NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD
NATIONAL FORUM ON EARLY CHILDHOOD POLICY AND PROGRAMS

Building the Brain's "Air Traffic Control" System:
How Early Experiences Shape the Development of Executive Function

WORKING PAPER 11

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The Issue

WE PREPARE DINNER WHILE SIMULTANEOUSLY HELPING OUR CHILDREN WITH THEIR HOMEWORK and making notes about appointments we need to schedule for the week. We focus on our jobs when we need to and our families when they need us. We remember the phone number that our neighbor just gave us so we can write it down as soon as we find a pen. We take a deep breath, rather than honk, if the car in front of us fails to move immediately when the light turns green. As adults, our capacities to multitask, to display self-control, to follow multiple-step directions even when interrupted, and to stay focused on what we are doing despite ever-present distractions are what undergird the deliberate, intentional, goal-directed behavior that is required for daily life and success at work. And while there are cognitive limits to anyone's ability to multi-task effectively, we need and rely on these basic skills in all areas of our lives. Without them, we could not solve complicated problems and make decisions, persist at tedious but important tasks, make plans and adjust them when necessary, recognize and correct mistakes, control our impulsive behavior, or set goals and monitor our progress toward meeting them. Children need to develop these skills, too, in order to meet the many challenges they will face on the road to becoming productive, contributing members of their communities.

As essential as they are, we aren't born with the skills that enable us to control impulses, make plans, and stay focused. We are born with the *potential* to develop these capacities—or not—depending on our experiences during infancy, throughout childhood, and into adolescence. Our genes provide the blueprint, but the early environments in which children live leave a lasting signature on those genes. This signature influences how or whether that genetic potential is expressed in the brain circuits that underlie the executive function capacities children will rely on throughout their lives. (See Working Paper 10, "Early Experiences Can Alter Gene Expression and Affect Long-Term Development.") These skills develop through practice and are strengthened by the experiences through which they are applied and honed. Providing the support that children need to build these skills at home, in child care and preschool programs, and in other settings they experience regularly is one of society's most important responsibilities.

Being able to focus, hold, and work with information in mind, filter distractions, and switch gears is like having an air traffic control system at a busy airport to manage the arrivals and departures of dozens of planes on multiple runways. In the brain, this air traffic control mechanism is called executive function. This refers to a group of skills that helps us to focus on multiple streams of information at the same time, monitor errors, make decisions in light of available information, revise plans as necessary, and resist the urge to let frustration lead to hasty actions. Acquiring the early building blocks of these skills is one of the most important and challenging tasks of the early childhood years, and the opportunity to build further on these rudimentary capacities is critical to healthy development through middle childhood and adolescence. Just as we rely on our well-developed personal "air traffic control system" to make it through our complex days without stumbling, young children depend on their emerging executive function skills to help them as they learn to read and write, remember the steps in performing an arithmetic problem, take part in class discussions or group projects, and

Having executive function in the brain is like having an air traffic control system at a busy airport to manage the arrivals and departures of dozens of planes on multiple runways.

What Are Executive Functions?

Completing most tasks requires the successful orchestration of several types of executive function skills. Among scientists who study these functions, three dimensions are frequently highlighted: **Working Memory**, **Inhibitory Control**, and **Cognitive or Mental Flexibility**.[1,2,3] In most real-life situations, these three functions are not entirely distinct, but, rather, they work together to produce competent executive functioning.

WORKING MEMORY is the capacity to hold and manipulate information in our heads over short periods of time. It provides a mental surface on which we can place important information so that it is ready to use in the course of our everyday lives. It enables us to remember a phone number long enough to dial it, to return to our place in a magazine article before a friend interrupted us, and to recall whether we had added the salt to what we were cooking before we had to help our child find a missing shoe. It enables children to remember and connect information from one paragraph to the next, to perform an arithmetic problem with several steps, to keep track of the moves and make a logical next step in a game of checkers, and to follow multiple-step instructions without reminders ("go to your cubbies, put away your storybooks, bring back your arithmetic books, and open them to page 30"). It also helps children with social interactions, such as planning and acting out a skit, taking turns in group activities, or easily rejoining a game after stepping away to get a drink of water.

INHIBITORY CONTROL is the skill we use to master and filter our thoughts and impulses so we can resist temptations, distractions, and habits and to pause and think before we act. It makes possible selective, focused, and sustained attention, prioritization, and action. This capacity keeps us from acting as completely impulsive creatures who do whatever comes into our minds. It is the skill we call on to push aside daydreams about what we would rather be doing so we can focus on important tasks. It is the skill we rely on to help us "bite our tongue" and say something nice, and to control our emotions at the same time, even when we are angry, rushed, or frustrated. Children rely on this skill to wait until they are called on when they know the answer, to be good at games like "Simon Says" and "Red Light/Green Light," to stop themselves from yelling at or hitting a child who has inadvertently bumped into them, and to ignore distractions and stay on task in school.

COGNITIVE OR MENTAL FLEXIBILITY is the capacity to nimbly switch gears and adjust to changed demands, priorities, or perspectives. It is what enables us to apply different rules in different settings. We might say one thing to a co-worker privately, but something quite different in the public context of a staff meeting. If a friend asks if we like her new haircut and we don't, we are able to flexibly shift to the social convention that governs not hurting people's feelings. Likewise, we teach our children about "outside voices" and "inside voices" and the different situations in which they should use each. As the author of *The Executive Brain,* Elkhonon Goldberg, notes, "The ability to stay on track is an asset, but being 'dead in the track' is not."[4] Stated differently, self-control and persistence are assets, rigidity is not. Cognitive flexibility enables us to catch mistakes and fix them, to revise ways of doing things in light of new information, to consider something from a fresh perspective, and to "think outside the box." If the "church in two blocks" where we were told to turn right is actually a school, we adjust and turn anyway. If we are missing a recipe ingredient, we call a neighbor or make a substitution. Children deploy this skill to learn exceptions to rules of grammar, to approach a science experiment in different ways until they get it to work, or to try different strategies when they are working out a conflict with another child.

enter into and sustain play with other children. The increasingly competent executive functioning of childhood and adolescence enable children to plan and act in a way that makes them good students, classroom citizens, and friends. Children who do not have opportunities to use and strengthen these skills, and, therefore, fail to become proficient—or children who lack the capacity for proficiency because of disabilities or, for that matter, adults who lose it due to brain injury or old age—have a very hard time managing the routine tasks of daily life. Studying, sustaining friendships, holding down a job, or managing a crisis pose even bigger challenges.

The process of development is sometimes portrayed as one in which children gradually manage more and more aspects of their environments and lives on their own. We would not trust two-year-olds to stop going after a ball just because it rolled into the street, get ready in the morning (brush their teeth, pick out their clothes, and get dressed) by themselves, or even clean up their toys without reminders. Adults set up the framework (i.e., establishing routines, providing cues, breaking big tasks into smaller chunks) that helps children use the executive function skills they are developing to the best of their abilities. We call these techniques "scaffolding." Just as a scaffold supports workers while a building is being erected, adults can use these activities to support the emergence of children's executive function skills until they can practice and perform them on their own. And, just as construction workers remove the scaffolding when the building itself can support them, over time we can reduce scaffolding activities and allow children to organize themselves and get their tasks done without constant reminders and direction.

