WHY IMPROVING AND ASSESSING EXECUTIVE FUNCTIONS EARLY IN LIFE IS CRITICAL

ADELE DIAMOND

To be successful in school or in one's career takes creativity, flexibility, self-control, and discipline. Central to all those are executive functions (EFs), including mentally playing with ideas, giving a considered response rather than an impulsive one, and being able to change course or perspectives as needed, resist temptations, and stay focused. These are core skills critical for cognitive, social, and psychological development, success in school and in life, and mental and physical health. They begin to emerge early (even during infancy) but are not fully mature until young adulthood, although EFs in early childhood are highly predictive of EF skills later in life. EFs are very sensitive to environmental factors (including negative ones such as poverty and positive ones such as sensitive parenting). Accumulating evidence indicates that several different approaches can successfully improve EFs and that improving them early in life may be absolutely critical for an individual's happiness and success throughout life and for reducing social disparities in
achievement and health. Whether an approach produces sustained benefits to EFs can be determined only by assessing EFs over time using the same or comparable measures. Hence longitudinal assessment tools for the early years of life become critical to the goal of finding what works. I delve into each of these points briefly in this chapter and invite you to read the other chapters in this volume where these points are elaborated in greater depth.

EXECUTIVE FUNCTIONS DEFINED

I refer to EFs in the plural because the term refers to a family of skills, not just one skill. These skills are needed when you have to concentrate and think, when going on automatic or acting on your initial impulse might be ill-advised. In the title to this volume and in some of the other chapters within, the singular term executive function is used. These skills depend on a neural circuit in which prefrontal cortex plays a pivotal role (Aron, Behrens, Smith, Frank, & Poldrack, 2007; Braver, Cohen, & Barch, 2002; Eisenberg & Berman, 2010; Leh, Petrides, & Strafella, 2010; Zanto, Rubens, Thangavel, & Gazzaley, 2011).

Working Memory and Inhibitory Control

One core component of EFs is working memory (holding information in mind and working with it). Working memory is critical for making sense of anything that unfolds over time, for that always involves relating what came earlier to what came later. Understanding written or spoken language requires this because as you focus on the next phrase, the previous one is no longer present or you are no longer looking at it. Doing any math in your head requires this, as does reasoning, because it involves holding bits of information in mind and seeing how they relate. As Nelson et al. note in Chapter 3 of this volume, the ability to hold information in mind develops very early and even extremely young children can hold one or two things in mind for quite a long time. Indeed, infants of only 9 to 12 months can update the contents of their working memory, as seen on tasks such as A-not-B (Diamond, 1985; see also Chapter 7, this volume). However, being able to hold many things in mind or do any kind of mental manipulation (e.g., reordering mental representations of objects in order of size) is far slower to develop and shows a prolonged developmental progression (Bachevalier, 1990; Barrouillet, Gavens, Vergauwe, Gaillard, & Camos, 2009; Cowan, Saults, & Elliott, 2002; Luciana, Conklin, Hooper, & Yarger, 2005; Schleepen & Jonkman, 2009).

Holding a piece of information in mind for some seconds could just as correctly be described as keeping your attention focused on a piece of information for some seconds. Indeed, the distinction between these aspects of
memory and attention appears to be arbitrary. They are similar in many ways including in their neural bases. The same prefrontal system that enables you to selectively remain focused on the information you want to hold in mind also helps you selectively attend to stimuli in your environment, tuning out irrelevant stimuli. Hence it is virtually impossible to try to hold something in mind that is at odds with what you are trying to keep your attention focused on in the environment (Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006; Gazzaley, 2011; Gazzaley & Nobre, 2012; Zanto et al., 2011).

The other core EF skill is inhibitory control, which is more heterogeneous than working memory. It includes inhibition of attention (selective or focused attention), which is often referred to as interference control and involves inhibiting (or suppressing) attention to other things in the environment (distracters) so you can stay focused on what you want. Inhibitory control also includes inhibition of action (motor responses, including verbal ones), which includes several subtypes. Most of the subtypes are aspects of self-control: (a) inhibiting the impulse to respond or react immediately—making yourself wait or giving yourself time to give a wiser, more considered response (e.g., not sending off a blistering email, but waiting until you are calmer; giving yourself time to acquire more information before jumping to a conclusion); (b) delaying gratification—making yourself wait, forgoing an immediate pleasure for a greater reward later (often termed delay discounting by neuroscientists and learning theorists; Louie & Glimcher, 2010; Rachlin, Raineri, & Cross, 1991); (c) inhibiting your first inclination and substituting a more appropriate response (e.g., not butting in line but going to the end of the line, not blurting out something that could offend but saying something more considerate instead, or not giving the more natural response to a stimulus when instructed to give a different response instead); (d) holding up on making a response that had almost reached response threshold (e.g., a batter checking his or her swing); (e) resisting temptations (e.g., temptations such as eating foods that are not good for you, overindulging, trying forbidden substances, or taking something you are addicted to). The other subtypes of inhibitory control are aspects of discipline: (f) staying on task, including (f.1) finishing one’s work though it might be tedious or difficult, inhibiting temptations to do something more fun, and (f.2) sustaining your attention on something for several long minutes despite distractions even if the task seems boring and pointless.

