At the Crossroads of Education and Developmental Neuroscience: Perspectives on Executive Function

by C. Cybele Raver and Clancy Blair

Recently, educational policies at both the U.S. federal and state levels have undertaken major initiatives based on new findings in the field of “brain science and early learning,” with the promise that advances in cognitive neuroscience have the potential to improve children’s chances of academic success. What, exactly, are these new advances, and how do they relate to children’s acquisition of key academic skills such as reading and math? In the following article, we briefly outline an important area of developmental scientific inquiry focusing on children’s higher-order cognitive skills, called “executive function” or EF, for short. We highlight the ways that these cognitive skills play a key role in young children’s day-to-day experiences in classroom contexts, facilitating both their social and academic opportunities. We then briefly provide a thumbnail sketch of EF across developmental epochs, illustrating the role of EF as children transition from early childhood through elementary to middle school contexts. Finally, we briefly discuss ways that EF can be supported through home- and classroom-based interventions and programs, with significant implications for children’s opportunities for learning across multiple educational settings. In so doing, we aim to provide educators, health-care providers, and parents with a simplified roadmap of this new area of scientific inquiry, alerting readers to new opportunities afforded by innovative programs and policies supporting children’s development of EF.

Executive Functions: What Do Scientists Mean By It and Why Is It So Important to Learning?

When teachers watch children working or playing together in the classroom, they undoubtedly notice a wide array of skills and talents that are important for early learning, including children’s inquisitiveness, their engagement with new information such as new words or concepts, and their ability to remember and talk about that new information. When we as developmental scientists watch those same children, we see those many skills connected and coordinated into a coherent system, like a trio of concert orchestra members playing three different instruments to form a single, highly organized musical composition. That connected system involves a) children’s attention, b) children’s working memory, and c) children’s ability to inhibit a dominant (or most quickly reactive) response in favor of a more reflective response. How are those three components organized or connected? An example might best illustrate: Imagine the moment when a teacher introduces new information about tree frogs in a science unit. A kindergartner in her classroom must orient her attention to the details that are being shared (did that teacher just say “sticky toes?”), must be able to hold that information in working memory, and then must be able to inhibit a set of impulses (such as calling out) in order to raise her hand to share what she knows or to learn more. Increasingly, findings in the field of developmental neuroscience suggest that multiple, interconnected areas of the brain are responsible for those three domains of cognitive function; moreover, those three domains of cognitive function work together to facilitate learning and remembering new information. That is, learning is possible when these “executive” components of higher-order cognitive function allow the student to reflect rather than react to that moment and the other many moments like it in classroom settings.

Advances in both clinical and neuroscientific research have provided new tools that help us to understand EF at both behavioral and physiological levels. In research settings such as ours, children’s EF is measured by assessing their performance on a set of games or tasks to tap attention, set-shifting, working memory, and inhibitory control (e.g., Blair, Zelazo, & Greenberg, 2005; Davidson, Amso, Anderson, & Diamond, 2006; Diamond & Taylor, 1996; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Wiebe, Espy, & Charak, 2008). This area of research has provided robust evidence of ways that children’s performance on these neuropsychological tasks is related to the prefrontal and parietal cortex function and connectivity using a wide array of neuroimaging methods (e.g., Jolles, Kleibeuker, Rombouts, & Crone, 2011; Zelazo & Müller, 2010). In addition, researchers in the fields of clinical psychology and psychiatry have considered the ways that children’s EF can be characterized in terms of supporting or interfering with everyday functioning at home, in school, or in other settings. That is, teachers and parents are asked to report on children’s strengths and difficulties in modulating their attention, planning, memory of rules and directions, and inhibition of their impulses through empirically validated questionnaires such as the Brief Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000; Gioia, Isquith, & Armengol, 2000) and the Barratt Impulsivity Scale (BIS-11; Patton, Stanford, & Barratt, 1995). These tools provide an empirical “snapshot” that is informative for educational policy, helping us to widen our attention to include children’s cognitive self-regulation as an important target of educational investments and reforms.