Elementary school teachers are keenly aware of executive function skills. It is often within the group setting of a classroom and the demands of schoolwork that delays or deficits in the development of age-expected executive function skills are first noted. Teachers identify problems with paying attention, managing emotions, completing tasks, and communicating wants and needs verbally as major determinants of whether a child is ready to succeed in the school setting. In many ways, coming to school with a solid base of these foundational executive function skills is more important than whether children know their letters and numbers.[5,6] Imagine a classroom of first graders in which some children are unable to control their impulses, wait their turn, stay focused on their work, or remember instructions. Even when only a couple of the children have underdeveloped executive function abilities, an entire classroom can become disorganized, and precious time will be diverted from productive learning activities. This can have a profound impact on the overall climate of the classroom and is often reported by teachers as a source of exasperation and burnout.[7]

Executive function skills are crucial building blocks for the early development of both cognitive and social capacities.

The scientific evidence on the development and consequences of executive functioning in the earliest years of life conveys three important messages. First, executive function skills are crucial building blocks for the early development of both cognitive and social capacities. Second, both normative differences in the nature and pace of individual developmental trajectories and the impacts of significant adversity will affect how the development of executive functioning will unfold for any given child. Third, several interventions focused on supporting the development of specific executive function skills have demonstrated at least short-term effectiveness, with evidence also emerging that they may have impacts on other aspects of learning as well.

Executive functions underlie a broad range of large and small (as well as complicated and straightforward) life skills, competencies, and behaviors. The lifelong importance of these skills and their effect on learning makes it clear that parents, practitioners, and policymakers alike need to be aware of what we now understand about the development of executive function skills, the experiences that foster the healthy emergence of these skills, and the conditions that appear to undermine them.

What Neuroscience and Developmental Research Tell Us

The building blocks of children's capacities to retain and use new information, focus attention, control impulses, and make plans are acquired during early childhood, but the full range of executive function skills continues to develop into the adolescent years. The rudimentary signs of these capacities emerge toward the end of the first year of life.[8,9,10,11,12] By age three, most children can organize themselves to complete tasks that involve following two rules (e.g., "If it's red, put it here, but if it's blue, put it there."), thus showing that they can direct and re-direct their attention to make deliberate choices (mental flexibility), maintain focus in the face of distractions (inhibitory control), and hold rules "on line" mentally as they figure things out (working memory). While we can see clear evidence that these capacities are developing in the three-year-old, they remain relatively limited. The five-year-old mind, by contrast, is remarkably complex. Older preschoolers are capable of conscious problem-solving that involves the ability to shift their attention from one rule to another that is incompatible with the first, and then back again (e.g., "If it's the color game, put the red square here, but if it's the shape game, put the red square there."). They also have the capacity to inhibit responses that are inappropriate even if they are highly desirable (e.g., "I want to eat the candy right now, but I'll wait, because I will get more candy later if I do.") or habitual (e.g., "I've been sorting by color for five minutes, but now I need to shift to the shape rule."), and to execute multi-step, deliberate plans (e.g., "To stack these balls in the right order with just three moves, I need to start here, do this next, and then do that."). A more familiar demonstration of this remarkable development can be seen in the growing proficiency with which young children play "Simon Says" and "Red Light/Green Light." At age 5, these skills are just emerging and still require considerable practice. They are also heavily dependent on the situation and a child's experience with it, and there are large individual differences in children's capacity to deploy these evolving skills. By age 7, some of the capabilities and brain circuits underlying executive function skills are remarkably similar to those found in adults.[3] Once these foundational capacities for directing attention, keeping rules in mind, controlling impulses, and enacting plans are in place, the subsequent developmental tasks of refining them and learning to deploy them more efficiently can proceed into the adolescent and early adult years as tasks grow increasingly complicated and challenging.

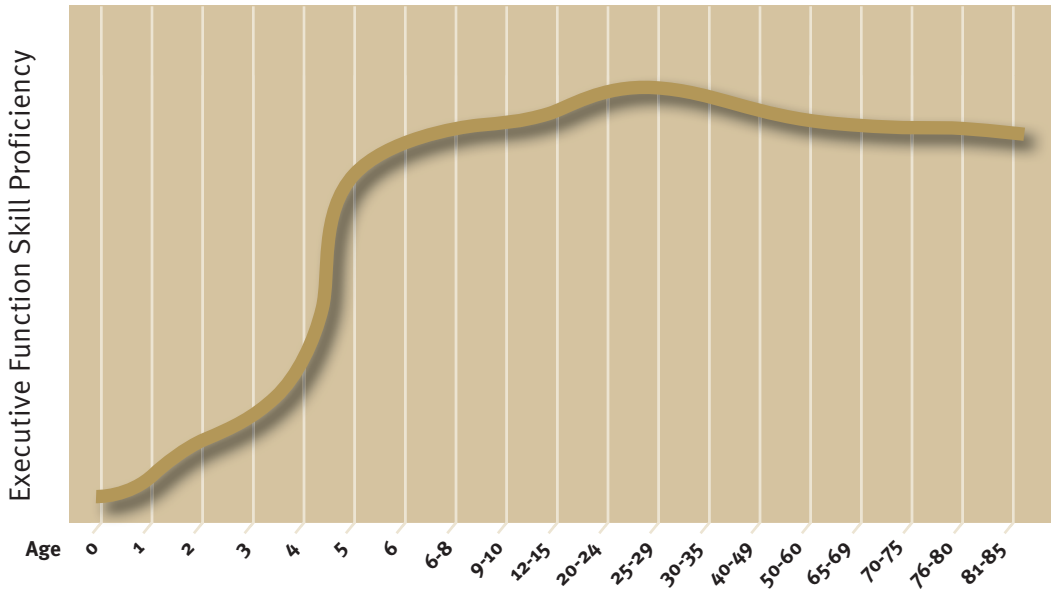
Scientists are making major strides in identifying the key brain regions on whose development the healthy emergence of these executive function skills depends. These include circuits and systems that primarily involve the prefrontal cortex, but also include the anterior cingulate, parietal cortex, and hippocampus. The gradual acquisition of executive function skills corresponds closely to the extended development of these prefrontal brain regions from infancy through late adolescence.[8,13,14,15] The formative development of these regions occurs during early childhood, as the relevant circuits emerge, mature, and forge critical interconnections. These circuits are then refined and made more efficient during adolescence and into the early adult years. It is also important to note that the brain regions and circuits associated with executive functioning have extensive interconnections with deeper brain structures that control the developing child's responses to threat and stress.[16,17,18] This implies that the developing executive functioning system both influences and is affected by the young child's experience and management of threat, stress,[10,19] and strong emotions. Thus, extended exposure to threatening situations can compromise the development and deployment of executive function skills, yet well-developed capabilities in these areas can also help children (and adults) manage stress effectively.

Executive functioning is distinct from (yet foundational to) school readiness and academic success. Scientists who study executive function skills refer to them as the biological foundation for school readiness.[20,21] They argue that strong working memory, cognitive self-control, and attentional skills provide the basis upon which children's abilities to learn to read, write, and do math can be built. In practice, these skills

support the process (i.e., the *how*) of learning—focusing, remembering, planning—that enables children to effectively and efficiently master the *content* (i.e., the *what*) of learning—reading, writing, computation. They enable children to acquire knowledge and to participate in the school experience as actively engaged and competent learners. Children with stronger working memory, inhibition, and attentional skills also have been found to make larger gains on tests of early math, language, and literacy development during the preschool years than their peers with weaker executive function skills.[22,23,24,25,26,27,28,29] Moreover, the working memory and attention control of economically disadvantaged children at the beginning of preschool predicted kindergarten math and reading achievement over and above the contribution of earlier math and reading ability.[30] Similarly, children whose behavior was well-regulated and who demonstrated academic engagement at the beginning of the Head Start year scored higher on tests of early reading and language skills in first grade, compared with children who demonstrated less well-developed executive functioning.[31]

Children's executive function skills provide the link between early school achievement and social, emotional, and moral development. Executive function skills are considered to be a common denominator for both learning and social interaction. Young children who have problems staying focused and resisting urges to respond impulsively—two core executive function skills—not only have trouble in school but also have trouble following directions generally and are at elevated risk of displaying aggressive and confrontational behavior with adults and other children.[32,33,34] Executive functions like completing tasks, solving problems, organizing information, and making (and revising, if necessary) deliberate plans, are important facilitators of interpersonal interactions and behavior. Indeed, some researchers have hypothesized that

Executive Function Skills Build Throughout Childhood and Adolescence



A range of tests measuring different forms of executive function skills indicates that they begin to develop shortly after birth, with ages 3 to 5 providing a window of opportunity for dramatic growth in these skills. Growth continues throughout adolescence and early adulthood; proficiency begins to decline in later life.

