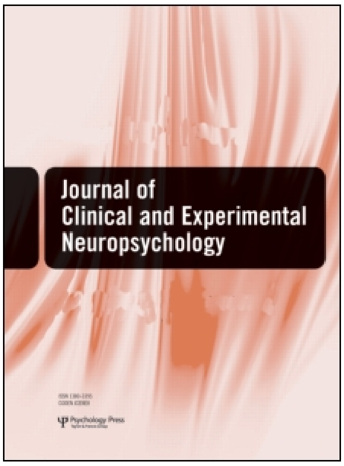

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The contribution of executive functioning to academic achievement among male adolescents

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The contribution of executive functioning to academic achievement among male adolescents

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Recent factor analytic work suggests that the dimensions of conceptual flexibility, monitoring, and inhibition are distinguishable under the executive functioning (EF) umbrella. We examine relations between these constructs and performances on academic achievement tests among a sample of 11–16-year-old males ($N = 151$). EF contributed to the prediction of all academic domains beyond general intellectual functioning in distinct ways: Conceptual flexibility predicted reading and science, monitoring predicted reading and social studies, and inhibition predicted mathematics and science. These findings suggest that demands related to specific academic domains access different cognitive abilities and have implications for both intervention and research science.

Keywords: Executive functioning; Academic achievement; Conceptual flexibility; Monitoring; Inhibition.

Executive functioning (EF) constitutes abilities related to higher order cognitive processes that encompass a number of subdomains including judgment, decision making, and coordinating/sequencing cognitive operations and social conduct. Specifically, EF entails the ability to plan and sequence complex behaviors, simultaneously attend to multiple sources of information, grasp the gist of complex situations, resist distractions and interference, inhibit inappropriate responses, and sustain behavior for prolonged periods (Baron, 2003; Lezak, Howieson, & Loring, 2004). Skills associated with the capacity to perform well academically are highly dependent upon abilities that fall under the EF umbrella (Blair, 2002). Following, we present a brief explanation of specific models of EF and a review of the extant research on the relationship between EF and academic achievement.

Structure of EF

Although historically the structure of EF has been difficult to elucidate, recent factor analytic work has begun to show convergent evidence of both unity and disunity in EF (Latzman & Markon, 2009; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). That is, EF consists of a central executive with diverse functions. Additionally, these investigations, utilizing samples across the life span, have resulted in consistent factor patterns emerging, suggesting a stable, replicable factor structure.

Converging research suggests that EF may be conceptualized best as consisting of three separable, yet related, dimensions. These dimensions emerge across investigations, even when disparate EF batteries are utilized. In a recent investigation of the factor structure of

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the Delis–Kaplan Executive Function System—D-KEFS (Delis, Kaplan, & Kramer, 2001), the first conormed battery aimed solely at the assessment of EF and the EF battery used in the current investigation—Latzman and Markon (2009) termed these three EF dimensions: conceptual flexibility, monitoring, and inhibition. Conceptual flexibility, which is highly similar to Miyake et al.'s (2000) shifting dimension, reflects the ability to engage in flexible thinking and behavior. Monitoring, which is similar to Miyake's updating dimension, reflects the abilities of actively monitoring and evaluating information in working memory, and inhibition concerns the ability to deliberately inhibit a dominant or automatic response.

EF and academic achievement

Although sparse, some research has examined the relation between aspects of EF and academic achievement. For example, EF has been shown to relate to mathematic (Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Espy et al., 2004; Geary, 1993), reading (Helland & Asbjørnsen, 2000; Swanson, 1999), and reasoning (van der Sluis, de Jong, & van der Leij, 2007) performance.