In addition, advances in developmental science have also underscored the importance of emotions for learning; Children must recruit additional areas of the brain responsible for emotional arousal to capitalize on the instruction provided in classroom settings. Specifically, children must modulate their arousal so that they are sufficiently excited and “tuned in” to learn and remember the information being shared, without becoming so over-excited that they have trouble staying organized or focused. Teachers also recognize and value these “socio-emotional” or “soft” skills that children bring to the classroom, noting ways that children’s modulation of behaviors and emotions such as impulsivity, frustration, boredom, or anxiety are key to their ability to learn. Research in our lab and in

Continued on page 28
others have underscored the ways that these emotional self-regulatory skills work in concert with children’s EF, where emotional arousal can alternately support or erode children’s attention, working memory, and inhibitory control. In the example provided earlier, we can easily imagine another student in the classroom who is on the verge of sharing what she knows about the adhesive properties of tree frogs’ feet when her anxiety about speaking in front of a group suddenly kicks in and her mind draws a blank. New findings in neuroscience help us to understand that children's modulation of emotional arousal is not peripheral to learning, but actually serves as an important foundation for the acquisition, encoding, and retrieval of new information (Ramirez, Gunderson, Levine, & Beilock, 2013).

What evidence do we have to support this framework? A growing body of research has demonstrated that children’s EF (along with their skills in modulating emotion) are central to school readiness in early childhood (Blair & Razza, 2007; Carlson, Mandell, & Williams, 2004; Hughes & Ensor, 2007; McClelland et al., 2007; Raver et al., 2009, 2011). For example, Blair and colleagues have found in two different studies that children’s EF predicts their performance in math across the early school years, even after taking into account children’s general cognitive abilities (i.e., IQ: Blair & Razza, 2007; Blair et al., revised and resubmitted). The results of our studies are consistent with research findings from other research teams that have found that EF, as well as impulse control and low levels of negative emotionality, are predictive of superior academic achievement over the early elementary years. Several studies demonstrating the relation of these self-regulatory skills to later achievement are particularly impressive given that they have taken into account (or statistically controlled for) early measures of children’s achievement (e.g., McClelland et al., 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010).

Our work as well as the work of others has demonstrated that those same three components of EF (including children’s ability to modulate their attention, to use planning and organization skills indicative of inhibitory control, along with higher levels of working memory) continue to be important for opportunities for learning in later elementary and middle school (Friedman-Krauss & Raver, 2014; Raver et al., 2012). In adolescence, a number of researchers in clinical psychology and psychiatry as well as developmental psychology have hypothesized that EF (including difficulties with planning, working memory, and inhibitory control) may place some students at greater risk for cigarette smoking, alcohol, and other substance-use problems than others, suggesting that EF has an important role for adolescent health as well as academic outcomes (Miller, Barnes, & Beaver, 2011; Somerville, Jones, & Casey, 2010; Zucker, Heitzeg, & Nigg, 2011; Buckner, Mezzacappa, & Beardslee, 2003).

Can EF Be Shaped By the Environment?

Given its importance, the next logical question is whether EF is malleable to environmental input or influence. That is, can it be shaped by social contexts such as neighborhood and family poverty, by parents’ and teachers’ practices, and by educational programs or policies? Evidence from many different types of research suggests that the answer is “yes.”

Based on neurobiological models of development, our work over the past several years has focused on ways that exposure to high levels of adversity associated with income poverty can place children’s optimal development of EF and emotion regulation in jeopardy (see Blair & Raver, 2012, for review). Our findings are consistent with research by other developmental and neuroscientific teams suggesting that lower SES is clearly associated with children’s greater difficulty with EF tasks (see as examples, Noble, Norman, & Farah, 2005; Noble, McCandliss, & Farah, 2007; Raizada & Kishiyama, 2010). Drawing on past research on the link between trauma exposure, brain function, and risk of later symptomatology, it is clear that highly stressful environmental conditions have negative consequences for the neurobiological system underlying EF (see Bryck & Fisher, 2012, for review). We and others have made the case that less acutely traumatic but longer-term (or chronic) stressors associated with poverty (such as living in less stable households in unsafe neighborhoods) also take a toll on children’s physiological stress response systems important for the development of EF. Our longitudinal research across two different samples of children living in low-income families across periods of harsh economic recession has supported this model, offering a plausible mechanism for ways that poverty affects children’s prospects for success in school (Blair et al., 2011a; Sheridan, How, Araujo, Schamburg, & Nelson, 2013; Mezzacappa, 2004). For example, we have found that income poverty, the psychological distress associated with chronic financial strain, and household instability have each been associated with significant compromise in children’s inhibitory control and other executive functions in early childhood (Blair et al., 2011b; McCoy & Raver, 2013; Raver et al., 2012). As children from low income families grow older, we have found that they continue to be at significant risk of facing a high number of poverty-related stressors and of facing correspondingly higher risk of difficulties with attention, working memory, and inhibitory control over time. For example, we have found that unsafe schools and residential mobility are both clearly associated with substantial decrements in children’s EF, even after controlling for other factors (Raver, Blair, Willoughby, & the FLP Investigators, 2013; Roy, McCoy & Raver, 2013).