Source: Weintraub et al. (In Press).[99]

the complexity of human social relationships, rather than the need to do higher math, is why the human prefrontal cortex is so large and our executive function abilities are so advanced.[20,35]

Children's social play is believed to be an important practice ground for the development of executive function skills. Partly, this is because children need to test for themselves the skills that adults have been scaffolding for them. For example, they have to come up with the plan for playing house, communicate with each other about role assignments and then remember that Susie will be the bossy older sister, Ralph will play the dog, and Jackie will be the baby. In this scenario, keeping track of what each actor has done and inserting a new piece of the story that makes sense to everyone requires the effective exercise of emerging executive function skills. The child who cannot demonstrate sufficient executive competence either is told what to do by others, gets pushed out, or causes the play to fall apart. As toddlers, children can barely manage to coordinate play with one other child; by the time they enter first grade, they typically can play cooperatively with several children simultaneously and can work on projects that span hours or even days. Children who lag behind in their emerging executive function capacities relative to their age mates find themselves at a disadvantage, because they cannot keep up with the complexity of the play and, therefore, get frustrated, act out, and may cause other children to not want to play with them.[36] Thus, the skills that help children master many academic tasks are the same as those that help them get along with their peers and be viewed as good classroom citizens.

Large individual differences in executive functioning at kindergarten entry can have important implications for children's adjustment and success in and out of school as well as in their relationships with others. Children enter school with distinct profiles of strengths and weaknesses in executive function skills.[21,37,38] As both teachers and parents know, young children differ widely in how well they are able to adjust their attention, control impulses, follow rules and directions, and adapt to other demands of their environments. Some children have less well-developed executive functioning and are less able to orchestrate their capacities. Children with special needs, such as those associated with autism, for example, or reading disabilities,[39] may have particular difficulty with executive functioning demands. A child's temperament can also make this orchestration more challenging, as illustrated by individuals who typically react more rapidly and intensely (with either anger and frustration or exuberance) to their experiences.[9,40] Another example of the marked variability in developing skills is the observation that some children can be highly capable in focusing their attention and managing distractions, but have less well-developed working memory capacity. Understanding these individual differences can help adults figure out how much support and structure to provide as children develop and learn. A new generation of educational interventions is available to address this challenge by working with classrooms of children who span the broad spectrum of executive function capacities. (See "What Evaluation Research Tells Us," below.)

A young child's environment of relationships plays an important role in the development of executive capacities. Environments that foster executive functioning are characterized by adult-child relationships (both within and outside the home) that guide children from complete dependence on adult support to gradual assumption of the "executive" role for themselves. Such environments neither expect children to have more advanced skills than are reasonable for their age, nor do they treat them as if they had no executive capabilities. Growth-promoting environments provide substantial "scaffolding" to help young children practice emerging skills before they are expected to perform them on their own. Enhancing the development of executive functioning involves sensitive, responsive caregiving and individualized teaching in the context of situations that require making choices, opportunities for children to direct their own activities with decreasing adult supervision over time, effective support of early emotion regulation, promotion of sustained joint attention, and the availability of adults who are not under such pressure that they cannot make time for children to practice their skills.[34,41,42,43,44,45]

Children who routinely experience social interactions that provide these kinds of opportunities are more capable of resisting distractions, controlling their behavior and emotions towards others, complying with adult requests

and rules, and engaging in goal-directed behavior by the time they get to school. Experts also hypothesize that more ordered and predictable environments foster the development of executive function skills by offering children ample experiences that involve give-and-take interactions with others.[20,46,47,48]

Adverse environments resulting from neglect, abuse, and/or exposure to violence can impair the development of executive function skills as a result of the disruptive effects of toxic stress on the developing architecture of the brain. Chaotic (and thus, from the child's standpoint, unpredictable) environments can also lead to poor self-regulatory behaviors and impulse control.[104] A number of studies have shown that exposure to highly stressful early environments is associated with deficits in the development of children's working memory, attention, and inhibitory control skills.[45,49,50] Damaging fear and toxic stress[51,52,53,54] are likely mechanisms that explain these effects, in part, because they affect the chemistry of brain circuits involved in the development of these capacities, and they impair the specific neuronal architecture that is engaged when we try to keep information in working memory, inhibit a habitual action, or address problems in a flexible manner. All adults have had the experience of encountering a threat, being gripped by fear or anxiety, and having trouble thinking. Under such circumstances, the brain goes into high "fight-or-flight" mode, and we have to calm ourselves down before we can mobilize our executive function skills to plan and execute a well-considered response. In adults and children, acute stress can even cause less-efficient prefrontal cortex activity, leading to a temporary "blip" in executive functioning.[105] Thus, chronic fear and anxiety associated with living in highly threatening, chaotic, or stressful environments can make it very difficult for young children to engage their executive abilities—even in situations (like school) where they may, in fact, be safe.[55,56]

Mounting evidence is revealing the roles played by community, school, and family contexts, as well as socioeconomic status, in the development of executive function skills. Children from lower (versus higher) socioeconomic backgrounds show poorer performance on tests of working memory, cognitive flexibility, and inhibition,[57,58,59,60,61] as well as electrophysiological evidence of altered prefrontal functioning between ages 7 to 12.[57] One reason that social class may be related to the development of executive function skills is that young children with greater access to resources experience environments that are more likely to contain features that protect and foster the development of these skills (e.g., scaffolding, responsive caregiving, order and predictability, and freedom from sustained threats.) This underscores the importance of efforts to improve children's early environments and experiences as a strategy for increasing the likelihood of positive developmental outcomes later.

Children who experience adversity at an early age are more likely to exhibit deficits in executive functioning, suggesting that these capacities are vulnerable to disruption early in the developmental process.

Children who experience adversity at an early age are more likely to exhibit deficits in executive functioning, suggesting that these capacities are vulnerable to disruption early in the developmental process. Among the conditions that have been studied and found to affect the development of executive function skills are early abuse and neglect,[62] orphanage rearing,[63,64,65] prematurity and/or perinatal complications,[66,67,68] and prenatal alcohol exposure.[69] For example, children with a history of exposure to alcohol before birth have been found to display high levels of impulsivity and disorganization, along with evidence of impaired development of the prefrontal cortex.[70] Evidence is also accumulating that childhood maltreatment disrupts the attention systems that affect how children notice, interpret, and respond to social interactions.[71,72] Despite subsequent adoption, maltreated children who experienced unstable foster care placements have been found to perform poorly on tests of executive functioning,[73] as well as to display oppositional behavior towards their adoptive parents. Furthermore, larger numbers of unique foster care placements have been found to predict lower scores on a wide range of neuropsychological executive functioning tests,[74,75]

suggesting that frequent changes in a child's primary caregiver may disrupt the development of these important skills. In light of this evidence, it is not surprising that children with a history of early social deprivation from being raised in an orphanage have also been found to perform significantly more poorly than their non-institutionalized peers on neuropsychological tests of executive function skills.[63,64,76] While all young children benefit from experiences that scaffold executive functioning, those who exhibit problems in self-regulation need particularly sensitive adult support. When children have experienced serious trauma or abuse, special concern is always warranted.