Although there is some consistency in the literature relating EF to academic achievement, relations between specific aspects of EF and achievement are more equivocal. Some research has shown, for example, that conceptual flexibility is associated with reading, arithmetic, and nonverbal reasoning in samples of preschool children (Blair & Razza, 2007; Espy et al., 2004) and a sample of school-aged children (van der Sluis et al., 2007). Van der Sluis and colleagues (2007) found that their shifting factor was related to nonverbal reasoning and reading in a sample of 9- to 12-year-old children. However, research accounting for differences in relevant covariates (e.g., general intellectual functioning) indicates that these associations no longer remain once the relevant statistical adjustments are made (van der Sluis, van der Liej, & de Jong, 2005). Interestingly, and in direct contrast to previous studies (e.g., Bull et al., 2008; Bull & Scerif, 2001), in their sample of school-aged children, van der Sluis et al. (2005) also found no relation between a conceptual flexibility dimension and mathematics once accounting for general intellectual functioning. These mixed findings may be due to van der Sluis and colleagues' (2005) use of a preschool population versus Bull and colleagues' (Bull et al., 2008; Bull & Scerif, 2001) use of school-aged children. The ability to shift flexibly may be more critical for more complex mathematical problems assessed in later elementary school, versus simple counting and number recognition assessed in preschool (Bull et al., 2008).

Research also is equivocal with regard to relations of monitoring with reading and mathematics achievement. In van der Sluis and colleagues' (2007) examination, updating ability was shown to be related to reading, arithmetic, verbal, and nonverbal reasoning. Additionally, research examining working memory capacity, which has been shown to be closely linked to monitoring, suggests strong relations between this construct and academic achievement in both reading and mathematics. For example, in their sample of youth aged 9 to 15 years, Sesma and colleagues (Sesma, Mahone, Levine, Eason, & Cutting, 2009) found working memory to be uniquely associated with reading comprehension—but not word recognition skills. Further, Bull et al. (2008) found visual short-term and working memory were able to predict math achievement in a sample of 7-year-olds. Examinations of this same topic from a bottom-up perspective have shown that, in comparison to controls, children with deficits in both reading and mathematics have been shown to exhibit poorer working memory abilities (de Jong, 1998; McLean & Hitch, 1999; Swanson, 1999; Swanson & Ashbaker, 2000). Similar to the aforementioned research on cognitive flexibility, these differences have been shown to disappear once accounting for relevant covariates such as general intellectual functioning (van der Sluis et al., 2005).

Inhibitory control has been shown to be uniquely associated with reading and mathematics performance independent of other relevant covariates such as general intelligence (Blair & Razza, 2007). In comparison to controls, children with both reading and mathematics disabilities have been shown to exhibit significantly poorer ability to inhibit a dominant or automatic response (Hale, Fiorello, Bertin, & Sherman, 2003; Helland & Asbjørnsen, 2000). In a study of 3- to 5-year-old children from low-income homes, Blair and Razza (2007) found that the inhibitory control aspect of EF was an important correlate of early math and reading ability independent of general intelligence. The relation between children's inhibitory skills and mathematics ability may be particularly strong (e.g., Bull & Scerif, 2001; Espy et al., 2004; St. Clair-Thompson & Gathercole, 2006). In fact, only inhibitory control contributed unique variance in the prediction of mathematic skills when all other dimensions of EF were controlled (Espy et al., 2004). However, these findings still appear to be equivocal. For example, van der Sluis and colleagues (van der Sluis, de Jong, & van der Leij, 2004) found that, in their sample of 4th- and 5th-grade children, children with disabilities in mathematics did not exhibit problems with inhibition per se. Rather, they exhibited problems associated with more general EF tasks requiring the combination of EF abilities.

Less is known about relations between various cognitive functions and achievement scores in areas other than mathematics and reading (e.g., social studies, science). Social studies skills and strategies involve the ability to apply knowledge proficiently in a variety of contexts in repeated performances (National Council for the Social Studies, NCSS, Curriculum Review Task Force: National Council for the Social Studies, 2008), whereas science skills involve the ability to understand particular ways of observing, thinking, experimenting, and validating (American Association for the Advancement of Science, 1990). Although these subjects typically are part of elementary-, middle-, and high-school curricula, no previous research has directly examined relations between EF and social studies or science achievement. Many of the processes involved in understanding information from each domain are potentially unique and directly related to various processes of executive functioning. For example, understanding social variables regarding a complex political system involves awareness of acceptable social conduct that is contextually and culturally bound, simultaneous attention to numerous sides of an issue, and problem solving of a different nature than that required for more subjects traditionally associated with EF evaluations (i.e., mathematics and reading). Likewise, understanding of the scientific process of discovery potentially emphasizes critical evaluation of experimental methodology and unique, complex, sequential problem-solving steps outside the bounds of any of the above-mentioned subjects.

