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MIND, BRAIN, AND EDUCATION

Informing the Development of School-Based Strategies to Promote Children's Executive Function Skills: Considerations, Challenges, and Future Directions

Jennie K. Grammer[1] and Sammy F. Ahmed[2]

ABSTRACT— In recent years awareness of the importance of executive function (EF) skills for students' academic growth has increased. Research suggests that experience in school promotes EF development; however, recommendations regarding evidence-based practices that educators can use to support EF in their classrooms are limited. Here we outline two main reasons that this may be the case. First, there are significant challenges in the measurement of EF, which have implications for our understanding of how children use EF skills in support of learning in the moment and in real-world settings like the classroom. Second, there is limited direct research on the types of classroom experiences that promote EF. In describing both, we highlight emerging evidence and new methods that are helping us better understand the development of EF and the ways in which school experiences shape this growth, which will ultimately inform the development of school-based strategies to promote these skills.

Evidence of the role of executive functions (EF, including working memory, inhibitory control, and cognitive flexibility) for children's academic development has been shared widely with teachers and practitioners (Zelazo, Blair, & Willoughby, 2016), who have an increasing interest in and awareness of the importance of these skills for student academic success. Less clear is how this knowledge can be used to inform instructional practice. We suggest that there are two important roadblocks preventing EF research from being leveraged for work with students. First is a lack of clarity surrounding EF measurement. Different EF measurement approaches have resulted in a vague understanding of the parameters of EF components, and how they manifest and function in classroom settings. Additionally, a general lack of developmentally sensitive EF measures has limited our understanding of EF's developmental progression and how these skills might support children's academic growth throughout schooling. Second, although EF skills are generally thought of as foundational for academic success, we know relatively little about how experiences in school promote their emergence and refinement. Understanding the development of EF, and the ways in which school experiences shape this growth, are essential first steps in developing school-based strategies to promote these skills.

Here we address both of these issues in EF research as they relate specifically to the development of reading skills. First we describe the use of multiple approaches to measure EF across childhood and adolescence ranging from tightly controlled neuroscientific tasks to naturalistic activities embedded in the classroom, providing examples of the implications of EF measurement for understanding the links between EF

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skills and reading achievement. We then present evidence that experience in school promotes changes in EF, and conclude with a summary of school factors that promote the development of EF.

EXECUTIVE FUNCTION MEASUREMENT ACROSS DEVELOPMENT: IMPLICATIONS FOR READING RESEARCH

Although definitions and emphases differ, there is general consensus that EF refers to a set of cognitive skills used for purposeful, future-oriented behavior (e.g., Diamond, 2013). These skills underlie flexible adaptation to changing task demands, including the regulation of attention, inhibition of inappropriate responses, coordination of information in working memory, and organization and planning of adaptive behavior (Morrison & Grammer, 2016). Evidence for associations between children's EF and academic achievement has accumulated steadily over the past two decades (e.g., Ellis et al., 2021; Gathercole & Pickering, 2000; McClelland et al., 2007; Ribner, Ahmed, Miller-Cotto, & Ellis, 2022; Welsh et al., 2010; Woods, Ahmed, Katz, & Morrison, 2020). Although EF has been linked to children's academic development in the domains of math, reading, and science achievement (e.g., Ahmed, Montroy, Skibbe, Bowles, & Morrison, 2023; Kim, Ahmed, & Morrison, 2021; Kim, Bousselot, & Ahmed, 2021; Nguyen & Duncan 2019; Schmitt et al., 2017), interest has steadily mounted on the role of EF for children reading achievement across development (Ahmed, Tang, Waters, & Davis-Kean, 2019; Blair & Razza, 2007). An extensive body of research has demonstrated the supportive role of EF in the development of reading skills, including but not limited to, decoding, vocabulary, and both oral and written language comprehension (Follmer & Sperling 2019; Ober et al., 2020). Despite the large body of literature linking EF and reading development, there are several challenges that might obscure how we understand EF's role in children's reading development. In this section, we outline the ways that EF measurement can present challenges and opportunities for the field of EF research.

