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Cognitive control goes to school: The impact of executive functions on academic performance

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Abstract

The general aim of the present study was to investigate EF in relation to academic performance. We chose tasks evaluating three EF dimensions: working memory (WM), inhibition (resistance to interference and negative priming), and set-shifting. Subjects (N = 70) were school-aged children in the 5th and the 8th Grades. Regression models supported the contribution of individual differences in EF performance to explaining over half of total variance in school performance, revealing the main role of WM in predicting Mathematics performance. Results are discussed in terms of relevance of meaningful assessment practices and for educational interventions.

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Keywords: cognitive control, executive functions, academic performance, predictors, school-age children

1. Problem statement and motivation

Executive functions (EFs) play a central role in sustaining and calibrating the development of academic skills and in school performance in general; however, few studies have directly targeted EF as a predictor and/or correlate of school readiness and achievement. According to the EF model proposed by Miyake and collaborators (2000), which received the largest empirical support for adults and children after the age of 5 (Best, Miller, & Jones, 2009; Visu-Petra, Benga, & Miclea, 2007), there are three main EF dimensions: updating, set-shifting, and inhibition. These EFs represent essential ingredients for optimal academic functioning, and are also one of the important potential sources of school dysfunction (Rose & Rose, 2007), as deficits in EF have been noted in learning disabilities in both mathematics and reading (McLean & Hitch, 1999; Swanson, 1999). Recently, the link between EF and academic achievement has begun to be more systematically investigated, with EF seen as a multifaceted construct, related to multiple academic outputs (St Clair-Thompson & Gathercole, 2006; Mazzocco & Kover, 2007; Swanson, 2006).

The general aim of this study was to investigate EF as a prerequisite and correlate of academic performance. We cross-sectionally evaluated the three EF dimensions (WM, inhibition, and shifting) in school-aged children in the 5th and the 8th Grades. School performance (General semester grade, Mathematics and Romanian semester grades) and performance on a specially designed Mathematics test was related to these EF measures, in an attempt to identify executive prerequisites of the target academic outcomes.

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2. Methods

Participants

A total of 87 children from a school in the northwest Romania (rural area) participated in the study. 70 children completed all EF tasks and had all school performance measures, so only their data will be reported here. From the 5th Grade there were 35 participants (mean age = 140 months, SD = 4.38; 19 girls); from the 8th Grade there were 35 participants (mean age = 180 months, SD = 6.23; 17 girls). Considering their Mathematics semester grades (on a scale from 1-10), the children were split into three groups, because we were interested in the specific EF processes related to underachievement as compared to high achievement in Mathematics. Children who had semester grades of 4, 5 or 6 were included in the Low-Math-achievers group (N = 23), those who had grades of 7 and 8 were rated as Medium-Math-achievers (N = 34), and finally, those with general grades of 9 and 10 were rated as High-Math-achievers (N = 13).

Measures

Working memory. Three memory tasks were selected: *Corsi span* (investigating visual-spatial short-term memory - STM), *backwards digit span* and *listening span* (investigating verbal WM), from the adapted version of AWMA (Alloway, 2007; Visu-Petra, 2008, the Romanian version). In these tasks a sequence of elements is first demonstrated by the examiner (as a motor output: touching different blocks in the Corsi display, or as a verbal output: a series of spoken digits in backwards digit span, a series of sentences in listening span), and the child is requested to repeat the sequence. Supplementary processing demands are introduced to the child in the WM tasks by the reversed order imposed by backwards digit span, and by the request to evaluate the sentences as true/false in the listening span task.

Inhibition. As a measure of active inhibition suitable for school-aged children throughout this age interval, we chose the negative priming version of the Stroop test provided by the Focused Attention (FA) test from the Cognitrom Assesment System (CAS, Miclea, Porumb, Cotârlea, & Albu, 2009). This test was designed to measure sustained attention measured through the requests for inhibition in a negative priming paradigm (Neill, Valdes, & Terry, 1995). From this task, we analyzed the accuracy/time ratio on each list by dividing the number of items correctly solved to the total solving time. A classical Stroop list measuring simple resistance to interference (without negative priming) was also included.

Shifting. As a measure of shifting suitable for older children, we chose the Attentional Switching (AS) test from the CAS. This measure evaluates the ability to flexibly switch the categorization rule according to a signal. Two scores are computed as a result of this test: an Accuracy score, representing the number of items correctly solved, and a Switching Index, calculated by dividing the total time on the correctly solved items to the total number of switches from these items.