Although the extant literature suggests the importance of various aspects of EF in understanding performance on measures of academic achievement, their specificity is unclear. Additionally, the majority of the research is at the group level, comparing participants with various learning difficulties to those without (for exceptions, see Blair & Razza, 2007; van der Sluis et al., 2007). Furthermore, there is a notable lack of research with adolescent samples. Lastly, the contribution of various aspects of EF to the wide range of achievement domains beyond reading and mathematics has yet to be examined.

Current study

The purpose of the current study, therefore, is to fill this gap in the literature by examining the contribution, beyond that of general intelligence, of three factor-analytically derived aspects of EF (Latzman & Markon, 2009) to a wide range of academic achievement scores in a sample of typically developing male adolescents. Understanding relations among these variables is critical to advancing the foundation of this area of work en route to the development of curricula and interventions targeted to specific EF capabilities. This is an especially important consideration for individuals enrolled in special education, wherein limitations in these abilities (where they exist) could reasonably be predicted to interfere with educational attainment. Studying the relations of EF to academic achievement in the context of typically developing populations is the first step to understanding what specific processes may be affected in individuals with EF deficits. Furthermore, EF may be an avenue through which interventions designed to improve youths' academic achievement may be approached.

METHOD

Participants

Participants were drawn from a sample of 174 male adolescents, aged 11 to 16 years (mean age = 13.64, *SD* = 1.35) who participated in the Iowa Youth Development Project (I-YDP), a larger investigation of relationships among adolescents, their parents, and adolescent psychopathology. As adolescent males are more likely to exhibit greater variance in internalizing and externalizing behaviors than females, data collection resources were focused on males. On average, adolescents were White (87.4%) and came from families that were relatively high in socioeconomic status based on education and income. Most mothers had completed college or postgraduate education (71.9%), and one third (34.1%) of adolescents came from families that had an annual family income above $100,000 (ranging from under $15,000 to over $150,000). Participants had an average full scale IQ of 108.74 (*SD* = 13.26).

Procedure

The University of Iowa's Institutional Review Board approved all the study procedures. The I-YDP used a broad-based sampling strategy to accrue a sample of male adolescents representative of the Midwestern area in which participants lived. Participants were recruited from a child participant pool maintained at the University's Psychology Department, by fliers in the community, and via advertisements placed in the daily newsletter of the local university hospital. To ensure a typically developing sample, exclusion criteria included mental retardation, autism spectrum disorder, neurological disorder, past head injury requiring hospitalization, life-threatening medical illness, having been held back a grade, and being diagnosed with a reading disorder, all assessed by maternal report. Participants and their mothers provided informed assent/consent, respectively, before beginning the study procedures. Additionally, mothers of participants completed a release of information document to allow the researchers to gather information from participants' schools. Adolescents and their mothers were compensated monetarily for their time.

During the final month of the school year during which the I-YDP was conducted, statewide, standardized academic testing data were requested from participants' schools. Of the 174 participants in the full sample, standardized testing data were obtained for 151. Participants for whom information was or was not available did not differ in age, $t(172) = 0.25$, $p > .10$, or intellectual functioning, $t(172) = 0.16$, $p > .10$ for verbal intelligence; $t(172) = 0.66$, $p > .10$ for nonverbal intelligence.