Developmentally Sensitive EF Measures

A large body of research has focused on how changes in EF skills in early childhood as they relate to school readiness and early learning. Reflecting this, recent work has highlighted the importance of early EF for children's school readiness and academic achievement at school entry, however, meta-analyses have also found that relations between EF and reading skills persist across elementary school (e.g., Spiegel, Goodrich, Morris, Osborne, & Lonigan, 2021), and that links between reading difficulties and deficits in specific EF components become increasingly pronounced with age (Peng et al., 2022). This work highlights the importance of EF skills over a longer developmental period for struggling readers in particular. Notably, EF appears to play a role in a range of processes involved in the development of skilled reading, from emergent literacy skills to reading comprehension (e.g., Butterfuss & Kendeou, 2018), trends that may also be partially attributed to the protracted nature of EF development, which extends into middle childhood and adolescence (Ahmed, Ellis, Ward, Chaku, & Davis-Kean, 2022; Best & Miller, 2010).

Despite this, there remains a need for developmentally sensitive EF measures to more accurately characterize skills of children and youth, clarify the developmental course of different EF components, and permit modeling associations between EF and reading that span early childhood and adolescence. For example, recent evidence has shown small-to-null relations between EF measures during early childhood and adolescence, suggesting that direct assessments of EF might be tapping different constructs across development (e.g., Ahmed et al., 2019). Additionally, given that the functional organization of EF might also change throughout development (Ahmed, Grammer, & Morrison, 2021; Ahmed, Kuhfeld, Watts, Davis-Kean, & Vandell, 2021; Brydges, Reid, Fox, & Anderson, 2012; Usai et al., 2014), it is important that research consider the measurement properties of EF assessments across the school years.

Construct Validity of EF Components

In addition to concerns about developmentally sensitive measures, the "measurement mayhem" and "conceptual clutter" issues in EF research *broadly* warrant questions about construct validity (Morrison & Grammer, 2016). In our work, we have shown that associations between EF and reading differ not only by individual EF components but also across different modalities of measurement (e.g., Ahmed, 2019). Children's EF skills can be assessed using a variety of methods and measures—including neuroscientific approaches, behavioral tasks, and observer report—each reflecting the different research traditions (e.g., neuroscience, cognitive development, developmental psychopathology, education) on which they are based. The tendency to use discipline-specific measures, combined with an overall lack of shared theoretical and operational definition of EF, has had meaningful implications for the construct and ecological validity of EF measurement and has contributed to lack of clarity with respect to the links between EF and literacy skills.

Even at the level of individual measures there exist non-trivial methodological challenges that relate to construct validity. For example, each measure of EF yields many behavioral indicator variables (e.g., reaction time, accuracy), which are not always highly associated with one another—a

sort of within-task version of the jingle fallacy, where the single term EF is used to describe a range of different, and sometimes poorly related, behaviors. This issue is rarely if ever addressed in developmental research despite having a direct impact on conclusions that are drawn about associations between EF and reading achievement. Take, for example, tightly controlled experimental EF measures, like a child-friendly Go/No-Go task (Grammer, Carrasco, Gehring, & Morrison, 2014), which was designed to assess response inhibition while recording electrophysiological data (electroencephalography (EEG)). Research on the links between reading and EF using tasks like the Go/No-Go typically reports associations between an academic outcome and a single score of behavioral performance or EEG measure. However, this Go/No-Go task can yield as many as nine behavioral outcome indicators (and there are at least as many different ways to quantify the EEG outcomes).

To understand the implications of the indexing of different indicators from the Go/No-Go, Torgrimson (2022) compared predictive models using separate individual behavioral indicators to a latent model of task performance, finding that modeling multiple indicators drawn from the task was superior for predicting variance in academic outcome measures as compared to single-indicator regression approaches. These discrepant findings suggest that relations between EF and reading depend on analytic decisions regarding how multiple indicator measures such as the Go/No-Go are scored and analyzed. This also has implications for how we conceptualize the skills involved in this type of response inhibition task. Multiple cognitive processes can be estimated from performance on a single EF task; while the full richness of data afforded by EF measures is not often used, this level of analysis may provide important insight into the strengths and weaknesses in the cognitive and behavioral processes that underlie EF skills for individual children.

