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An Introduction to the Special Issue:

Contributions of Executive Function to Academic Skill

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Executive functions (EFs) resist easy definition, both within and across fields of study. Therefore the question “What is (are) executive functions?” is an important one to address in its own right, from both theoretical and practical perspectives, and particularly if the result is to cross disciplinary lines. EF can be conceptualized broadly as domain general control processes important for managing goal-directed behaviors. The history of behaviors associated with EF spans over a century, but the definitional history of EF is rather more recent – Lezak (1983) for example identified four component processes: goal formation, planning, carrying out goal directed plans, and effective performance. EF is also defined more operationally, according to the functions assessed by clinical or experimental tasks. These are quite varied (Jurado & Rosselli, 2007), but include planning, working memory, cognitive flexibility, and inhibition. The influential work of Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000) identified both the unity and diversity of EF, focusing on updating, inhibition, and shifting; later, Miyake and Friedman (2011) proposed a hierarchical model with inhibition subsumed in a common EF. Others have distinguished between metacognitive and emotional EF (Ardilia, 2008), overlapping with “cool” versus “hot” conceptualizations of EF (Zelazo & Carlson, 2012). The overall complexity is reflected in a review by Suchy (2007), who identified seven *types* of definitions of EF.

Given the above, it seems unlikely that the field will agree upon a single “correct answer” for defining EF. Despite the work that remains to be done to clarify a unanimously agreed upon definition, there is strong interest in how these cognitive control processes operate. To this end, the focus of this special issue regards a more specific practical question: “How do executive functions contribute to our understanding of academic skill”? This question is pertinent for students with learning disabilities, as well as for other neurodevelopmental disorders in children where learning difficulties have often been implicated.

There are several reasons for this choice of focus. First, although other special issues of EF exist and provide important and substantial results, the current issue is the first to

specifically examine the relation between EF and academic performance. Second, where children are involved, academic skill is paramount, given the amount of time children spend as students, highlighting the rationale for a focus on reading, mathematics, and writing. Third, early work on executive function focused on adults, and understanding of EF in children is growing but is less robust, particularly across different developmental periods (e.g., preschool, school-age, adolescence). Fourth, in developmental and educational contexts, EFs are somewhat less constrained to the way they are often thought of in adulthood – as “frontal lobe behaviors”. Instead, concepts such as self-regulation and self-regulated learning, which bear similarity to EF at the conceptual level, are invoked in addition to, or instead of, executive function, often without regard to neuroanatomy. Finally, to whatever extent executive function is important for “outcomes”, it is unlikely uniformly so. By focusing on a key domain (academics), we might gain depth and subtlety of understanding in a way that is not possible without this common thread.

The outstanding contributions of the present special issue each in some way examines the importance of EFs for academic skill(s). These studies include a diverse set of samples and approaches that each inform the core question in different ways. For example, all seven papers examine the relation between EF and word reading, but several manuscripts also include measures of math or reading comprehension, and one study examines the relation between EF and written language. The studies cover a wide developmental range, with two manuscripts that focus on preschool children, three that include a sample at the elementary level, and two studies that include a wide developmental age range, some of which also incorporate a longitudinal design. Multiple papers incorporate sophisticated analytic techniques such as growth mixture modeling and multi-level modeling, and several contributions examine the strength of the relations of EF and academic skill in the context of other key influences on academic functioning. Finally, one study focuses on the impact of EF on academic outcomes after intervention, providing a unique perspective on the role of executive functions for academic skill.

The special issue opens with a study by Willoughby, Magnus, Vernon-Feagans, Blair and FLP Investigators; their contribution is a longitudinal study of EF at preschool, and its utility for academic skills in kindergarten. This study utilizes a very large sample focused on geographic areas with high poverty rates, and employs sophisticated statistical analyses to identify young children with low growth in EF across preschool. This subgroup was also found to have difficulties with standardized kindergarten readiness skills such as vocabulary, letter-word identification, and math applications, in addition to teacher ratings, as well to receive school assistance such as an individualized educational plan or “wrap around” services. This study employed a very strong group of covariates including income, education, race, sex, age, and general cognitive abilities. These covariates reduced the impact of EF, primarily for the standardized measures of reading and language, though other effects remained moderate to strong. Although subgroups were formed on the basis of overall growth, group membership was most consistent with the last measured EF time point (age 5, just prior to kindergarten). This might suggest that EF is more variable earlier in development, but additional and cross-lagged data may more completely answer this question (e.g., How well do age 5 EF scores predict age 7 academic skills and school

services, with and without age 5 academic skills?; How stable is EF across other developmental epochs?).