Measures

Kaufman Brief Intelligence Test, Second Edition (KBIT-2)

The Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman & Kaufman, 2006) is a brief, individually administered measure of verbal and nonverbal intelligence. The KBIT-2 yields three scores: IQ composite, verbal, and nonverbal. The KBIT-2 has been shown to have good psychometric properties including excellent internal consistency and test–retest reliability. Additionally, performances on the KBIT-2 have been shown to have good convergent validity with longer, widely used measures of intellectual functioning (Kaufman & Kaufman, 2006). In the current study, only the verbal and nonverbal indices were used. Age-based standard scores were used in all analyses.

Delis–Kaplan Executive Functions System (D-KEFS)

Delis–Kaplan Executive Functions System (D-KEFS; Delis et al., 2001) provides a standardized assessment of executive functions in individuals between 8 and 89 years of age. Eight of the D-KEFS tests have been standardized and normed for use with children as young as 8 years and thus were administered in the current study: (a) Trail Making Test, which assesses attention, concentration, resistance to distraction, and cognitive flexibility; (b) Verbal Fluency Test, which requires speeded lexical production and automatic lexical access and reflects efficient lexical organization; (c) Design Fluency Test, an established nonverbal task analogous to verbal fluency; (d) Color–Word Interference Test, which assesses selective or focused attention, the ability to shift from one perceptual set to another as test requirements change, and the ability to inhibit inappropriate responding; (e) Sorting Test, a measure of conceptual flexibility, (f) Twenty Questions Test, which assesses strategic thinking; (g) Word Context Test, which assesses deductive reasoning, hypothesis testing, and flexibility of thinking by requiring participants to discern what is intended by a made-up word based on its use in a series of sentences; and (h) Tower Test, which assesses forward planning of a sequence of steps as the participant tries to move a pattern of discs efficiently from a start configuration to a goal configuration to match a target pattern.

The D-KEFS was standardized on a nationally representative, stratified sample of 1,750 nonclinical children, adolescents, and adults, ages 8 to 89 years. The D-KEFS has research support for both its general validity and internal consistency reliability (Delis, Kramer, Kaplan, & Holdnack, 2004), as well as test–retest reliability (Homack, Lee, & Riccio, 2005). As described above, recent factor analytic work (Latzman & Markon, 2009) has found that D-KEFS individual achievement scores can be reduced to three domains: conceptual flexibility, monitoring, and inhibition. Conceptual flexibility is reflected in all three scores from the Sorting Test: free sort, free sort description, and sort recognition. Monitoring is reflected by the two category switching scores from the Verbal Fluency tests and the Twenty Questions Test. Lastly, inhibition consists of the inhibition and inhibition/switching scores from the Color–Word Test in addition to the Trail Making Test and Design Fluency Test. In previous factor analytic work (Latzman & Markon, 2009), the remainder of the scores derived from the D-KEFS did not load significantly on one discrete factor and were therefore not included in the calculations of composite scores. Composite scores for each of the three EF dimensions were created by taking the mean of each participant's standard scores across the various tests that fall within each dimension. Thus, each participant's score that contributed to analyses was an average of his performance across the multiple scores loading on each of the three empirically derived factors.

Iowa Tests of Basic Skills and Iowa Tests of Educational Development

The Iowa Tests of Basic Skills (ITBS; Hoover et al., 2001) and the Iowa Tests of Educational Development (ITED; Forsyth et al., 2001) are standardized, group-administered tests that are used in many areas across the United States to assess students' academic achievement across a wide range of subject areas. The ITBS is used in Grades K through 8, while the ITED is used in Grades 9 through 12. In general, the same academic domains are assessed by both.

In this study, we used state percentile ranks on these achievement tests, which allow the two tests to be used interchangeably as measures of achievement across the various domains. State percentiles were selected as the metric of comparison rather than national percentile ranks so as to minimize confounds due to state-based variability in curricular sequence, emphasis, and breadth of coverage. The percentile rank reveals the student's relative position or rank among a group of Iowa students who were in the same grade and who were tested at the same time of year.

Reading total. The reading total score consists of two sections. The first section provides a measure of reading vocabulary. Students are instructed to read a target word in context and then select the word or phrase that most closely conveys the same meaning as the target word, while the second section provides a measure of reading comprehension.