You are in good company if you think (a) and (c)—or (b), (e), and (f)—are so related as to perhaps be the same thing, or if you think the above list is so long and diverse that a single construct (inhibitory control) does not do justice to the heterogeneity or that surely the neural basis for all of these aspects of inhibitory control (e.g., inhibition at the level of attention or action, or inhibition when motivation is high [hot situations] and inhibition when motivation
is minimal [cool situations]) could not possibly be the same (Dempster, 1993; Harnishfeger, 1995; Kerr & Zelazo, 2004; Nigg, 2000). Those are among the many debates concerning EFs. It is interesting that some confirmatory factor analyses find that inhibition of attention (resistance to distractor interference) and inhibition of action (inhibiting a prepotent response) are highly related and form a single factor (Friedman & Miyake, 2004). Moreover, when required to exert one type of self-control (e.g., resisting sweets) and then required immediately after to exert a second type of self-control (e.g., the Stop-Signal task), people are consistently found to be more impaired on the second task than if they did a different difficult task first that did not require self-control (e.g., math calculations; Muraven & Baumeister, 2000). One group reports that all the diverse types of self-control appear to rely on substantially similar neural bases (Cohen, Berkman, & Lieberman, 2013). However, many studies have found that interference control (inhibiting extraneous thoughts or inhibiting attention to environmental distraction) is much more strongly linked to working memory than to other forms of inhibitory control (e.g., response inhibition). In particular, selective attention and working memory appear to be very tightly linked (see above as well as Awh & Jonides, 2001; Gazzaley, 2011). Working memory and inhibition are highly interrelated. A situation might place a higher demand on one than the other, and two conditions of a task might differ more in their working memory demands or their inhibitory demands, but rarely if ever are either of these exercised in the absence of the other. How can you know what to inhibit unless you maintain your goal in working memory? How can you stay focused on the relevant information in working memory if you do not inhibit (suppress) environmental distractions and mental distractions, such as irrelevant thoughts?

Different theories of EFs postulate inhibitory control (Barkley, 2001), working memory (Cepeda & Munakata, 2007; Cohen, Dunbar, & McClelland, 1990; Morton & Munakata, 2002; Pennington, 1994), or attention (Garon, Bryson, & Smith, 2008; Rothbart & Posner, 2001) as primary. As Nelson et al. outline in Chapter 3 (this volume), early in development, working memory and inhibitory control appear to be relatively undifferentiated behaviorally, consistent with intellectual skills developing from a relatively unified, general ability in childhood to more differentiated, specific cognitive abilities with age (Garrett, 1946; Werner, 1957). There was already evidence that this characterized the development of working memory and inhibition from 4 to 14 years of age (e.g., Shing, Lindenberger, Diamond, Li, & Davidson, 2010). Willoughby and Blair (Willoughby, Blair, Wirth, & Greenberg, 2010; see also Chapter 4, this volume) and Espy and colleagues (Wiebe et al., 2011; see also Chapter 3, this volume) provided evidence that, consistent with this relative nondifferentiation early in development, working memory and inhibitory control fall along a single factor in children 3 to 5 years of age. It
has also been known for some time that progressive differentiation occurs at the neural level from childhood to adolescence, with first many brain regions being recruited to exercise EFs followed by progressive fine-tuning of neural activation to prefrontal cortex and other members of the EF neural network (Durston et al., 2006). In Chapter 7 of this volume, Bell and Cuevas present new data showing that this progressive fine-tuning of neural activation also characterizes changes from infancy to the preschool period.

More Advanced Executive Functions

To shift mental sets or see something from different perspectives, you need to activate and maintain a new set or perspective in working memory and you need to inhibit the set or perspective that was just being used. Thus cognitive flexibility (also called set shifting) the third core EF, builds upon and requires working memory and inhibitory control (Diamond, 2010; Morasch, Raj, & Bell, 2013; see Figure 1.1). Whereas factor analyses of EFs in adults routinely come up with three factors (working memory, inhibitory control, and cognitive flexibility; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000), factor analyses with children are more likely to find only two factors (working memory and inhibitory control; Hughes, Ensor, Wilson, & Graham, 2009; St Clair-Thompson & Gathercole, 2006; Wiebe et al., 2011). Not surprisingly, cognitive flexibility emerges later than working memory or inhibitory control (Cepeda, Kramer, & Gonzalez de Sather, 2001; Davidson, Amso, Anderson, & Diamond, 2006; Garon et al., 2008). Being able to flexibly switch between two rules or two ways of sorting cards on a trial-by-trial basis is utterly beyond the ability of most preschoolers, and before they are 2.5 or 3 years old there is little or no evidence that children can make a switch between blocks of trials (using one rule for all trials in one block, and a different rule for all trials in the next block; Marcovitch & Zelazo, 2009). Still more advanced EFs that build upon working memory, inhibitory control, and cognitive flexibility include reasoning, problem solving, and planning (Collins & Koechlin, 2012; Daniels, Toth, & Jacoby, 2006; Niendam et al., 2012).