What Evaluation Research Tells Us

The healthy development of executive function skills can be supported with specialized practice and training. The same neuroplasticity that leaves executive functioning skills vulnerable to genetic and environmental disruption also presents the possibility of actively promoting the successful development of these skills. Thus, scientists and clinicians have begun to design and assess specific training programs aimed at helping young children who face difficulties with several aspects of executive functioning, particularly with attention and working memory. One laboratory-based approach that relies on computerized programs strengthens the neural circuits that control specific executive function skills through "staircase" training that adjusts task difficulty as a child's performance improves.[10,77,78,79,80,81,82] In addition to improving targeted skills (such as inhibitory control and attention set shifting), emerging evidence indicates that the benefits of these programs also extend to enhanced performance on tests of general intelligence. Selected measures of brain activity further suggest that these interventions have direct, beneficial effects on the ways in which the prefrontal cortex is developing; however, these effects have not yet been tested on preschool children.

Focused preschool interventions can also protect and enhance executive functioning. Recent evaluations of a range of preschool interventions designed to strengthen children's capacities to use these executive function skills in the classroom (in contrast to programs focused primarily on cognitive training) are also demonstrating that these skills are open to improvement during the early childhood years. These interventions tend to adopt one of three strategies: (1) programs aimed explicitly at fostering emerging executive function skills (e.g., the capacities to retain and use information, focus and resist distractions, and plan actions and revise plans as needed);[83,84] (2) programs that train and support teachers in effective classroom management strategies (e.g., rewarding positive student behavior, redirecting negative behavior), supplemented with the assistance of a mental health consultant who helps with both overall classroom challenges and the needs of particular children;[85,86,87] and (3) programs that train teachers to model and coach children as their social-emotional skills are developing, with the focus on children's prosocial behavior, social problem-solving skills, ability to understand and express emotions constructively, and ability to control impulsive behavior and organize themselves to accomplish goals.[48,88,89] What these approaches all have in common is a focus on supporting self-control and effective, goal-oriented approaches to learning and social encounters.

The clearest example of the first strategy, known as Tools of the Mind, has been shown to improve the inhibitory skills of children from low-income families above and beyond what has been accomplished from standard classroom practices.[84,90,91] Evidence from randomized trials of the second and third approaches have documented significant effects on young children's engagement in academic tasks, attention skills, and control of impulsive behavior.[22,92,93] These interventions also had significant impacts on the quality of the teaching experienced by the children, including improved literacy environments, use of preventive behavior management, and overall more positive emotional climate.[83,94]

A review of existing evaluation data on interventions focused on executive functioning reveals no evidence that one approach is superior to the others. Moreover, little is known about

Building the Foundations of an "Air Traffic Control" System in the Brain

Executive function skills do not just appear in adulthood. They are built over time, starting as early as the first year of life, with more complex skills building on the simpler skills that came before. Executive function skills are also highly interrelated. Just as an air traffic control system requires the interaction of multiple people—pilots, navigators, controllers, weather forecasters—our human executive functioning system requires that each type of skill utilize elements of the others. For example, it takes working memory to hold two rules in mind and inhibitory control to ignore one of the rules in order to flexibly switch between rules as they change. This table presents examples of how these interrelated executive function skills develop when children have the proper scaffolding by adult caregivers.

WORKING MEMORY	INHIBITORY CONTROL	COGNITIVE FLEXIBILITY
ADULT Can remember multiple tasks, rules, and strategies that may vary by situation	**ADULT** Consistent self-control; situationally appropriate responses (e.g., resists saying something socially inappropriate, resists "tit for tat" response)	**ADULT** Able to revise actions and plans in response to changing circumstances
5-16 YEARS Develops ability to search varying locations, remember where something was found, then explore other locations (e.g., a game of Concentration or hiding a penny under one of three cups)	**10-18 YEARS** Continues to develop self-control, such as flexibly switching between a central focus (such as riding a bike or driving) and peripheral stimuli that may or may not need attention (road signs and pedestrians vs. billboards and passing houses)	**13-18 YEARS** Continued improvement in accuracy when switching focus and adapting to changing rules
4-5 YEARS Comprehends that appearance does not always equal reality (e.g., when given a sponge that looks like a rock)	**7 YEARS** Children perform at adult levels on learning to ignore irrelevant, peripheral stimuli (such as a dot on the side of a screen) and focus on the central stimulus (such as a picture in the middle of the screen)	**10-12 YEARS** Successfully adapts to changing rules, even along multiple dimensions (okay to shout on playground, not okay in school, okay sometimes in theater rehearsal)
3 YEARS Can hold in mind two rules (e.g., red goes here, blue goes there) and act on the basis of the rules	**4-5 YEARS** Reductions in perseveration (persisting with following a rule even when knowing that the rule has changed). Can delay eating a treat; also can begin to hold an arbitrary rule in mind and follow it to produce a response that differs from their natural instinct (sort colored cards by shape rather than color)	**2-5 YEARS** Succeeds at shifting actions according to changing rules (e.g., takes shoes off at home, leaves on at school, puts on boots for rain)
9-10 MONTHS Can execute simple means-to-ends tasks and two-step plans; also able to integrate looking one place and acting (e.g., reaching) at another place	**9-11 MONTHS** Able to inhibit reaching straight for a visible but inaccessible reward, such as a toy on the other side of a window, and instead delay a moment to recognize the barrier and detour around it	**9-11 MONTHS** Develops ability to seek alternate methods to retrieve objects beyond directly reaching for what's in view
7-9 MONTHS Develops ability to remember that unseen objects are still there (toy hidden under a cloth); learns to put two actions together in a sequence (remove cloth, grasp toy)	**8-10 MONTHS** Begins to maintain focus despite distractions during brief delays in a task	
	6 MONTHS Rudimentary response inhibition (able to not touch something instructed not to touch)	

Sources: Best & Miller (2010)[100]; Diamond (1991a, 1991b, 2002, 2006).[101,102,8,103]

how these programs produce the benefits that they do. Interventions that include an explicit focus on executive function skills do not need to be implemented separately from those focused on instruction in early literacy and math abilities. Indeed, the complex interactions that occur among executive functioning, social competence, and academic skills in preschool classrooms underscore the likely value of blending interventions designed to strengthen working memory, inhibition, and attention control with curricula focused on early literacy and math skills.[30]

Improvements in executive functioning extend to young children's performance on measures of social skills and academic performance. In three randomized trials, children in classrooms that emphasized the improvement of executive function skills through a range of strategies showed improved performance on other developmental outcomes as well. In the first instance, children assigned to Tools of the Mind classrooms showed significant reductions in teacher-rated problem behavior[83] compared with preschool children in classrooms that focused on literacy instruction without explicit attention to executive functioning. In the second instance, preschoolers who received instruction that included a focus on executive function skills (i.e., attention and impulsivity) showed significant improvements in these capacities compared with their peers who were enrolled in "usual practice" classrooms, which researchers attribute to the concurrent effects on their early literacy and math skills.[92] Children who experienced a curriculum that combined support for executive function skills and an interactive reading program also performed better than their "usual practice" peers on tests of early literacy abilities,[22] as well as on measures of emotional understanding and social problem-solving.[48] While we cannot be certain that demonstrated improvements in children's abilities to direct their attention, control impulsive behavior, and stay focused on their schoolwork contributed to their academic gains, evidence is increasingly supporting this interpretation.[22,30,48,92,95]

Correcting Popular Misconceptions of Science

THE FACT THAT YOUNG CHILDREN HAVE A difficult time with self-control, planning, ignoring distractions, and adjusting to new demands is hardly news to the adults who care for them. It is not widely recognized, however, that these capacities do not automatically develop with maturity over time. Furthermore, it is even less well known that the developing brain circuitry related to these kinds of skills follows an extended timetable that begins in early childhood and continues past adolescence and that it provides the common foundation on which early learning and social skills are built. Based on this new understanding, the following common misconceptions about the development of executive function skills can be laid to rest.

