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

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A B S T R A C T

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