DIFFERENCES AND SIMILARITIES BETWEEN EXECUTIVE FUNCTIONS AND RELATED TERMS

Self-regulation refers to processes that enable people to maintain optimal levels of emotional, motivational, and cognitive arousal (Liew, 2011). Eisenberg, Hofer, and Vaughan (2007) define emotion-related self-regulation as “processes used to manage and change if, when, and how (e.g., how intensely) one experiences emotions and emotion-related motivation and physiological states, as well as how emotions are expressed behaviorally”
EXECUTIVE FUNCTIONS

Working Memory
- Including mental math, re-ordering items, or relating one idea or fact to another.
- Maintaining your goal, or what you should & shouldn't do, in working memory is critical for knowing what to inhibit.
- Inhibiting environmental & internal distractions is critical for staying focused on the working memory contents of interest.

Inhibitory Control
- Interference Control
  - Inhibition of thoughts & memories (Cognitive Inhibition)
  - Inhibition at the level of attention (Selective or Focused Attention)
- Response Inhibition
  - Inhibition at the level of behavior (Self-Control & Discipline)

Self-Regulation

Cognitive Flexibility
- Including being able to "think outside the box," see something from many different perspectives, quickly switch between tasks, or flexibly switch course when needed.
- Supports creativity and theory of mind.

Higher Level Executive Functions
- Reasoning
- Problem Solving
- Planning

Fluid Intelligence is completely synonymous with these.

While conceptually Interference Control would seem to belong under Inhibitory Control, empirically much evidence points to it being part of Working Memory, whether one looks at factor analyses of behavioral performance or the underlying neural bases. Note that Engle and Kane's definition of working memory has always included interference control within it (Engle & Kane, 2004).

Self-Regulation includes (a) response inhibition, (b) attention inhibition, and also (c) maintaining optimal levels of emotional, motivational, and cognitive arousal.

Figure 1.1. The components that together comprise executive functions (EFs) and the relation of executive functions to other related concepts. The two primary EFs are working memory and inhibitory control. Those together make cognitive flexibility possible. From those three core EFs, the higher order EFs of reasoning, problem solving, and planning are built.
These processes include effortfully "managing the perception of stimuli and manipulating cognitions and behavior associated with emotion, generally in the service of biological or social adaptation and/or accomplishing goals" (Eisenberg & Zhou, Chapter 5, this volume, p. 118).

Self-regulation does not include a working memory component (unlike EFs), but it overlaps substantially with the inhibitory control component of EFs (see Figure 1.1). Self-regulation refers primarily to control and regulation of one's emotions (Eisenberg, Spinrad, & Eggum, 2010; Mischel & Ayduk, 2002; Raver, 2004; Rothbart & Jones, 1998). EF researchers have historically focused more on the control of thoughts, attention, and actions; only recently have they included control of one's emotions. Whereas EF researchers have addressed emotions only as troublesome things to be inhibited, self-regulation also embraces the importance of motivation and interest as emotional responses that can be critical to the achievement of one's goals (Blair & Diamond, 2008). Historically, self-regulation has been assessed through (a) adult ratings of children's behavior, observed over the course of time in real-world settings such as home or school, and (b) observation of children's behavior when they have to delay gratification in an emotionally laden, hot situation (Mischel, Shoda, & Rodriguez, 1989) or in a frustrating situation (Kochanska, Philibert, & Barry, 2009). Historically, EFs have been assessed directly from children's performance on arbitrary laboratory-based tests far removed from the real world in fairly emotionally neutral, cool situations. Finally, EF researchers have historically focused on the brain bases for component EFs, whereas self-regulation researchers have focused more on the peripheral, autonomic nervous system, using measures such as heart rate variability or respiratory sinus arrhythmia as indices of parasympathetic nervous system activity (Porges, Doussard-Roosevelt, & Maiti, 1994). For a more thorough discussion of what self-regulation is and how it compares to EFs, see Chapter 5, this volume.

Effortful control (Rothbart & Bates, 2006) refers to an aspect of temperament, a largely innate predisposition, which involves a tendency to exercise self-regulation with ease (e.g., easily able to slow down or lower one's voice), perhaps even being too regulated (lacking in spontaneity) versus finding regulation harder or less natural. It is usually measured by parental report (Goldsmith, 1996; Rothbart, Ahadi, Hershey, & Fisher, 2001).