The way that Willoughby et al. assessed EF was a strength from a measurement perspective, employing an array of performance-based assessments. A composite measure of EF offers many psychometric advantages, but may be more difficult to employ in practice, unless the means of generating such a score were readily available. It is not unreasonable to expect that such a procedure might be possible. For example, the NIH EXAMINER (Kramer et al., 2014) produces IRT based factor scores of EF across development, and these may prove differentially predictive of outcomes via a readily available platform.

Continuing within the preschool age-range, and also in a large sample in a longitudinal context, Lonigan, Allan, Goodrich, Farrington, and Phillips address an issue of burgeoning relevance – namely, the extent to which English language learners show differential impact of a strong EF (inhibitory control) for predicting emergent literacy and math performance across a preschool year, in both English and Spanish languages. These authors find that their measure of inhibitory control contributes to academic outcomes over time. The impact of EF was relatively small in unique terms, though it must be noted that initial performance and covariates were all included, and the authors note the consistency of the size of their effects. Most notably, prediction was similar regardless of the language of the outcome measure, and regardless of the language of administration of the inhibitory control task. There was also variability in the outcomes that are predicted (e.g., phonological awareness and math skills, but not vocabulary and print awareness), which is attributed to the degree of language specificity of the latter relative to former outcomes. In combination, their results suggest that EF is language independent in its predictive power, particularly when the outcome is also less language specific.

Swanson, Orosco, and Kudo focus on the working memory component of EF, and like Lonigan et al., also assessed children in both Spanish and English, employed a longitudinal design with a large sample, and incorporated a wide range of important demographic and cognitive covariates. Beyond these similarities, the studies of Lonigan et al. and Swanson et al. complement one another nicely. The former focuses on a single measure of EF, assessed in one of two languages, and focused on an array of early outcomes assessed in both languages; in contrast, the Swanson et al. contribution investigates only English language learners, on a different EF assessed comprehensively in both languages, with measures of reading in English as outcome measures. Swanson et al. report that growth in working memory (and specifically its executive as opposed to short-term memory components) predicted English reading outcomes. Students at-risk for reading difficulty (RD) at time 1 lagged behind their peers across an array of cognitive measures, though growth in these non-EF variables was unrelated to English reading outcomes. The study of Swanson et al., also adds direct data to support that designation as RD occurs along a continuum rather than at a designated interval or cut-point, by demonstrating similarity of results with and without this group structure.

Both Willoughby et al. and Lonigan et al. evaluated both reading and math skills. More specifically addressing the topic of comorbidity is the contribution of Peterson, Boada,

McGrath, Willcutt, Olson, and Pennington. This work evaluates a large sample of children and adolescents not only with regard to reading and math, but also including attention deficit hyperactivity disorder symptomatology. Their results demonstrate both overlap and independence of predictors, offering a nice illustration of their multiple deficit framework for neurodevelopmental disorders, and rejecting a phenocopy hypothesis (that attention accounts for the overlap between reading and math). For the overlap of reading and math, the common factor was instead verbal comprehension, which when accounted for, substantially reduced the relationship between reading and math. For the overlap of reading and attention, and math and attention, processing speed accounted for their overlap. No single factor accounted for the overlap across all three symptom dimensions. Further, each area was associated with at least one specific predictor (for reading, phonological awareness and rapid naming; for math, verbal working memory; and for attention, response inhibition). Of particular relevance to this special issue beyond its focus on academic outcomes, this study employed measures of EF (working memory and inhibition), and evaluated the extent to which these skills accounted for symptom overlap. It did not. Instead, these predictors had more unique influences on specific outcomes rather than their comorbidity. A final key result was the stability of the structure of their measurement and comorbidity model across younger and older children, which is important particularly given that much work particularly regarding cognitive factors such as EF has focused on either the preschool or adult age groups.