Contrary to popular belief, learning to control impulses, pay attention, and retain information actively in one's memory does not happen automatically as children mature, and young children who have problems with these skills will not necessarily outgrow them. The evidence is clear that, by 12 months of age, a child's experiences are helping to lay the foundation for the ongoing development of executive function skills. These early abilities to focus attention, control impulses, and hold information "on-line" in working memory appear to be easily disrupted by highly adverse early experiences or biological disruptions. Evidence also shows that early interventions aimed at improving these capacities before a child enters school can have beneficial impacts across a broad array of important outcomes.

Contrary to popular belief, young children who do not stay on task, lose control of their emotions, or are easily distracted are not "bad kids" who are being intentionally uncooperative and belligerent. Young children with compromised or delayed executive function skills can display very challenging behaviors for which they are often blamed. In most circumstances, however, it is the protracted development of the prefrontal cortex that is to "blame." Efforts to help affected children develop better executive function skills

and adjustments of the demands placed upon them to avoid overtaxing their capabilities are much more helpful than punishment for difficult behavior. Particularly when adverse experiences or environments elicit a toxic stress response,[96] it can be very difficult for even the most competent children to enlist whatever executive function skills they have. In these circumstances, the provision of a safe and predictable environment offers the sense of security needed for successful behavior change to occur.

Contrary to the theory that guides some early education programs that focus solely on teaching letters and numbers, explicit efforts to foster executive functioning have positive influences on instilling early literacy and numeracy skills. Early evidence from randomized trials of interventions designed to foster the cluster of executive function skills (working memory, attention, inhibitory control, etc.) indicates benefits in early literacy and math skills compared with children who experience "regular" classroom activities.[48,92] Indeed, there is also evidence that emerging executive function skills contribute to early reading and math achievement during the pre-kindergarten years and into kindergarten.[28,30] This is not surprising insofar as the acquisition of traditional academic skills depends on a child's capacity to follow and remember classroom rules, control emotions, focus attention, sit still, and learn on demand through listening and watching. Neuroscientists are also beginning to relate specific aspects of executive functioning, notably attentional skills, to specific steps involved in learning to read and to work with numbers.[9]

It is important to emphasize that this research is in its infancy, and much remains to be learned. Not only do we need to understand the effectiveness factors that account for the emerging impacts on school readiness from interventions designed to focus on executive function skills, but we also need to examine whether effective early education programs that focus directly on social, numeracy, and language skills also have positive impacts on executive functioning. Thus, the highly interrelated nature of these capacities makes it difficult to label any single intervention as focused explicitly (or not) on the critical domains of executive functioning.

Early education policies that emphasize literacy instruction alone are missing an important opportunity to increase their effectiveness by including attention to the development of executive functioning skills.

The Science-Policy Gap

AS ADULTS, MOST OF US DEPLOY EXECUTIVE functioning automatically (and virtually unconsciously) in our everyday lives, as we strive to accomplish both short-term tasks and longer-term goals. Yet, a growing body of evidence shows that acquiring this bundle of skills and putting those skills to work in a variety of roles, such as friend, family member, and student, is highly challenging for many young children—and may explain many disparities in later school achievement. Despite this mounting evidence, little attention has been paid to the development and implementation of strategies to identify children who are at risk for poor executive functioning and to provide supports for them, their families, and the other adults who care for them. This gap between what we know and what we do is illustrated by the following three examples.

Early education policies that emphasize literacy instruction alone are missing an important opportunity to increase their effectiveness by including attention to the development of executive function skills. Emerging evidence from early intervention programs explicitly aimed at fostering these skills indicates that beneficial effects on components of executive function (e.g., attention, working memory) also have positive secondary impacts, such as improving the quality of teaching that children receive (including improved literacy environments) and

the promotion of other facets of early learning, including task engagement and reading skills. Indeed, the most effective early education programs of the future are likely to teach preschool curriculum content (e.g., early literacy, math, social skills) in a way that optimizes the scaffolding and practice of executive function skills.

The expulsion of young children from prekindergarten programs[97,98] because of unmanageable behavior illustrates the need for greater availability of expertise and resources to improve the executive function skills of vulnerable young children. Research shows that young children who have problems staying focused and controlling impulsive, reactive behavior—two core executive function skills—are at elevated risk of experiencing behavior problems. Evidence from kindergarten teachers who rank self-control and sustained attention as more critical for school readiness than content knowledge[6] further highlights the importance of supporting the early development of executive function skills as a critical prerequisite to a successful transition into school. The extent to which the combination of serious self-regulation problems in young children and excessive stress experienced by early childhood teachers leads to a greater likelihood of expulsion from preschool programs underscores the need for greater attention to innovative interventions that promote more adaptive behavior.

The lack of services that directly address sources of toxic stress during the earliest years of life indicates a disconnect between policies and the known vulnerability of many aspects of brain development (including executive function skills) to the effects of early adversity and the need for preventive policies to reduce such lost opportunities. It is widely understood that biologically based sources of vulnerability, (e.g., prematurity and other medical complications at birth) and disruptions in brain architecture related to difficulties in early rearing conditions (e.g., child abuse and neglect) place children at tremendous risk for developmental problems ranging from attachment disorders to learning disabilities. Emerging evidence also shows that these adverse conditions, as well as low socioeconomic status, place children at a disadvantage with regard to the development of working memory, cognitive flexibility, and behavioral inhibition. This connection between toxic stress and executive functioning suggests new and important opportunities for interventions focused on these skills to improve the likelihood of success in school and later life for children facing adversity.

Implications for Policy and Programs

THE STATE OF SCIENTIFIC KNOWLEDGE ABOUT the development of executive function skills is sufficiently mature to support a number of evidence-based implications for those who develop and implement policies and programs that affect the health and well-being of young children. The following observations warrant particularly careful consideration by policymakers.

Given the importance of young children's executive function skills and emerging evidence that these capacities can be improved through focused early intervention programs, efforts to support the development of these skills deserve much greater attention in the design of early care and education programs. In recent years, a growing body of sophisticated intervention and evaluation research has documented positive short-term impacts for programs aimed explicitly at strengthening young children's executive function skills, including working memory and attentional capacities. Concurrently, evidence from neuroscience is beginning to demonstrate specific changes in the brain that accompany improvements in these skills. Successful interventions have been implemented in a variety of programs that serve low-income children, including Head Start. Although additional replications and evaluations will add important information, the current evidence base is strong enough to warrant systematic, scaled-up initiatives to teach executive function skills in early care and education programs that focus on vulnerable populations in conjunction with evidence-based curricula that promote early literacy and numeracy skills.

Early care and education professionals—as well as kindergarten and early elementary teachers—would be better equipped to understand and address behavioral and learning challenges in their classrooms if they had professional training in (and easy-to-use tools for) the development of executive function skills. Teacher training programs, including degree programs in schools of education, currently devote little or no time to instruction about the development of executive function skills. Yet, teachers of young children are often the first to recognize serious problems with controlling impulses, focusing attention, staying organized, and following instructions that require well-developed working memory. The consequences of mislabeling these problems as "bad behavior" can be severe, leading, in some instances, to expulsion or inappropriate use of medication and, in others, to a highly disrupted classroom. In simple terms, many young children who need assistance are not getting it. Teachers equipped with knowledge and curriculum tools to support the development of executive function skills would be in a better position to calibrate their expectations to the developing capabilities of young children and better prepared to address these classroom challenges appropriately. They would also be in a better position to call upon specialized mental health consultation, when needed.[52]

Parents would benefit from greater access to tools and approaches that provide useful knowledge and ways of supporting the early development of executive function skills. Lessons learned from interventions that have proven successful in fostering executive functioning in young children hold considerable promise for incorporation into parent-focused interventions, such as home visiting, parenting education, and family support programs. The translation of effective management strategies for use in these programs should be a high priority.