Executive attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Posner & DiGirolamo, 1998; Rueda, Posner, & Rothbart, 2005) refers to the top-down regulation of attention as opposed to alerting (maintaining a state of high readiness to attend to potential stimuli) or orienting (exogenous attention—being pulled by a stimulus to attend to it). As the name and definition imply, it sounds synonymous with inhibitory control of attention. Indeed, it is usually assessed using measures of selective attention such as the flanker task (Fan et al., 2002; Rueda et al., 2005). Much confusion has been engendered by the overly broad use of the term executive attention to apply
to such skills as working memory capacity (Engle, 2002; Erickson, 2008) and response inhibition, which is also known as the resolution of response conflict (e.g., whether to press on the left or right on a Simon-type task; Gerardi-Caulcton, 2000; Jones, Rothbart, & Posner, 2003).

Fluid intelligence is the ability to reason, problem solve, and see patterns or relations among items (Cattell, 1963). It is synonymous with the reasoning and problem-solving subcomponents of EFs. No surprise then that measures of fluid intelligence (e.g., Raven's Matrices; Raven, Raven, & Court, 2004) are very highly correlated with independent measures of EFs (Boone, 1999; Conway, Kane, & Engle, 2003; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Duncan et al., 2008; Engle, Tuholski, Laughlin, & Conway, 1999; Roca et al., 2010).

Working memory is often referred to as a subcomponent of EFs, although many working-memory researchers use the term working memory more broadly. For example, Kane and Engle define working memory as the ability to (a) maintain selected information in an active, easily retrievable state while (b) inhibiting (blocking) distracters or interference, such as from other information that might otherwise enter that active state (i.e., memory maintenance + interference control, which seems consistent with the close empirical tie between these two skills; Conway & Engle, 1994; Kane & Engle, 2000, 2002). Hasher and Zacks (1988; Zacks & Hasher, 2006) also insert interference control components into their definition of working memory: (a) gating out irrelevant information from the working-memory workspace and (b) deleting no-longer-relevant information from that limited-capacity workspace. Functions of the central executive in Baddeley's working-memory model (Baddeley, 1992; Baddeley & Hitch, 1994) include inhibitory control and cognitive flexibility: (a) multitasking, (b) shifting between tasks or retrieval strategies, and (c) the capacity to attend and inhibit in a selective manner. Working-memory researchers often use complex span tasks (also called working memory span tasks; Bailey, Dunlosky, & Kane, 2008; Barrouillet et al., 2009; Chein & Morrison, 2010; Conway et al., 2005; Pardo-Vázquez & Fernández-Rey, 2008; Unsworth, Redick, Heitz, Broadway, & Engle, 2009) to study what they call working memory but what EF researchers would call EFs (because these tasks require more subcomponents of EFs than just holding information in mind and manipulating it). It would probably cause less confusion if they were called EF tasks.

**EVIDENCE OF THE IMPORTANCE OF EFs**

EFs are critical for success in school. EF skills have been repeatedly found to be more important for school readiness than IQ or entry-level reading or math (e.g., Blair, 2002, 2003; Blair & Razza, 2007; Normandeau & Guay,
EFs continue to be critical for school success from preschool through university, even controlling for initial achievement levels and IQ. Working memory and inhibitory control each independently predict both math and reading competence throughout the school years, and often do so much better than IQ (e.g., Alloway & Alloway, 2010; Borella, Carretti, & Pelegrina, 2010; Duckworth & Seligman, 2005; Duncan et al., 2007; Gathercole, Pickering, Knight, & Stegmann, 2004; see also Chapter 10, this volume).

EFs are also critical for job success. Poor EFs lead to poor productivity and difficulty finding and keeping a job (Bailey, 2007). EFs are important for marital harmony because people with poor EFs are more difficult to get along with, less dependable, and more likely to act on impulse (Eakin et al., 2004). Poor EFs can lead to social problems such as aggression, emotional outbursts, and crime (Broidy et al., 2003; Denson, Pedersen, Friese, Hahm, & Roberts, 2011; Moffitt et al., 2011; Saarni, 1999; Winstok, 2009). EFs are impaired in many mental health disorders (such as addictions, attention-deficit/hyperactivity disorder, obsessive-compulsive disorder, depression, conduct disorder, and schizophrenia; Baler & Volkow, 2006; Barch, 2005; Diamond, 2005; Lui & Tannock, 2007; Miller, Barnes, & Beaver, 2011; Penadés et al., 2007; Taylor Tavares et al., 2007; Verdejo-García, Bechara, Recknor, & Pérez-García, 2006). Such disorders are increasing at alarming rates (Moffitt et al., Robison, Sclar, Skaer, & Galin, 1999) and account for more lost years of life and productivity than any other illness including cancer (Prince et al., 2007). Not surprisingly, given all of these findings, poorer EFs are associated with a poorer quality of life (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010; Moffitt, 2012).

