifting ability on academic performance. However, there are some concerns regarding the utility of working memory training programs due to various methodological challenges (Melby-Lervåg & Hulme, 2012; Shipstead, Redick, & Engle, 2012). Therefore, future work in this area should explore whether shifting ability can be improved independent of task-specific learning (Shipstead et al., 2012), whether this improvement can be long-lasting and transferable to other cognitive skills (e.g., intelligence), and how the presumed relations of common and specific parts of shifting ability are influenced by training.

4.4. Conclusion

In sum, our meta-analyses showed that shifting, the ability to flexibly switch between different rules, strategies or tasks, is a domain-free contributor to academic achievement, regardless of variations in samples and procedures. Although previous studies have shown that the working memory is an important contributor to academic success, the evidence was not that clear for the shifting component of EF. In addition, our analyses provide an insight into the relative contributions of intelligence and shifting to academic outcomes. By showing the substantial association between shifting and intelligence, the current study addresses the importance of taking into account the impact of intelligence in exploring the contribution of shifting and other EF components to academic performance.

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