Measuring EF in Real-World Settings

Although many experimental EF measures offer rigorous control and precision relative to options like observer reports, it is not clear to what extent they reflect how children use EF skills in the classroom (Cameron et al., 2012; Bodnar et al., 2007; Domitrovich et al., 2007). Learning environments place demands on children's EF, especially as they begin learning how to filter distractions to focus on instruction (Silver, 2014). For example, research has shown that classmates' EF skills, as early as in elementary school, can impact children's EF, language, and literacy development (Finch, Garcia, Sulik, & Obradović, 2019; Montroy, Bowles, & Skibbe, 2016; Skibbe, Phillips, Day, Brophy-Herb, & Connor, 2012). Despite this, virtually all direct cognitive assessments have been designed to measure children's EF in isolation and free from external distractors. Understanding and measuring how EF manifests and develops in classroom contexts, however, is an important step toward developing school-based strategies to promote these skills. Historically, researchers have largely relied on observer reports to understanding how children employ EF skills in real-world settings, which are primarily based on behavioral cues, such as inattention, classroom wandering, and frequent interruptions (e.g., see assessments such as the BRIEF, Roth et al., 2013). However, issues with low conceptual precision and rater bias continue to limit their utility for studying EF in applied settings (see McCoy, 2019, for review).

In light of these limitations, researchers have begun using novel administration techniques to understand how children employ EF in classroom settings. For example, Obradović, Sulik, Finch, and Tirado-Strayer (2018) administered computerized EF assessments to groups of 3rd, 4th, and 5th grade students in classroom settings, finding differential performance when administered individually versus in a classroom setting (Obradović et al., 2018). However, it remains unclear whether EF measures designed to be administered individually in highly controlled settings are sensitive to the complexities of employing EF in socially demanding environments. Thus, there has been a recent emphasis on developing more ecologically sensitive measures to understand how children employ EF in socially demanding contexts such as a classroom setting. One recent example includes a battery of group-based assessments developed by Ahmed, Grammer, and Morrison (2021), that are administered in schools and involve instructing groups of kindergarten students to complete tasks that place demands on their EF abilities. In an initial validation study, the authors demonstrated the feasibility of administering experimental EF measures in schools that were designed specifically to capture how young children employ EF in the presence of their peers. In this study, they found that performance on these group assessments was related to traditional, individually assessed EF measures and was uniquely related to children's academic achievement during kindergarten (Ahmed, Grammer, & Morrison, 2021; Ahmed, Kuhfeld, et al., 2021). Taken together, despite recent methodological and measurement advances in studying children's EF in real-world settings, there is still a need for developing contextually sensitive EF measures to understand how EF skills are employed, develop, and fluctuate in classroom settings. Doing so would be a first step toward understanding how educators can promote the development of EF skills using school-based strategies.

DYNAMIC RELATIONS BETWEEN EF AND READING ACROSS DEVELOPMENT

A greater understanding of EF development and how relations between EF and reading might change over time

could have benefits for translating research on EF for educational practice. Doing so can lead to increased specificity in the diagnostic profiles and the identification of children at-risk for reading difficulties and, in turn, contribute to developmentally appropriate and targeted teaching strategies. The relevance of EF measurement for our understanding of reading development, and the utility of related research for informing practice, become increasingly apparent when one considers the broader context of theoretical assumptions regarding the link between these processes across development, and the timescale at which these processes unfold. Historically, our approach to examining associations between EF and reading has focused on static assessments of each process, assessed using report measures and standardized behavioral tasks administered once or twice a year, which provide insight into linear relations between EF and reading skill. Analyzed this way, the timescale of these associations is long (e.g., EF at school entry being linked to reading at grade 3), and the causal, temporal pathway between early EF skills and later academic success is implied. Although unintended, the focus on linear relations has contributed to the sense that EF is a trait—stable and static—akin to IQ. This is a message that has been conveyed in our writing. For example, reading text such as, "after controlling for general intelligence and attentional control/flexibility, inhibition has also been identified as a unique predictor of math achievement and literacy in kindergarten" (Morrison & Grammer, 2016, p. 330), it is possible to infer that there is something about the child entering the kindergarten classroom that is a stable "starting set" that limits (or enhances) that child's literacy growth.

Our conversations with many general educators in the United States indicate that this is the characterization of EF that has also been disseminated. In these discussions, EF is often described as a key factor that limits a student's ability to read and one that is most effectively intervened on outside of the classroom setting (in contrast to early educators in China; Mao & Grammer, in review). Less frequently is EF described as dynamic, with children's skills shaped by context and coactively develop with academic skills. However, this alternative view is aligned with recent theoretical conceptualizations (Connor, 2016; Peng & Kievit, 2020), suggesting that the relationship between reading and EF is better characterized as dynamic bidirectional interactions that occur over time. We see this distinction as having important implications for the translation of EF research for educational practice.