In general, these associations are particularly true for the inhibitory control component of EFs. For example, Moffitt et al. (2011) found that children, who at ages 3 through 11 had worse inhibitory control (were less persistent, more impulsive, and had poorer selective attention), as adults 30 years later had worse health (were more likely to be overweight and have substance abuse problems), earned less, committed more crimes, and were less happy than those with better inhibitory control as children, controlling for IQ, gender, social class, and their home lives and family circumstances growing up. This finding is based on a sample of 1,000 children born in the same city in the same year followed for 32 years with a 96% retention rate.

Inhibitory control is also disproportionately difficult for young children. For example, the difference in both speed and accuracy of children at all ages from 4 through 9 for always responding on the same side as a stimulus versus inhibiting that impulse and always responding on the side opposite a stimulus is greater than the difference in either their speed or accuracy for holding two associations in mind versus six (Davidson et al., 2006). This is true whether or not the same-side trials come before or after the opposite-side ones (Wright & Diamond, 2014).
far harder to hold six associations in mind than two but it is no harder to always respond on the side opposite a stimulus than to always respond on the same side as a stimulus (adults’ speed and accuracy for each are equivalent; Davidson et al., 2006; Lu & Proctor, 1995). Preschool and early elementary school programs that target EFs have thus wisely focused on improving inhibitory control (focused attention, self-control, and discipline; Bodrova & Leong, 2007; Kusche & Greenberg, 1994; Raver et al., 2008; Webster-Stratton & Reid, 2004). Inhibitory control is by no means fully mature by age 9; indeed, it continues to improve throughout adolescence (Bedard et al., 2002; Christakou, Brammer, & Rubia, 2011; Klein, Foerster, Hartnegg, & Fischer, 2005; Leon-Carrion, García-Orza, & Pérez-Santamaría, 2004; Luna, 2009; Olson et al., 2009; Rubia, Smith, Taylor, & Brammer, 2007; Steinberg et al., 2009).

**BENEFITS OF EARLY IMPROVEMENTS OF EFs**

EFs can be improved. That is true throughout life from infancy through old age (Bryck & Fisher, 2012; Diamond & Lee, 2011; Greenberg & Harris, 2012; Klingberg, 2010; Kovács & Mehler, 2009; Morrison & Chein, 2011; Muraven, 2010; Wass, Porayska-Pomsta, & Johnson, 2011). Why bother to try to improve EFs early if (a) those with poorer EFs might just be slower maturers and might catch up and (b) EFs can be improved later if the children do not catch up on their own? The early gap between those with better and worse EFs often does not disappear on its own but can grow larger over time (O’Shaughnessy, Lane, Gresham, & Beebe-Frankenberger, 2003; Riggs, Blair, & Greenberg, 2004) and EF problems (especially inhibitory control problems) in early childhood predict EF problems years later (Eigsti et al., 2006; Friedman et al., 2007; Moffitt et al., 2011; Shoda, Mischel, & Peake, 1990). Similarly, children’s school readiness (which depends heavily on children’s EFs) strongly predicts academic performance years later in middle school through college (Entwisle, Alexander, & Olson, 2005; McClelland, Acock, Piccinin, Rhea, & Stallings, 2013; O’Shaughnessy et al., 2003; Petit, Courtney, Maisog, Ungerleider, & Haxby, 1997; see also Chapter 12, this volume).

Prefrontal cortex is not fully mature until early adulthood (one’s mid-20s; Gogtay et al., 2004; Paus et al., 1999). Some people have asked, therefore, “Isn’t it nonsense to try to improve EFs in preschoolers? There isn’t enough of a biological substrate to work with; wait until prefrontal cortex is more mature.” In response, I think it is helpful to consider an analogy. Certainly toddlers’ legs are not at their full adult extent, and they probably will not be for another 15 years or so, but with those immature legs toddlers can walk and even run. That is to say that even though the prefrontal cortex is immature, it...
is able to subserve EFs to some extent (not at the full adult level, but to some extent) and with training and practice, that immature prefrontal cortex can probably subserve EFs at a higher level of proficiency.

Being able to improve EFs early in a child's life may be absolutely critical because it affects the trajectory (the negative or positive feedback loop) on which a child gets launched. Children who start school with relatively poor inhibitory control tend to blurt out the answer, jump out of their seats, take things from other children, and have difficulty paying attention and completing their assignments. They are always getting scolded and get poor grades. Teachers come to expect poor performance from them and the children come to expect the same from themselves. A downward spiral of self-doubt, low expectations, and not wanting to be in school begins. Contrast that with the self-reinforcing positive feedback loop that develops when children start off with better EFs. They are able to pay attention, complete their assignments, and not misbehave. They are often praised, get good grades, and enjoy school. Teachers come to expect them to succeed and the children come to expect the same. Improving EF skills early gets children started on a trajectory for success. Conversely, letting children start school behind on EF skills is letting them get started on a negative trajectory that can be extremely difficult and expensive to reverse. It can be astonishingly difficult to change self-perceptions, self-expectations, and the expectations of others and of an institution for you once those have been formed.