Central to our program of research has been the equally important question of whether positive aspects of children’s environments can shape EF for the better. Observational studies of child development have long suggested the important role that parents play in shaping children’s higher-order cognitive skills such as their ability to shift and maintain attention and their inhibitory control (see, e.g., Bernier, Carlson, & Whipple, 2010). Experimental research in field-based contexts has provided robust affirmation of this causal claim. In a recent intervention study with low-income families, for example, training parents to support children’s attention and emotion-regulation...
(along with direct child training) led to substantial gains (across both neurological and behavioral measures) in preschoolers’ executive attention skills (Neville et al., 2013).

Investments can be made in classrooms as well as at home: In one of our preschool-based intervention studies, for example, we trained teachers to provide support for children’s regulation across the school day, using an adapted version of Webster-Stratton’s Incredible Years approach. We found that children in the treatment group made substantial short-term academic strides relative to their control-group-assigned counterparts, and that those school readiness gains were due at least in part to improvements in the children’s EF (Raver et al., 2012). Additional studies in our research laboratory and in laboratories run by many of our colleagues continue to support those findings, with benefits found for children’s attention and inhibitory control across other rural as well as urban metropolitan settings and older age groups (Biener, Nix, Greenberg, Blair, & Domitrovich, 2008; Diamond, Barnett, Thomas, & Munro, 2007; Morris, Millenky, Raver, & Jones, 2013; Pokhrel et al., 2013). Similarly impressive results have been found in studies that combine parent- and teacher-training (see work by Brotman and colleagues, in press) and in programs that expand children’s access to high-quality prekindergarten throughout a given school district (Weiland & Yoshikawa, 2013). That is, we and other researchers find ample evidence of the ways that children reap cognitive benefits when families and teachers take steps to support their development. As these empirical examples illustrate, investments in both homes and classrooms (with parents as well as with teachers) clearly support substantial gains in children’s EF across multiple types of programs and interventions (see Diamond & Lee, 2011 for review). For these reasons, we view the inclusion of EF in proposed measures of innovative school and educational reform as a promising new direction for educational research and policy.

It is imperative as we consider the question of environmental “repair” to consider the potential benefits to children’s neurocognitive function and emotional control by reducing their exposure to poverty itself. One data set (called the Family Life Project) allows us to begin to answer this question by following a large number of families since the child’s birth. Those analyses suggest that children’s EF looks markedly better when their families transitioned out of poverty and into better financial circumstances over time, as compared to other children whose families continued to struggle below the poverty line, even though both groups of children and their families looked very similar at the study’s outset (Blair et al., 2011b; Raver et al., 2013). Past research on the impact of anti-poverty programs for children leads us to view this new area of research as having high scientific potential. Past research that has considered both policy experiments and “natural experiments” where families experience a significant financial windfall have found significant improvements in child academic achievement as well as lowered risk of mental illness (Duncan, Morris, & Rodrigues, 2011). For example, in the Great Smoky Mountains study where poor families received a $6,000 cash transfer (associated with the opening of a casino in their community), their children’s odds of developing behavioral problems were subsequently dramatically reduced (Costello, Compton, Keeler, & Angold, 2003). Although there have been several innovative social policy experiments to test the impact of reducing families’ poverty through transfers of income over the past 50 years, we do not know of any income transfer studies that have specifically included measurement of children’s EF as a proposed mediator or outcome. We view this question (that is, a test of whether experimentally reducing families’ experiences of financial hardship substantially improves children’s EF and emotion regulation) as vitally important for understanding ways to support educational success among our nation’s most vulnerable children. We look forward to working out the answers to this and other pressing questions at the intersection of neuroscience and education in the years ahead.

References


Continued on page 30


C. Cybele Raver and Clancy Blair examine the mechanisms that support children’s self-regulation in the contexts of poverty and social policy. As professors in New York University’s Department of Applied Psychology, Raver and Blair conduct several federally-funded longitudinal studies of children’s executive function, emotion regulation, and attention as well as RCT interventions designed to support low-income children’s chances of early school success.

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