School performance. As the children were assessed at the beginning of the second semester of their 5th and 8th Grade, the general grades from the previous semester were available. We considered the General grade and the semester grade in Mathematics and Romanian as the target academic outcomes. Two mathematics tests were constructed together with the teacher from those classes; one for the 5th and one for the 8th grade, in order to investigate target components of their mathematics skills in relation to EF performance.

Procedure. While the Mathematics test was applied to the whole classroom, the EF tests were applied in a separate, individual session, lasting for approximately 30 minutes. The order of applying the Mathematics test or the EF tasks was counterbalanced across the whole sample.

3. Results

In order to investigate the explanatory value of different EFs to the school performance measures, separate hierarchical regressions were conducted with the school grades (Mathematics, Romanian, general semester Grade), and with the results on the special Mathematics test as dependent variables. The predictors were entered in the order in which they had been previously documented in the literature: in Step 1, the contribution of Age was investigated; in Step 2, the memory tasks (STM and WM) were entered, followed by the inhibition measures (resistance to interference and negative priming) in Step 3. Finally, in Step 4, the contribution of shifting (switching accuracy and switching time indexes) was introduced, in order to see if it would account for an additional variance in the school performance outputs than the previously entered predictors.

Taking into account only the influence of age and of the EF measures, we managed to account for significant portions of the variance in school performance measures: 54% in the case of Mathematics grade, 53% in the case of Romanian, 56% for General semester grade, and 54% for the Mathematics test.

Looking at the explanatory value of our predictors, *age* alone did not bring a significant contribution to explaining any of the school performance measures. The introduction of *Memory* tasks in Step 2 brought highly significant contributions to the prediction of all school performance measures: $\Delta R^2 = .38$, $p < .01$ in Mathematics, $\Delta R^2 = .29$, $p < .01$ in Romanian, $\Delta R^2 = .31$, $p < .01$ in General semester grade, and $\Delta R^2 = .35$, $p < .01$ in the Mathematics test. However, from the tasks included in this step, the best predictor for Mathematics (both school grade and test) turned out to be Corsi span, followed by listening span, and (only marginally significant) by backwards digit span. In the case of Romanian and General semester grades, the best predictor from the memory tasks was listening span, followed by Corsi span; backwards digit span did not bring a significant contribution in this case.

The introduction of the *Inhibition* measures in Step 3 brought an additional contribution, above the influences of age and memory, only in the case of Romanian, General semester grade, and the Mathematics test ($\Delta R^2 = .10$, $p < .01$ in Romanian, $\Delta R^2 = .12$, $p < .01$ in General semester grade, and $\Delta R^2 = .09$, $p < .01$ in the Mathematics test), but not of Mathematics grade ($\Delta R^2 = .05$, *n.s.*). In all the cases in which its contribution was relevant, the only significant predictor was actually the negative priming measure.

Finally, it appeared that in the case of all school performance measures, the introduction of the *Shifting* measure in Step 4 brought additional significant contributions, even when controlling for the effects of age, memory and inhibition factors ($\Delta R^2 = .09$, $p < .01$ in Mathematics, $\Delta R^2 = .09$, $p < .01$ in Romanian, $\Delta R^2 = .11$, $p < .01$ in General semester grade, and $\Delta R^2 = .08$, $p < .05$ in the Mathematics test). Accuracy on solving this task actually represented the significant predictor, the influence of the time to shift index being non-significant (probably camouflaged by the previously entered predictors from the inhibition task, because it correlated strongly with it).

The next step was to investigate which EF processes were significantly different between the Low-, Medium, and High- Math-achievers groups. One-way ANOVAs were computed for each EF measure with Math group as a between-subjects variable. Figure 1 presents the significant differences between these groups' performances on WM measures as a result of post-hoc Tukey tests. The differences between the three groups were significant for Corsi span, $F(1, 69) = 15.65$, $p < .01$, backwards digit span, $F(1, 69) = 4.97$, $p = .01$, and to a lesser degree for listening span, $F(1, 69) = 3.80$, $p < .05$. Finally, we analyzed the effect of belonging to a Math-Achievers group on the *shifting* ability (see Fig. 7.9). The difference between the three groups was significant on both the AS Accuracy index, $F(1,69) = 10.73$, $p < .01$, and on the AS Switching Index, $F(1, 69) = 4.31$, $p < .05$.