We suggest that, in addition to the longer time scale of EF/reading associations across intervals of "school" time, it is also important to consider in-the-moment use of EF while students are engaged in reading in real-time. Consider, for example, the experience of a struggling reader in an 8th grade classroom. While engaged in a reading activity, this student must use working memory to retain information about what has been read while also decoding less familiar words, inhibit the prepotent response to skip challenging text, and control attention in the face of frustration with the task at hand. Each of these EF demands may fluctuate; perhaps the first few paragraphs cover content familiar to the student, reducing the working memory demand, but peers at the next table are doing something really interesting, increasing the need for strong attention control. In addition, depending on the length of the activity, the student must be able to persist, which involves not only the EF skills needed for sustaining attention and inhibiting inappropriate responses but also the motivation to do so (Torgrimson et al., 2021), all processes that could fluctuate in the moment or day-to-day.

Recent advances in Ecological Momentary Assessments (EMA), have provided empirical evidence for these types of fluctuation in EF skills. EMA is a measurement approach that gathers repeated assessments in naturalistic settings, and has been used as another tool for assessing EF skills in real-world settings (Moore et al., 2017). For example, Wang, Zhang, Chen, and Chen (2021) recently developed a daily assessment of adolescents' EF use to understand how EF manifests in natural environments. In this study, researchers administered a battery of ambulatory EF assessments to adolescents for 14 consecutive days, finding considerable fluctuation in adolescents' (aged 13–17 years old) EF performance over the course of the study (Wang et al., 2021). The authors also found that daily fluctuations in EF were associated with adolescents' academic and affective outcomes (Wang et al., 2021).

The extent to which dynamic fluctuations in EF relate to reading performance remains largely unexplored, but it is possible that these in-the-moment associations are just as important for reading as longer-term relations with EF. These are also the processes that teachers observe every day, which may represent opportunities for supporting students and helping them practice their EF in authentic activities. In the case of the 8th graders described above, for example, a teacher might set these students up for success by making small changes to the environment to reduce distraction, while also guiding them in the use of strategies to reduce frustration and thus inhibit the default response of avoiding the task at hand. It is perhaps repeated, similar experiences in the classroom that contribute to EF development across the school years.

SUPPORTING EF DEVELOPMENT IN SCHOOL

Natural experiments that allow researchers to estimate the causal effect of schooling on children's outcomes have

revealed that the experience of going to school might promote children's EF development (Brod et al., 2017; Burrage et al., 2008; Kim, Ahmed, & Morrison, 2021; Kim, Bousselot, & Ahmed, 2021; Morrison & Grammer, 2016). Combined, this evidence suggests that the classroom environment can present a key lever for supporting EF development and, in turn, that understanding mechanisms by which experience in school impacts children's EF could have meaningful implications for instruction in classroom settings. Despite evidence for a causal link between school experience and EF development, surprisingly little is known about *how* this happens, either in the moment or across the school years. Two main areas of research have provided insight into the schooling mechanisms that might shape children's EF. The first includes EF training studies, in which the goal is often to improve EF skills over a period of weeks or months using activities targeting the skills of individual children (for review, see Diamond & Ling, 2019). Accumulating evidence from EF training studies indicates that success in directly training EF through discrete, short-term interventions is limited. This might be because most EF training programs are short-lived, decontextualized, and designed in ways that fail to account for the developmental progression of EF.

Consistent with this idea, in a largely separate line of work, researchers have examined the role of educational experiences and instructional strategies in shaping children's EF development. Much of this work has been motivated by research suggesting that children's EF skills at the start of kindergarten are important for academic growth. As a result, much of this research has involved interventions at the level of the preschool classroom environment, with emphasis on helping children develop these skills before they transition to elementary school. These efforts (e.g., the Chicago School Readiness Project [GSRP, Raver et al., 2011]) have produced modest effects on children's EF development through the use of curricula with explicit instruction and activities to support children's EF skills, such as providing greater levels of structure and classroom routines, and providing coaching for teachers' classroom management strategies and stress management (see Mattera, Rojas, Morris, & Bierman, 2021 for review). However, like EF training studies, preschool interventions alone are unlikely to produce sustained benefits to children's EF across development (see Bailey et al., 2020 for commentary on fade-out effects). The insights gleaned from EF training and ECE intervention programs, however, support the idea that longer-term and broader exposure to the continued practice of EF skills in real-world settings, like those made possible through experiences that students have in school through engagement with educators and increasingly challenging academic content, may be necessary for promoting EF skills across development.