Mathematics total. The mathematics component consists of two sections: concepts and estimations; and problem solving and data interpretation. These include measures of students' ability to solve quantitative problems and to use appropriate mathematical reasoning. The questions require the ability to use logical thinking and to perform basic arithmetic, estimations, and data interpretation. This subtest, in combination with the reading section above, comprises a traditional evaluation of academic proclivity and educational attainment, which are closely bound to processes of EF (Blair, 2002).

Social studies. This domain measures objectives of the social studies curriculum that are distinct from related material measured elsewhere across these achievement tests. Questions are primarily presented in visual form and demand interpretation of various social data depicted graphically, analysis of politics through oblique presentation (e.g., political satire cartoons), and responses to quotes from historical texts. The content of the questions is taken from the areas of geography, history, government, economics, sociology, and other social sciences. The demands of this subtest emphasize processes of understanding above factual recall. As such, it accesses several unique features of EF, including those relevant to social conduct, simultaneous attention to multiple stimuli, and complex social decision-making processes involved with interpretation of such.

Science. The knowledge and skills measured in the science domain come from the areas of life, earth, space sciences, and physical science. Considerable emphasis also is given to the nature of science, including the methods and process skills used therein. Constructs assessed in this section are unique from those assessed elsewhere, and most strongly emphasize understanding of the process of scientific problem solving. The test gives real-life examples of scientific inquiry and requires respondents to offer a critical appraisal of the methods utilized. Numerous features of EF are relevant to the demands of these tasks, in particular the ability to plan and sequence events to solve complex problems. Additionally, given that the emphasis of this section is on methodology and critical understanding of the principles involved in problem solving, it represents a test of EF distinct from straightforward verbal ability.

Analyses

Zero-order correlations among academic achievement (ITBS or ITED), intellectual functioning (KBIT-2), and the three executive functioning (D-KEFS) scores were examined first. Then, hierarchical multiple regressions were used to examine the unique relations of EF in the prediction of various academic achievement scores, accounting for verbal and nonverbal intelligence in Step 1 for all models. Age was not included in analyses as it is accounted for in the standardized scores for all measures. It should be noted that of the 151 adolescents for whom academic achievement data were available, social studies (N = 147) data were not available for the full sample due to school district differences in administration procedures. As such, sample sizes differ slightly across academic achievement domains.

RESULTS

Interrelations among academic performances and intellectual and executive functioning

Interrelations among academic performance and intellectual and executive functioning are presented in Table 1. As expected, verbal and nonverbal intelligence are highly correlated, and both were moderately to highly correlated with the three EF composites (*Mdn* r = .38; ranging from .23 for nonverbal intelligence with monitoring to .53 for verbal intelligence with conceptual flexibility). All academic achievement scores were highly correlated with verbal intelligence (*Mdn* r = .62), moderately to highly correlated with nonverbal intelligence (*Mdn* r = .50) and conceptual flexibility (*Mdn* r = .51), and moderately correlated with monitoring (*Mdn* r = .42) and inhibition (*Mdn* r = .41).

Predicting academic achievement from executive functioning

Five hierarchical multiple regressions were performed to examine the contribution of EF in predicting the five academic achievement scores. Both verbal and nonverbal IQ were included in all models to assess the contribution of EF beyond that of general intellectual functioning. As stated previously, age was not included, as all independent variables already were standardized on that basis.

Table 2 presents the results of the regression analyses for performances across all academic achievement domains. As indicated in the table, verbal and nonverbal intelligence were included in Step 1 of all models and produced significant main effects for all academic domains except for reading, for which only verbal intelligence was a significant contributor. Furthermore, EF significantly (p <.001) contributed to the prediction of all academic domains, accounting for a 6–10% increase in variance explained beyond general intellectual functioning.