Adding assessments of executive function skills to the repertoire of evaluation tools used in early childhood programs would not only provide important data for program planning but would also encourage attention to this critical domain of skill development.

Adding assessments of executive function skills to the repertoire of evaluation tools used in early childhood programs would not only provide important data for program planning but would also encourage attention to this critical domain of skill development. Policymakers and practitioners measure what they value. The growing availability of valid and practical tools for assessing early executive functioning now makes it feasible for program evaluators to measure impacts on these foundational skills. As attention to executive functioning increases in the early childhood arena, this critical domain of development will receive more prominent attention in the public debate about how best to promote the emerging competencies of young children.

References

1. Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "Do as I say, not as I do." *Developmental Psychobiology, 29*(4), 315-334.
2. Greenberg, M.T., Riggs, N. R. & Blair, C. (2007). The role of preventive interventions in enhancing neurocognitive functioning and promoting competence in adolescence. In D. Romer & E. F. Walker (Eds.), *Adolescent psychopathology and the developing brain: Integrating brain and prevention science* (pp. 441-461). New York: Oxford University Press.
3. Rothbart, M.K., Posner, M.I., & Kieras, J. (2006). Temperament, attention and the development of self-regulation. In K. McCartney & D. Phillips (Eds.), *The Blackwell handbook of early child development* (pp. 328-357). Malden, MA: Blackwell Press.
4. Goldberg, E. (2001). *The executive brain: Frontal lobes and the civilized mind.* New York: Oxford University Press.
5. Lewitt, E. M. & Baker, L. S. (1995). School readiness. *The Future of Children, 5*(2), 128-139.

6. Rimm-Kaufman, S. E., Pianta, R. C., & Cox, M. J. (2000). Teachers' judgments of problems in the transition to kindergarten. *Early Childhood Research Quarterly, 15*(2), 147-166.
7. Brouwers, A., & Tomic, W. (2000). A longitudinal study of teacher burnout and perceived self-efficacy in classroom management. *Teaching and Teacher Education, 16*(2), 239-253.
8. Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function* (pp. 466-503). New York: Oxford University Press.
9. Posner, M.I. & Rothbart, M.K. (2006). *Educating the human brain* (1st Ed.). Washington, DC: American Psychological Association.
10. Rueda, M.R., Posner, M.I., & Rothbart, M.K. (2005). The development of executive attention: Contributions to the emergence of self-regulation. *Developmental Neuropsychology, 28*(2), 573-594.
11. Zelazo, P.D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences, 8*(1), 12-17.
12. Zelazo, P.D. Carlson, S.M., & Kesek, A. (2008). The development of executive function in childhood. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (2nd Ed.). (pp. 553-574). Cambridge, MA: The MIT Press.
13. Diamond, A. (1988). Abilities and neural mechanisms underlying AB performance. *Child Development, 59*(2), 523-527.
14. Goldman-Rakic, P.S. (1987). Circuitry of primate prefrontal cortex and regulation of behavior by representational memory. In F. Plum (Ed.), *Handbooks of physiology: A spectrum of physiological knowledge and concepts: Section 1: Nervous system: Vol. V, 2 parts: Higher functions of the brain* (pp. 373-417). Bethesda, MD: American Physiological Society.
15. Rothbart, M.K. & Posner, M.I. (2005). Genes and experience in the development of executive attention and effortful control. In L.A. Jensen & R.W. Larson (Eds.), *New horizons in developmental theory and research* (pp. 101-108). San Francisco: Jossey-Bass.
16. Bush, B., Luu, P., & Posner, M.I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*(6), 215-222.
17. Drevets, W. C., & Raichle, M. E. (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: Implications for interactions between emotion and cognition. *Cognition and Emotion, 12*(3), 353-385.
18. Kuhl, J., & Kazén, M. (1999). Volitional facilitation of difficult intentions: Joint activation of intention memory and positive affect removes Stroop interference. *Journal of Experimental Psychology: General, 128*(3), 382-399.
19. Blair, C., Zelazo, P.D. & Greenberg, M.T. (2005). The measurement of executive function in early childhood. *Developmental Neuropsychology, 28*(2), 561-571.
20. Barkley, R.A. (2001). The executive functions and self-regulation: An evolutionary neuropsychological perspective. *Neuropsychology Review, 11*(1), 1-29.
21. Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist, 57*(2), 111-127.
22. Bierman, K.L., Nix, R.L., Greenberg, M.T., Blair, C. & Domitrovich, C.E. (2008). Executive functions and school readiness intervention: Impact, moderation, and mediation in the Head Start REDI program. *Development and Psychopathology, 20*(3), 821-843.
23. Blair, C., & Razza, R.P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*(2), 647-663.
24. Espey, K., McDiarmid, M., Kwik, M., Stalets, M., Hamby, A., & Senn, T. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology, 26*(1), 465-486.
25. Fuchs, L.S., Compton, D.S., Fuchs, D., Paulsen, K., Bryant, J.D. & Hamlett, C.L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology, 97*(3), 493-513.
26. Gathercole, S.E., Tiffany, C., Briscoe, J., Thorn, A. & the ALSPAC Team. (2005). Developmental consequences of poor phonological short-term memory function in childhood: A longitudinal study. *Journal of Child Psychology and Psychiatry, 46*(6), 598-611.
27. Howse, R.B., Calkins, S.D., Anastopoulos, A.D., Keane, S.P., & Shelton, T.L. (2003). Regulatory contributors to children's kindergarten achievement. *Early Education and Development, 14*(1)101-119.
28. McClelland, M.M., Cameron, C.E., Connor, C.M., Farris, C.L., Jewkes, A.M., & Morrison, F.J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology, 43*(4), 947-959.
29. Sektnan, M., McClelland, M.M., Acock, A., & Morrison, F. (In Press). Relations between early family risk, children's behavioral regulation, and academic achievement. *Early Childhood Research Quarterly.*
30. Welsh, J.A., Nix, R.L., Blair, C., Bierman, K.L. & Nelson, K.E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology, 102*(1), 43-53.
31. Bulotsky-Shearer, R.J., Fantuzzo, J.W., Dominguez, X. & McDermott, P.A. (2009, April). *Unique contribution of social-emotional classroom behavior to school readiness for low-income urban preschool children.* Paper presented at the biennial meetings of the Society for Research in Child Development, Denver, Colo.
32. Eisenberg, N., Fabes, R.A., Nyman, M., Bernzweig, J., & Pinuelas, A. (1994). The relations of emotionality and regulation to children's anger-related reactions. *Child Development, 65*(1), 109-128.
33. Hill, A.L. Degnan, K.A. Calkins, S.D. & Keane, S.P. (2006). Profiles of externalizing behavior problems for boys and girls across preschool: The roles of emotion regulation and inattention. *Developmental Psychology, 42*(5), 913-928.
34. Kochanska, G., Murray, K., & Coy, K. C. (1997). Inhibitory control as a contributor to conscience in childhood: From toddler to early school age. *Child Development, 68*(2), 263-277.
35. Dunbar, R.I.M, & Shultz, S. (2007). Evolution in the social brain. *Science, 317*(5843), 1344-1347.
36. Diamantopoulou, S., Rydell, A.M., Thorell, L.B., & Bohlin, G. (2007). Impact of executive functioning and symptoms of attention deficit hyperactivity disorder on children's peer relations and school performance. *Developmental Neuropsychology, 32*(1), 521-542.