EXAMINING THE IMPACT OF CLASSROOM EXPERIENCE ON EF PROCESSES IN REAL-TIME

Missing from the work outlined above is a focus on factors that might contribute to student's use of EF in the moment. To examine the impact of classroom experiences on student EF, we have been developing methods for examining associated cognitive processes in students in the classroom using EEG, demonstrating that it is possible to measure—in real-time—the neural correlates of attention while students are learning in the college and elementary classroom (Grammer, Xu, & Lenartowicz, 2021; Xu, Torgrimson, Torres, Lenartowicz, & Grammer, 2022). By integrating neuroscientific methods to examine attention and distraction in students while they are engaged in learning activities (e.g., independent silent reading, group work, teacher-led instruction), it is possible to examine the moment-to-moment fluctuations in these processes while students are surrounded by teachers and peers. In our initial efforts using this methodology, we have been able to examine the effect of different instructional activities on the neural correlates of college student attention (Grammer et al., 2021), revealing that neural measures of attention differed significantly across different types of instructional activities and attention, such that lower alpha power as well as higher beta and gamma power, were observed during student-initiated activities like peer work than teacher-initiated activities. Notably, EEG measures did not consistently align with behavioral observations, suggesting that the behavioral cues teachers rely on to index student EF skills (e.g., sitting still, looking at the instructor) may not reflect the actual engagement for all students in their classroom.

Like EMA methods, mobile neuroimaging technologies (including EEG) have made it possible to examine cognitive processes while students are engaged in daily academic activities (Janssen et al., 2021). Ultimately we hope that by combining multiple methods to understand the dynamic relations between EF skills and reading with semi-naturalistic and fully naturalistic experiments in which classroom and task factors are manipulated, it will be possible to identify specific instructional practices that can support EF and reading development of individual students.

EDUCATIONAL IMPLICATIONS

The foundation of evidence accumulated over the past two decades has increased awareness of the role of EF in children's reading acquisition. Deep understanding of student learning and development is increasingly seen as foundational for educators (Darling-Hammond, Schachner, Wojcikiewicz, & Flook, 2023). In line with this idea, we see

educators' increased interest in EF skills as a promising step toward identifying strategies for promoting students' EF development in school. This is especially important given the variability in students' learning needs; while poor EF skills can contribute to, or exacerbate, academic difficulties, strong EF skills can support/bolster academic work.

When considering the broader developmental continuum, it is apparent that EF skills do not develop quickly and that this development does not end as children enter elementary school. Instead, EF skills emerge and are continually refined across childhood and into adolescence. With respect to relations between EF skills and academic performance, it is important to consider how students use them in complex environments like the classroom and also how they are deployed in real-time. However, much of what we know about EF development is focused on early childhood, draws on methods that fail to capture the complexities of EF use in authentic environments, and does not explore how students use these skills in the moment. So, while we have learned a great deal about EF skills, we have been limited in our ability to make evidence-based recommendations to educators regarding practices that contribute to students' growth.

Continued research involving novel approaches for EF measurement, including those described here, with students from pre-k through high school is a necessary step toward increasing the relevance of this work for educational practice. For example, incorporating group assessments that provide insight into EF when students are engaged in activities with peers (Ahmed, Grammer, & Morrison, 2021; Ahmed, Kuhfeld, et al., 2021) can contribute to educator's understanding of the important role that peers play in supporting (or undermining) student EF, which in turn could inform intentional decisions regarding the organization of classroom activities and student groups. Leveraging multiple methods—including EEG and eye tracking—that can be used in classroom settings to understand changes in EF processes in real-time would help educators understand the connection between covert cognitive processes that support EF and student behavior at different developmental stages. Using EMA methods—particularly with middle and high school students—could provide important insights for educators regarding the types of experiences that are optimal for supporting student EF, while also bringing to light metacognitive insights for the students themselves.

Finally, the roadblocks we have outlined are informed by what we have learned by stepping out of the lab and talking with teachers about student EF and observing in classrooms. However, most of the published studies on children's EF include in their justification the relevance of EF for educational outcomes—despite the research reported being far removed from real-world skills or questions of direct interest or relevance to educators. This work will be significantly strengthened if it is rooted in questions that emerge from practice and informed by the perspectives of those who work with students.

CONCLUSION

Understanding the development of EF, and the ways in which school experiences shape this growth, are essential first steps in identifying evidence-based strategies that educators can use to support development of their students. If our goal is to generate evidence that can be applied to the diverse needs of learners, a comprehensive, multi-method developmental science approach to the study of EF is needed. The emergence of new methods and approaches to the study of EF as an exciting step toward this end.

CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

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