TABLE 1
Interrelations among intellectual functioning, executive functioning, and academic achievement

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Intellectual functioning									
1 Verbal intelligence	1.00								
2 Nonverbal intelligence	.51	1.00							
Executive functioning									
3 Conceptual flexibility	.53	.43	1.00						
4 Monitoring	.35	.23	.38	1.00					
5 Inhibition	.24	.33	.43	.41	1.00				
Academic achievement									
6 Reading	.74	.42	.55	.45	.36	1.00			
7 Mathematics	.52	.55	.48	.37	.49	.65	1.00		
8 Social studies	.62	.48	.49	.47	.39	.79	.65	1.00	
9 Science	.63	.50	.56	.42	.43	.82	.75	.78	1.00

Note. N = 151 to 142 as described in the text.
All correlations significant at $p < .01$. Correlations >.27 significant at $p < .001$.

TABLE 2
Predicting academic achievement from intellectual and executive functioning

Step	Functioning	Reading			Mathematics			Social studies			Science		
			β	t		β	t		β	t		β	t
1	Intellectual												
	R^2	.55			.38			.42			.44		
	Verbal intelligence		.71	11.12***		.32	4.25***		.51	6.92***		.50	7.04***
	Nonverbal intelligence		.06	0.88		.39	5.23***		.23	3.10**		.25	3.44**
2	Executive												
	ΔR^2	.06***			.10***			.08***			.09***		
	Conceptual flexibility		.15	2.20*		.09	1.23		.09	1.12		.18	2.48*
	Monitoring		.15	2.43*		.07	1.06		.21	3.01**		.11	1.70
	Inhibition		.09	1.53		.27	3.86***		.12	1.73		.16	2.39*

Note. $N = 151$ for reading, mathematics, and science. $N = 147$ for social studies.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$. F test of change from Step 1 to Step 2 significant for all regressions ($p < .001$).

Specifically, conceptual flexibility was a significant contributor in explaining reading and science, monitoring significantly explained reading and social studies, and inhibition produced significant main effects for mathematics and science.

DISCUSSION

The current investigation is the first to examine the role of aspects of EF—namely, conceptual flexibility, monitoring, and inhibition—in the prediction of adolescent performance on a wide range of academic domains. This study builds upon previous examinations of EF and achievement and uses similar methodology to extend this research to new variables (specifically social studies and science scores). This more comprehensive approach to studying applied problems related to the area of study provides data concerning relations between EF and variables more broadly representative of the full educational setting (i.e., diverse topics relevant to educational outcomes). Additionally, the standardized tests from which achievement scores were derived represented real-world, state-level variables of interest to school systems. These results thus have implications for both developmental neuropsychology and school psychology and are particularly applicable to broad systems that use similar methods of standardized outcome assessment.

Analyses revealed significant correlations between the three empirically derived EF composites and various achievement scores. Results of multiple regressions predicting each of five academic domains indicated that aspects of EF made significant contributions beyond general intellectual functioning to the prediction of all academic scores and did so in specific, distinct ways. Conceptual flexibility, for example, which reflects the ability to engage in flexible thinking and behavior, uniquely explained performance in both reading and science in the current investigation. This aspect of EF requires shifting of mental sets, initiating problem-solving behavior, and formulating new concepts. As such, the current findings are not unexpected. For example, it is not surprising that conceptual flexibility was related to reading, given the test's emphasis on reading comprehension, which requires planning an organized response. In addition, conceptual flexibility was related to science, perhaps due in part to this subject's emphasis on methods and process skills, indicating the need for one to shift one's set flexibly with the presentation of new information. However, the lack of relation between conceptual flexibility and mathematics was surprising. As noted earlier, samples utilizing school-age versus preschool-age children have found relations between these two domains (e.g., Bull et al., 2008; Bull & Scerif, 2001). Our results may be due to the use of an adolescent sample in which inhibition may be particularly important in mathematic performance given the increased complexity of the material.

Monitoring uniquely predicted performance on measures of social studies and reading. The demands of the social studies subtest emphasize processes of understanding above factual recall. It requires simultaneous monitoring and evaluation of information entering working memory and updating this information, if appropriate. These processes are all subsumed under monitoring. These processes are also particularly important for the reading comprehension portion of the reading subtest and are consistent with prior research on school-age samples (Sesma et al., 2009). Taken together, these findings are consistent with a resource-interaction approach in which individual differences emerge in how reading processes, likely relevant to social studies as well, compete for a limited supply of working memory resources (Engle, Nations, & Cantor, 1990).