37. Fantuzzo, J., Bulotsky-Shearer, R., McDermott, P.A., McWayne, C., Frye, D., & Perlman, S. (2007). Investigation of dimensions of social-emotional classroom behavior and school readiness for low-income urban preschool children. *School Psychology Review, 36*(1), 44-62.
38. Raver, C.C., Garner, P., & Smith-Donald R. (2007). The roles of emotion regulation and emotion knowledge for children's academic readiness: Are the links causal? In R.C. Pianta, M.J. Cox, & K.L. Snow (Eds.), *School readiness and the transition to kindergarten in the era of accountability* (pp. 121-147). Baltimore, MD: Paul H. Brookes Publishing Co.
39. Swanson, H.L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology, 96*(4), 249-283.
40. Rothbart, M. K., & Rueda, M. R. (2005). The development of effortful control. In U. Mayr, E. Awh, & S. Keele (Eds.), *Developing individuality in the human brain: A tribute to Michael I. Posner* (pp. 167-188). Washington, DC: American Psychological Association.
41. Blair, C. & Diamond, A. (2008). Biological processes in prevention and intervention: The promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology, 20*(3), 899-911.
42. Goldsmith, D. F., & Rogoff, B. (1997). Mothers' and toddlers' coordinated joint focus of attention: Variations with maternal dysphoric symptoms. *Developmental Psychology, 33*(1), 113–119.
43. Kochanska, G., Murray, K., Jacques, T.Y., & Vandegeest, K. (1996). Inhibitory control of young children and its role in emerging internalization. *Child Development, 67*(2), 490-507.
44. Kochanska, G., & Knaack, A. (2003). Effortful control as a personality characteristic of young children: Antecedents, correlates, and consequences. *Journal of Personality, 71*(6), 1087-1112.
45. Lengua, L.J., Honorado, E. & Bush, N.R. (2007). Contextual risk and parenting as predictors of effortful control and social competence in preschool children. *Journal of Applied Developmental Psychology, 28*(1), 40-55.
46. Bodrova, E., & Leong, D. J. (2007). Play and early literacy: A vygotskian approach. In K. A. Roskos, & J. F. Christie (Eds.), *Play and literacy in early childhood: Research from multiple perspectives* (2nd ed.). (pp. 185-200). Mahwah, NJ: Lawrence Erlbaum Associates.
47. Bodrova, E. & Leong, D. (2005). Promoting student self-regulation in learning. *Education Digest, 71*(2), 54-57.
48. Bierman, K.L., Domitrovich, C.E., Nix, R.L., Gest, S.D. Welsh, J.A., Greenberg, M.T., Blair, C., Nelson, K.E, & Gill, S. (2008). Promoting academic and social-emotional school readiness: The Head Start REDI Program. *Child Development, 79*(6), 1802-1817.
49. Maughan, A. & Cicchetti, D. (2002). Impact of child maltreatment and interadult violence on children's emotion regulation abilities and socioemotional adjustment. *Child Development, 73*(5), 1525-42.
50. O'Connor, T.G., Rutter, M., Beckett, C., Keaveney, L., Kreppner, J.M. (2000). The effects of global severe privation on cognitive competence: Extension and longitudinal follow-up. *Child Development, 71*(2), 376-90.
51. National Scientific Council on the Developing Child. (2005). Excessive stress disrupts the architecture of the developing brain: Working paper no. 3. http://www.developingchild.net
52. National Scientific Council on the Developing Child. (2008). Mental health problems in early childhood can impair learning and behavior for life: Working paper no. 6. http://www.developingchild.net
53. Pollak, S.D., Cicchetti, D., and Klorman, R. (1998). Stress, memory, and emotion: Developmental considerations from the study of child maltreatment. *Development and Psychopathology, 10*(4), 811-828.
54. Sanchez, M.M., Ladd, C.O. & Plotsky, P.M. (2001). Early adverse experience as a developmental risk factor for later psychopathology: Evidence from rodent and primate models. *Development and Psychopathology, 3*(3), 419-49.
55. Liston, C., McEwen, B.S. & Casey, B.J. (2009). Psychosocial stress reversibly disrupts prefrontal processing and attentional control. *Proceedings of the National Academy of Sciences, 106*(3), 912-917.
56. Liston, C., Miller, M.M., Goldwater, D.S., Radley, J.J., Rocher, A.B., Hof, P.R., Morrison, J.H., & McEwen, B. (2006). Stress-induced alterations in prefrontal cortical dendritic morphology predict selective impairments in perceptual attentional set-shifting. *The Journal of Neuroscience, 26*(30), 7870-7874.
57. Kishiyama, M.M., Boyce, W.T., Jimenez, A.M, Perry, L.M., & Knight, R.T. (2009). Socioeconomic disparities affect prefrontal function in children. *Journal of Cognitive Neuroscience, 21*(6), 1106-1115.
58. Li-Grining, C.P. (2007). Effortful control among low-income preschoolers in three cities: Stability, change, and individual differences. *Developmental Psychology, 43*(1), 208-221.
59. Noble, K.G., McCandliss, B.D. & Farah, M.J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science, 10*(4), 464-480.
60. Noble, K.G., Norman, M.F. & Farah, M.J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8*(1), 74-87.
61. Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development, 75*(5), 1373-1386.
62. Sanchez, M.M., & Pollak, S.D. (2009). Socio-emotional development following early abuse and neglect: Challenges and insights from translational research. In M. de Haan & M.R. Gunnar (Eds.), *Handbook of developmental social neuroscience.* (pp. 497- 520) New York: Guilford Press.
63. Bos, K., Fox, N., Zeanah, C.H., & Nelson, C.A. (2009). Effects of early psychosocial deprivation on the development of memory and executive function. *Frontiers in Behavioral Neuroscience, 3*(16). doi: 10.3389/neuro.08.016.2009
64. Colvert, E., Rutter, M. Kreppner, J., Beckett, C., Castle, J., Groothues, C. et al. (2008). Do theory of mind and executive function deficits underlie the adverse outcomes associated with profound early deprivation?: Findings from the English and Romanian Adoptees study. *Journal of Abnormal Child Psychology, 36*(7), 1057-1068.
65. Gunnar, M.R. (2000). Early adversity and the development of stress reactivity and regulation. In C.A. Nelson (Ed.), *The effects of early adversity on neurobehavioral development: The Minnesota Symposia on Child Psychology: Volume 31* (pp. 163-200). Mahwah, NJ: Lawrence Erlbaum Associates.
66. Curtis, W.J., Lindeke, L.L, Georgieff, M.K., & Nelson, C.A. (2002). Neurobehavioral functioning in neonatal intensive care unit graduates in late childhood and early adolescence. *Brain, 125,* 1646-1659.