The fifth contribution to this series, from Jacobson, Koriakin, Lipkin, Boada, Frijters, and Lovett et al. also employed a large sample, and like the studies of Lonigan et al. and Swanson et al., focus on a population that is less well represented in the literature, in this case wholly children of minority backgrounds. This work is notable for its systematic and comprehensive assessment of multiple aspects of reading, including outcomes of word reading, reading fluency, and reading comprehension. Their suite of EF measures differentially predicted these outcomes, with working memory related to all three reading measures, attentional switching related to word reading and reading fluency, and problem solving uniquely related to reading comprehension. Overall, the EFs measured here contributed 4% to 8% of the variance in reading prediction, which itself is strong, and more impressive when these values pertain after controlling for demographics, processing speed, and reading-related skills such as vocabulary and phonological awareness.

Whereas the contributions above focus on combinations of reading, and occasionally math (Willoughby et al.; Lonigan et al.; Peterson et al) or attention (Peterson et al.), writing is relatively neglected in the literature. For their contribution, Berninger, Abbott, Cook, and Nagy examine the predictive role of EF for reading and aural/oral language, but also writing skill, and each of these is comprehensively evaluated in their sample of students in grades 4 through 9. Their results explore the prediction of each of these outcomes with not only EF performance measures, but also ratings of EF and of attentional symptomatology. The individually administered measures of EF, which focused on fluency, inhibition, and shifting, were more strongly related to each outcome than were ratings of such behaviors. Predictive power also varied somewhat in strength, with the strongest prediction for their reading composite, and weakest for aural/oral language outcomes. This study also provides intriguing links as regards the overlap among these language learning outcomes.

Finally, the study contributed by Cirino, Miciak, Gerst, Barnes, Vaughn, Child, and Huston-Warren takes a different approach from the correlational studies described above. They evaluate an experiment designed to incorporate executive functions (EF) and self-regulated learning (SRL) features into a reading intervention for students with weak reading comprehension over 4 weeks. Their results are sobering in terms of their impact on differentially increasing reading comprehension; the group that received a combined text-based reading comprehension and SRL/EF intervention did not differ from a group to receive only the text-based intervention. Both active groups outperformed controls on measures most proximal to the taught material, but effects were small/null for more distal outcomes. In terms of prediction, measures of EF and SRL correlated weakly with one another, and variably with reading outcomes. This study highlights the difficulty in moving from the level of relating EFs to academic outcomes, to using such relationships to intervene with students who have reading difficulty, or more generally to improve academic outcomes via intervention.

Conclusions and future directions

Overall, the studies in this collection convincingly demonstrate relations between EF and a range of academic skills in children. These relations are represented in a range of samples both developmentally (preschool to adolescence) and demographically (populations that are typical or at-risk, bilingual, or of minority background). The studies here offer several intriguing methodological approaches (e.g., growth mixture modeling in Swanson et al. and Willoughby et al.; multi-level models as in Lonigan et al. and Swanson et al.) in the context of stringent covariates (e.g., Willoughby et al; Lonigan et al; Swanson et al.; Jacobson et al.). Thus, the robustness of these relationships clearly adds to recent meta-analytic evidence indicating that EF are significantly associated with academic functioning; the study of Cirino and colleagues also highlights the relative difficulty of evaluating the impact of EF in an intervention context (e.g., Jacob & Parkinson, 2015; Melby-Lervag et al., 2013).

The next frontier for studies of the relation between EF and academic performance is likely to come from a renewed and robust focus on the measurement of EF, with a particular emphasis on consistency of conceptualization and operationalization across samples, ages, and populations. In doing so, it will be important to consider not only performance based measures of EF, but also ratings of EF and related behaviors. Continued improvements in the conceptualization and operationalization of EF are likely to provide important guidance for research that extends these results in innovative new directions. For example, studies of the relation between EF and learning disabilities may identify important targets for studies of neuroimaging and genetics, key basic science approaches that were not evaluated by the studies in this special issue. There is also likely to be a role for EF in applied studies of interventions with students who struggle academically, though this is unlikely to be easy or straightforward. Avenues for doing so will likely include studies that include measurement of the mechanisms through which EF might operate, as well as integrating these with interventions that target specific academic skills.

In sum, this special issue is unique and timely in its focus on the relationship of EF to academic skill. The contributions provide insight and clarity about the way that EF

influences key learning outcomes and for students who may struggle academically. We hope that you enjoy this collection.

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