The need to intervene early is probably particularly critical for children at risk because of social or economic disadvantage. They enter school with poorer EFs (Evans & Rosenbaum, 2008; Evans & Schamberg, 2009; Hackman & Farah, 2009; Lengua, Honorado, & Bush, 2007; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Raizada & Kishiyama, 2010; Sektnan, McClelland, Acock, & Morrison, 2010; see also Chapter 12, this volume). Those early differences increase with time. Disadvantaged children fall progressively farther behind each school year (O'Shaughnessy et al., 2003). They also become progressively more vulnerable to mental and physical health problems (Adler & Newman, 2002; Gianaros, 2011). A small difference between at-risk and more-advantaged children in EFs early can lead to a gap in achievement and mental health that grows ever wider each passing year. Reducing or erasing that gap at the outset could nip that dynamic in the bud. Intervening early thus has enormous potential to reduce inequalities in health and its determinants.

Indeed, there is already evidence that improving EFs early improves academic achievement. The Chicago School Readiness Project (CSRP) found that children's EFs (inhibitory control of attention and action) improved significantly more in those preschool classes where Head Start teachers had been trained on CSRP than in comparison classes (Raver et al., 2011). CSRP children also improved in vocabulary, letter-naming, and math significantly
more than did controls. CSRP’s improvement of academic skills was mediated largely via its improvement of EFs. EFs in the spring of preschool predicted achievement 3 years later in math and reading. Thus disadvantaged children who were lucky enough to have been randomly assigned to a CSRP class tended to continue to perform better in school 3 years later, and that was primarily mediated through their improved EFs (Li-Grining, Raver, & Pess, 2011).

MECHANISMS BY WHICH SOCIAL AND ECONOMIC DISADVANTAGE CAN IMPAIR EF DEVELOPMENT

The flip side of the neural plasticity that makes possible improvements in EFs due to environmental influences such as school curricula is that EFs are also particularly vulnerable to impairment by disadvantageous environmental influences. Growing up in poverty, in a community characterized by violence, moving often, having divorced parents, being removed from one’s parents, or being a member of a minority that is discriminated against each increases one’s stress (e.g., Blair et al., 2011; Bradley & Corwyn, 2002; Evans, 2004; Goodman, McEwen, Dolan, Schafer-Kalkhoff, & Adler, 2005). A plethora of evidence shows that stress impairs EFs and that EFs are exceptionally vulnerable to stress. When a person is stressed, prefrontal cortex gets flooded with too much dopamine (Arnsten, 2000; Cerqueira, Mailliet, Almeida, Jay, & Sousa, 2007; Roth, Tam, Ida, Yang, & Deutch, 1988) and the activity of the neural circuit that includes prefrontal cortex becomes less synchronized (Liston, McEwen, & Casey, 2009). One cannot think clearly and the ability to exercise self-control is weakened (Arnsten, 1998; Liston et al., 2009; Mueller et al., 2010; Oaten & Cheng, 2005; Steinhauser, Maier, & Hubner, 2007). Stressful life circumstances not only directly affect a child growing up in such circumstances, but also affect his or her parents and their ability to think clearly and be caring role models. Not only is their stress detrimental to their ability to be good parents but their child will pick up on their stress, which will increase the stress the child feels.

Another way that social or economic disadvantage can get inside the brain and affect prefrontal cortex and EFs is via parenting. For example, parents who are too fearful and overly protective or too controlling, coercive, or harsh tend to have children with worse EFs than do parents who are more supportive of their child’s developing autonomy (Bernier, Carlson, & Whipple, 2010; Eddy, Leve, & Fagot, 2001; Karreman, van Tuijl, van Aken, & Dekovic, 2006; Matte-Gagné & Bernier, 2011). Homes with a richer oral language environment (especially where utterances are more elaborated and conceptually rich, where parents ask open-ended questions and model how to problem solve out loud while their child is working on a problem, and where children
are encouraged to think out loud and ask questions) tend to produce children with better EFs (Hackman & Farah, 2009; Hart & Risley, 1992; Matte-Gagné & Bernier, 2011; Vallotton & Ayoub, 2011). Parents can also aid their child’s development of EFs by scaffolding or supporting their child’s attempts at problem solving or exercising self-control so their child can succeed when, without their help, their child would not (Bernier et al., 2010; Bibok, Carpendale, & Müller, 2009; Hughes & Ensor, 2009; Landry, Smith, Swank, Assel, & Vellet, 2001). This assistance can take the form of guiding questions; helping their child stay on task; helping their child wait rather than giving the immediate, impulsive response; making critical features more salient for their child; helping their child handle frustration and keep going; reducing the number of possible options for problem solution; and so on, thus bootstrapping a process by which children can gradually come to solve problems and exercise self-control on their own (Bibok et al., 2009). One way that scaffolding and a rich verbal environment might aid EF development is through improving the child’s verbal ability, which in turn then supports EF development (Landry et al., 2001; Matte-Gagné & Bernier, 2011; Vygotsky, 1978).