67. Feldman, R. (2009). The development of regulatory functions from birth to 5 years: Insights from premature infants. *Child Development, 80*(2), 544-561.
68. Luciana, M., Lindeke, L., Georgieff, M., Mills, M., & Nelson, C. (1999). Neurobehavioral evidence for working-memory deficits in school-aged children with histories of prematurity. *Developmental Medicine and Child Neurology, 41*(8), 521-533.
69. Jacobson, S.W., & Jacobson, J.L. (2000). Teratogenic insult and neurobehavioral function in infancy and childhood. In C. A. Nelson (Ed.), *The effects of early adversity on neurobehavioral development* (pp. 61-113). Mahwah, NJ: Lawrence Erlbaum Associates.
70. Olson, H.C., Streissguth, A.P., Sampson, P.O., Barr, H.M., Bookstein, F.L., and Theide, K. (1997). Association of prenatal alcohol exposure with behavioral and learning problems in early adolescence. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*(9), 1187-94.
71. Dodge, K.A., Pettit, G.S., Bates, J.E., & Valente, E. (1995). Social information-processing patterns partially mediate the effect of early physical abuse on later conduct problems. *Journal of Abnormal Psychology, 104*(4), 632-643.
72. Pollak, S.D. and Tolley-Schell, S.A.(2003). Selective attention to facial emotion in physically abused children. *Journal of Abnormal Psychology, 112*(3), 323-338.
73. Lewis, E. E., Dozier, M., Ackerman, J., & Sepulveda-Kozakowski, S. (2007). The effect of placement instability on adopted children's inhibitory control abilities and oppositional behavior. *Developmental Psychology, 43*(6), 1415–1427.
74. Korkman, M., Kirk, U., & Kemp, S.L. (1998). *NEPSY: A developmental neuropsychological assessment.* San Antonio, TX: The Psychological Corporation.
75. Pears, K., Bruce, J., Fisher, P., & Kim, H. (2010). Indiscriminate friendliness in maltreated foster children. *Child Maltreatment, 15*(1), 64-75.
76. Pollak, S.D., Nelson, C.A., Schlaak, M.F., Roeber, B.J., Wewerka, S.S., Wiik, K.L., Frenn, K.A., Loman, M.M., Gunnar, M.R. (2010). Neurodevelopmental effects of early deprivation in postinstitutionalized children. *Child Development, 81*(1), 224-236.
77. Klingberg, T., Fernell, E., Olesen, P.J., Johnson, M., Gustafsson, P., Dahlström, K., Gillberg, C.,G., Forssberg, H., & Westerberg, H. (2005). Computerized training of working memory in children with ADHD: A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177-186.
78. Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781-791.
79. Olesen, P.J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience, 7*(1), 75-79.
80. Rabiner, D.L., Murray, D.W., Skinner, A.T. & Malone, P.S. (2010). A randomized trial of two promising computer-based interventions for students with attention difficulties. *Journal of Abnormal Child Psychology, 38*(1), 131-142.
81. Rueda, M.R., Rothbart, M.K., McCandliss, B.D., Saccomanno, L., & Posner, M.I. (2005). Training, maturation and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America, 102*(41), 14931-14936.
82. Stevens, C., Fanning, J. Coch, D. Sanders, L., & Neville, H. (2008). Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children. *Brain Research, 1205,* 55-69.
83. Barnett, W. S., Jung, K., Yarosz, D. J., Thomas, J., Hornbeck, A., Stechuk, R., Burns, M. S. (2008). Educational effects of the Tools of the Mind Curriculum: A randomized trial. *Early Childhood Research Quarterly, 23*(3), 299-313.
84. Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318*(5855), 1387-8.
85. Raver, C.C., Jones, S.M., Li-Grining, C.P., Metzger, M., Champion, K.M., & Sardin, L. (2008). Improving preschool classroom processes: Preliminary findings from a randomized trial implemented in Head Start settings. *Early Childhood Research Quarterly, 23*(1), 10-26.
86. Raver, C. C., Jones, S. M., Li-Grining, C. P., Zhai, F., Metzger, M. W., & Solomon, B. (2009). Targeting children's behavior problems in preschool classrooms: A cluster-randomized controlled trial. *Journal of Consulting and Clinical Psychology, 77*(2), 302-316.
87. Webster-Stratton, C., Jamila Reid, M., & Stoolmiller. M. (2008). Preventing conduct problems and improving school readiness: Evaluation of the Incredible Years Teacher and Child Training Programs in high-risk schools. *Journal of Child Psychology and Psychiatry, 49*(5), 471-488.
88. Domitrovich, C.E., Cortes, R., & Greenberg, M.T. (2007). Improving young children's social and emotional competence: A randomized trial of the preschool PATHS curriculum. *Journal of Primary Prevention, 28*(2), 67-91.
89. Domitrovich, C. E., Greenberg, M. T., Kusche, C., & Cortes, R. (1999). *Manual for the Preschool PATHS Curriculum.* South Deerfield, MA: Channing-Bete Company.
90. Bodrova, E., & Leong, D.J. (1996). *Tools of the mind: The vygotskian approach to early childhood education.* Englewood Cliffs, NJ: Prentice Hall.
91. National Scientific Council on the Developing Child. (2008). Focus and planning skills can be improved before a child enters school. http://www.developingchild.net
92. Raver, C. C., Jones, S.M., Li-Grining, C., Zhai, F., Bub, K, & Pressler, E. (In Press). CSRP's impact on low-income preschoolers' pre-academic skills: Self-regulation as a mediating mechanism. *Child Development.*
93. Riggs, N. R., Greenberg, M. T., Kusché, C. A., & Pentz, M. A. (2006). The mediational role of neurocognition in the behavioral outcomes of a social-emotional prevention program in elementary school students: Effects of the PATHS curriculum. *Prevention Science, 7*(1), 91-102.
94. Domitrovich, C.E., Gest, S.D., Gill, S., Bierman, K.L., Welsh, J.A., & Jones, D. (2009). Fostering high-quality teaching with an enriched curriculum and professional development support: The Head Start REDI program. *American Educational Research Journal, 46*(2), 567-597.
95. Duncan, G.J., Dowsett, C.J., Claessens, A, Magnuson, K., Huston, A.C., Klebanov, P., Pagani, L.S.., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428-1446.
96. Shonkoff, J.P. Boyce, W.T., McEwen, B.S. (2009). Neuroscience, molecular biology and the childhood roots of health disparities: Building a new framework for health promotion and disease prevention. *JAMA, 301*(21), 2252-2259.

97. Gilliam, W.S. (2005). Prekindergarteners left behind: Explusion rates in state prekindergarten programs. *FCD Policy Brief Series, No. 3.* New York: Foundation for Child Development.
98. Grannan, M., Carlier, C., & Cole, C.E. (1999). *Early childhood care and education explusion prevention project.* Southgate, MI: Downriver Guidance Clinic, Department of Early Childhood Programs.
99. Weintraub S., Dikmen, S.S., Heaton, R.K., Tulsky, D.S., Zelazo, P.D., Bauer, P.J., Carlozzi, N.E., Slotkin, J., Blitz, D., Wallner-Allen, K., Fox, N.A., Beaumont, J.L., Mungas, D., Richler, J., Deocampo, J.A., Anderson, J.E., Manly, J.J., Borosh, B., Havlik, R. & Gershon, R. (In Press). NIH Toolbox for the Assessment of Behavioral and Neurological Function: Cognition domain instruments. *Neurology.*
100. Best, J.R. & Miller, P.H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641-1660.
101. Diamond, A. (1991a). Frontal lobe involvement in cognitive changes during the first year of life. In K.R. Gibson & A.C. Petersen (Eds.), *Brain maturation and cognitive development: Comparative and cross-cultural perspectives* (pp. 127-180). New York: Aldine de Gruyter.
102. Diamond, A. (1991b). Neuropsychological insights into the meaning of object concept development. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 67-110). Hillsdale, NJ: Lawrence Erlbaum Associates.
103. Diamond, A. (2006). The early development of executive functions. In E. Bialystok & F. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 70-95). New York: Oxford University Press.
104. Evans, G.W., & Wachs, T.D., eds. (2010). *Chaos and its influence on children's development: An ecological perspective*. Washington, DC: American Psychological Association.
105. Arnsten, A. (1998). The biology of being frazzled. *Science, 280*(5370), 1711-1712.

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