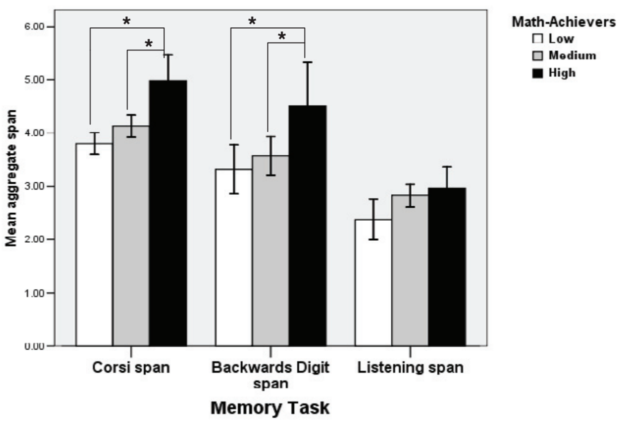

Figure 1. Performance on the WM tests (Corsi span, backwards digit span and listening span) as a function of Mathematics grades

4. Conclusions and Recommendations

The main aim of the study was to identify the relation between several EFs and the academic output measures. The regression models clearly revealed the contribution of individual differences in EF performance to explaining over half of total variance in school performance. We introduced the predictors in the canonical order dictated by previous findings in the literature: first age, then the WM tasks, then the inhibition tasks, and finally the attention shifting task. In this order, age turned out to be a very poor predictor of academic performance for this age interval, naturally revealing the "calibration" of the grades to the performance level of the child (it would have been unexpected to note a general increase in school performance only as an effect of being in a higher grade). When introducing the WM tests, these accounted for a highly significant proportion of variance, especially in Mathematics semestrial grade and in performance on the Maths test (but also on the other academic performance measures). The inhibition tasks (especially the non-interference task) made their largest contribution on explaining variance in General semester grade and Romanian semester grade, and to a lesser degree on Mathematics measures. Finally, the introduction of the shifting component (the accuracy index), brought additional contributions to all academic measures (and especially on the General semester grade), above the influence of all the other predictors. This is why we subsequently entered it in a regression model second after the influence of age; this change accounted for more variance than the WM tasks on all academic outputs, except Mathematics semester grade, for which the child's WM remained the best predictor. The EF "ingredients" that can help predict 50% of performance in Mathematics (but also in Romanian and General semester grade) are performance on visual-spatial STM (Corsi span), verbal WM (backwards digit span, listening span), inhibition, and shifting.

One of the most important limitations of our approach regarding EF and *school achievement* is that due to its correlational nature, it precludes conclusions about causation. In other words, despite being highly associated, and representing a good predictor of mathematical school performance, we don't know if good WM performance is a prerequisite of this academic outcome, or a result or correlate of mathematic-specific training. Early assessments of EF in the literature have pointed out to the contribution of EF to emergent mathematical skills in very young children (Espy et al., 2004). However, from school entrance onwards there is clearly a dynamic interplay between schooling and EF development. Several authors have proven that exposure to schooling in general (and to mathematics in particular) represents an essential source of progress for a wide repertoire of cognitive functions (for a review see Blair, Gamson, Thorne, & Baker, 2005), so we must remember the bidirectional nature of influences. The present study also documents this bidirectional influence, by showing that WM and shifting skills differ in low versus high Math achievers.

The documented value of screening for early EF as a prerequisite for school readiness has already been incorporated in early prevention and intervention programs (e.g. the Head Start REDI program, Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; or the Tools of the Mind curriculum, Diamond, Barnett, Thomas, & Munroe, 2007). These comprehensive programs are based on the assumption that cognitive control skills are important for success in school and are amenable to improvement in at-risk preschoolers without costly interventions. Monitoring for EF across the school-age is also a valuable strategy, because it suggests important sources of dysfunction, but it can also indicate academic success. In this respect, it has been demonstrated that gifted children outperform other children on executive, but not on non-executive tests (Arffa, 2007). Therefore, the current findings bring additional support to the need to include EF assessment as part of formal (pre)school evaluations, using proper instruments which tap the multidimensional nature of this construct.

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