Inhibition uniquely predicted performance on measures of mathematics and science. Relations between inhibitory control and mathematics achievement replicated earlier (albeit inconsistent) research using preschool- and school-aged samples (e.g., Blair & Razza, 2007; Bull & Scerif, 2001; Espy et al., 2004; St. Clair-Thompson & Gathercole, 2006). As noted earlier, we failed to find an association between conceptual flexibility and mathematics, perhaps due in part to the large role that inhibition played with regard to mathematical achievement in our sample ($t = 3.86$). This suggests that inhibition may be a particularly important aspect of EF in relation to mathematical performance in adolescents. Further research should examine age-related developmental differences in relations between academic achievement and various aspects of EF, particularly inhibition. Future research is also needed to help explain our finding with regard to the significant relation between inhibition and science. It may be due to the importance of structured problem-solving approaches (i.e., scientific method) and the need to inhibit one's conclusions until all steps have been conducted.

Strengths and limitations

One strength of the current study was the use of a typically developing community sample of adolescents. EF abilities are considered core abilities and show considerable individual differences. Therefore, the study of relations between various aspects of EF and academic achievement in a typically developing sample allows for a more detailed examination of the role of EF as an underlying mechanism in learning difficulties. Group-level examinations of children with and without certain learning disorders does not allow for this. Another strength of the current study was the manner in which the EF and academic achievement data were collected. As mentioned previously, the D-KEFS is the first set of tests designed exclusively for the assessment of executive functioning to be conormed on a large stratified, representative national sample (Delis et al., 2001), making it an ideal battery for use in such an investigation. Also, the collection of standardized, state-wide academic testing data allows for an examination of academic achievement of students as assessed via their schools, not simply laboratory-based assessments. This is a particularly important strength, given the focus of academic testing at the center of education reform as a means of evaluating both youth and schools, since the passage of the No Child Left Behind Act in 2001 (Orfield & Kornhaber, 2001). Furthermore, our extension achievement of scores to other, diverse subjects (e.g., science and social studies) is a unique strength to the current study. Our findings bolster the need for further applied research in these additional domains.

Due to the cross-sectional, correlational nature of these data, causal conclusions are not possible. Another limitation, which may have restricted sample variability, was that the sample was entirely male and relatively homogenous (e.g., white, married, college-educated mothers). Whereas this design results in fewer potential confounding variables, the degree of generalizability of results is unclear. Future research would benefit from including more demographically heterogeneous samples, including samples of both males and females. Research is mixed with regard to the relationship between sex differences and both EF (Carlson & Moses, 2001; Kerr & Zelazo, 2004) and academic achievement (Halpern, 2000). Therefore, it is unclear as to what the effect of sex may be with regard to relations between EF and various academic domains.

In sum, findings from the current study suggest that various academic domains require different cognitive abilities and suggest directions for future research and possible avenues for intervention. As discussed previously, the skills associated with the ability to perform well in school are dependent upon the development of EF (Blair, 2002; Bull et al., 2008). Given that testing has become a federally mandated benchmark for evaluating children and schools, the current findings have implications for curriculum considerations and educational interventions. Children with EF difficulties may be particularly disadvantaged with regard to performance on these high-stakes tests. As EF does not appear to be entirely "hard-wired" (Waber, Gerber, Turcios, Wagner, & Forbes, 2006, p. 462); thus, results of the current investigation, along with previous work in more at-risk samples (e.g., Waber et al., 2006), suggest the need for early interventions aimed at preparing children for school with the enhancement of EF as a core goal. For example, the Head Start REDI program has been shown to promote EF gains in preschool-age children (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008). It is hoped that results from the current investigation can be used to help guide future research in this direction, particularly in populations of children and adolescents who are struggling in various academic subjects.

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