Sensitive and responsive parenting and secure attachment can buffer children against the negative effects of environmental risk on EFs (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Bernier et al., 2010; Kochanska, Murray, & Harlan, 2000; Landry et al., 2001; Matte-Gagné & Bernier, 2011; Rhoades, Greenberg, Lanza, & Blair, 2011; Robinson, Burns, & Davis, in press; see also Chapter 11, this volume). Such fostering of better EF development translates directly into better grades in school (Sektnan et al., 2010) and better resiliency in general (Obradović, 2010). For a more extended discussion of the mechanisms by which socioeconomic disadvantage can impair EFs, and how this can be minimized, see the chapters in Part III of this volume, especially Chapters 10 and 11.

MEASUREMENT TOOLS FOR ASSESSING EF DEVELOPMENT

To investigate the factors mediating and moderating the effects of environmental risk on EFs and to investigate the causal relations between EFs and academic performance, tools for measuring EFs that can be used over a broad age range and that are valid not only for middle-class, European American children but also for children at social or economic disadvantage are needed. Zelazo has been working with others on the National Institutes of Health Toolbox to develop brief EF measures for use with people ages 3 through 85 (Weintraub et al., 2010). Diamond and colleagues have EF measures that can be used with people ages 4 through 85, but each takes about 10 to 12 minutes to administer (Davidson et al., 2006; Diamond, Barnett, Thomas, & Munro, 2007).
There are many EF tasks appropriate for the 3- to 5-year-old age range, including the Dimensional Change Card Sort (DCCS), Day-Night (Gerstadt, Hong, & Diamond, 1994), Tapping (Diamond & Taylor, 1996; also called the Hands task [Hughes, 1996]), Appearance-Reality (Flavell, 1986, 1993), Ambiguous Figures (Gopnik & Rosati, 2001), False Belief (Perner, Leekam, & Wimmer, 1987), Matrix Classification (Inhelder & Piaget, 1959/1964), and Go/No-Go (Livesey & Morgan, 1991). It has been hard to find EF tasks on which children of only 2.5 or 3 years can succeed, however. Carlson and colleagues (e.g., see Chapter 2, this volume) have been at the forefront of efforts to devise measures that can be used for children 2 through 5 years of age. The combined work of several people in the field seems to have produced one progression of performance on very similar tasks from 2 to 5 years of age (see Table 1.1): By roughly 2.5 years of age, children can do intradimensional switching (reversal tasks: e.g., first putting trucks with trucks, and stars with stars, and then switching to put trucks with stars, and stars with trucks; Brooks, Hanauer, Padowska, & Rosman, 2003; Pemer & Lang, 2002). By roughly 3.5 years of age, children can do extradimensional switching (switch between dimensions) from one block of trials to another but only if the dimensions are physically separated on the stimulus cards (e.g., color is a property of background rather than of the stimuli themselves, thus instead of white cards with a red truck or blue star, the front of the cards are

<table>
<thead>
<tr>
<th>TABLE 1.1</th>
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</thead>
<tbody>
<tr>
<td><strong>Developmental Progression in the Age at Which Children Can First Switch Rules When Sorting Cards</strong></td>
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</tbody>
</table>

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<thead>
<tr>
<th>Tasks that require switching rules</th>
<th>Age in years at which most children can first succeed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intradimensional switch: Reversal Tasks&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2½</td>
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<tr>
<td>Extradimensional switches (sort by 1 dimension and then by another):</td>
<td></td>
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<tr>
<td>DCCS With Separated Dimensions&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3½</td>
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<tr>
<td>DCCS (Standard)—Integrated Dimensions&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4½</td>
</tr>
<tr>
<td>DCCS—Mixed Block (switching dimensions randomly across trials)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7½</td>
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*Note. DCCS = Dimensional Change Card Sorting task.  
<sup>a</sup>On Reversal Tasks, first stimuli of Type 1 (say, care) go in the left bin (stimuli of Type 2 [say, animals] go in the right bin); then when the rules reverse, stimuli of Type 1 go in the right bin and Type 2 stimuli go in the left bin.  
<sup>b</sup>For DCCS with Separated Dimensions, the stimulus on the card is always black or white with a black outline, and color appears elsewhere on the card (either as the background or as a color patch on the other side of the card).  
<sup>c</sup>For DCCS (standard), the stimuli themselves are colored and the rest of the card is white. First, the participant sorts by one dimension for some trials and then there is a single switch to sorting by the other dimension for a block of trials. In other words, there are two single-task blocks.  
<sup>d</sup>For DCCS—Mixed Block, there are several switches of sorting by one dimension and then the other. These occur randomly over trials often after only 1, 2, or 3 trials. This is called a mixed-task block. Note how much longer it takes most children to master this.
red or blue and the trucks and stars are drawn entirely in black; Diamond, Carlson, & Beck, 2005; Kloo & Perner, 2005). By roughly 4.5 years of age, children can switch between dimensions from one block of trials to another, even when both dimensions are properties of the same objects (DCCS; Zelazo, Reznick, & Piñon, 1995). It is not until about 7.5 years of age, however, that children can flexibly switch between dimensions on a trial-by-trial basis (Cohen, Bixenman, Meiran, & Diamond, 2001), and not until about 10.5 years of age that they can begin to perform well on the Wisconsin Card Sorting Task (Chelune & Baer, 1986; Welsh, Pennington, & Groisser, 1991).

There is a dearth of research on the early development of EFs among low-income children, children living in sparsely populated rural areas, children who are not of European American descent, and especially among children who are both poor and members of ethnic minorities (the children at greatest risk for school failure and for mental and physical health problems). Work such as that by Caughy et al. (see Chapter 12, this volume) and Willoughby and Blair (see Chapter 4, this volume) is starting to fill that gap but much more work is needed. The timetable of EF development among monolingual North American children of European descent cannot be assumed to be true of all children. There is already evidence that, at least during early childhood, EFs develop faster in East Asian children (Lewis et al., 2009; Oh & Lewis, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006) and in children who are bilingual (Bialystok & Martin, 2004; Kovács & Mehler, 2009).

To test rural children, especially those of low income, the commonly used computerized tests of EFs are not always practical. Willoughby and colleagues (Willoughby & Blair, 2011; Willoughby et al., 2010; see also Chapter 4, this volume) have developed a flip-book version of EF measures, free of technological or electrical requirements. The flip-book version has its own drawbacks, however. One must forgo the collection of reaction-time data, which is often more sensitive than percentage of correct responses (e.g., Durston, Thomas, Worden, Yang, & Casey, 2002; Simpson & Riggs, 2005). Even with training and clear instructions, there is considerable room for between-tester differences in tone of voice, pacing, and other aspects of task administration. For example, although testers are instructed to flip pages at the rate of one page every 2 seconds, there is almost surely more between-tester variability in rate than if a computer controls the timing. A computer takes away much of the opportunity for intertester variations in task administration and reduces opportunities for human error. A final drawback is that the flip-book battery is labor and time intensive; it requires the presence of two staff persons per test administration (increasing labor costs) and it takes 2 hours. The pros and cons of each EF measure and method of administration need to be carefully considered as was indicated above when asking adults for their subjective assessments
of children’s behavior in real-world settings (as is often done by self-regulation researchers) was contrasted with obtaining objective assessments of children’s actual behavior on decontextualized, arbitrary laboratory tasks.

Researchers often assume that a measure labeled an EF measure is (a) really assessing EFs and (b) dependent on frontal cortex and interconnected brain regions thought to subserve EFs. Often those assumptions go untested. Any task requires multiple abilities, and children may have difficulty with a task not because of the ability the researcher was targeting but because of some other requirement of the task. Prefrontal cortex is late maturing; it is not impossible that earlier maturing brain regions subserve EF abilities in very young children. In Chapter 7 (this volume), Bell and Cuevas present initial electroencephalogram evidence of frontal activation during EF performance in preschoolers. Preschoolers exhibited task-related increases in medial frontal power and medial frontal-posterior coherence. (Medial frontal cortex is just behind prefrontal cortex.)

SUMMARY

One of the most critical societal needs is to develop effective, scalable, sustainable, and affordable strategies for supporting children from the youngest age possible, their parents, and their early child-care providers to get children started with good EFs when they first enter school, thereby launching them on a promising, positive trajectory, improving their life prospects and preventing problems, rather than trying to treat problems after they have been allowed to develop. To be able to determine whether a strategy is successful or not, sensitive and valid measures of EFs that can be administered longitudinally are absolutely essential.

REFERENCES


WHY IMPROVING AND ASSESSING EFs EARLY IN LIFE IS CRITICAL 27


WHY IMPROVING AND ASSESSING EFs EARLY IN LIFE IS CRITICAL


WHY IMPROVING AND ASSESSING EPS EARLY IN LIFE IS CRITICAL 35


WHY IMPROVING AND ASSESSING EFS EARLY IN LIFE IS CRITICAL 39


WHY IMPROVING AND ASSESSING EFs EARLY IN LIFE IS CRITICAL


CONTENTS

Contributors ........................................................................................................................................ ix

Introduction to Executive Function in Preschool-Age Children .............................................................. 3
James A. Griffin, Lisa S. Freund, Peggy McCardle, Rebecca DelCarmen-Wiggins, and Abigail Haydon

I. Conceptualization and Measurement of Executive Function ........... 9

Chapter 1. Why Improving and Assessing Executive Functions Early in Life Is Critical ................................ 11
Adele Diamond

Chapter 2. Incorporating Early Development Into the Measurement of Executive Function: The Need for a Continuum of Measures Across Development....... 45
Stephanie M. Carlson, Susan Faja, and Danielle M. Beck