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Perspectives
on Language and Literacy

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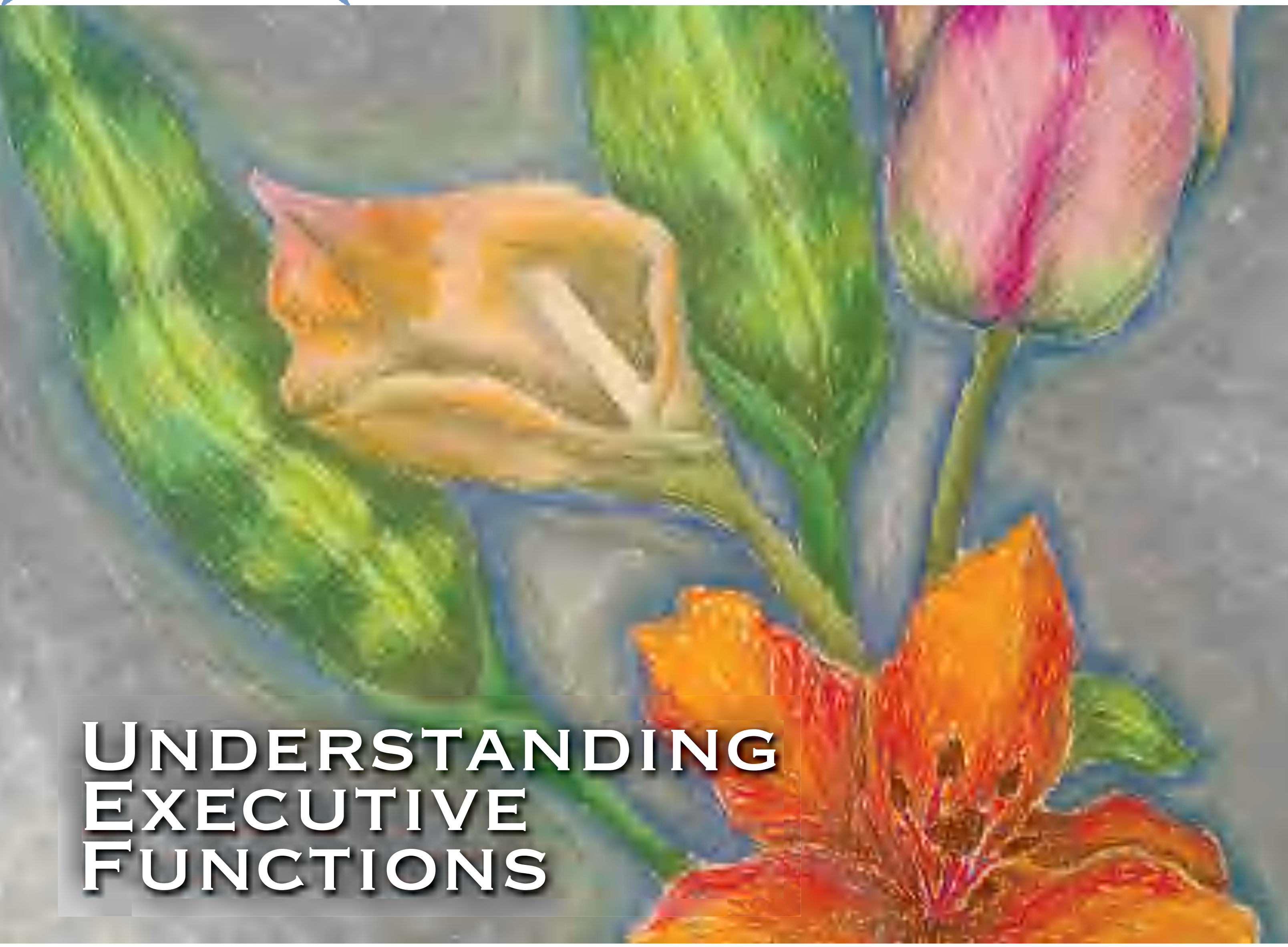

Understanding Executive Functions

The International DYSLEXIA Association®

Promoting literacy through research, education, and advocacy.™

SPRING EDITION 2014

PERSPECTIVES

ON LANGUAGE AND LITERACY

A Quarterly Publication of The International Dyslexia Association *Volume 40, No. 2*

IDA PURPOSE STATEMENT

The purpose of IDA is to pursue and provide the most comprehensive range of information and services that address the full scope of dyslexia and related difficulties in learning to read and write…

In a way that creates hope, possibility, and partnership…

So that every individual has the opportunity to lead a productive and fulfilling life, and society benefits from the resource that is liberated.

The International Dyslexia Association (IDA) is a 501(c)(3) non-profit, scientific and educational organization dedicated exclusively to the study and treatment of the specific language disability known as dyslexia. We have been serving individuals with dyslexia, their families, and professionals in the field for over 55 years. IDA was first established to continue the pioneering work of Samuel T. Orton, M.D., in the study and treatment of dyslexia.

IDA's membership is comprised of people with dyslexia and their families, educators, diagnosticians, physicians, and other professionals in the field. The headquarters office in Baltimore, Maryland is a clearinghouse of valuable information and provides information and referral services to thousands of people every year. IDA's Annual Conference attracts thousands of outstanding researchers, clinicians, parents, teachers, psychologists, educational therapists, and people with dyslexia.

UNDERSTANDING EXECUTIVE FUNCTIONS

ON THE COVER: "Flowers of Warm Colors" was contributed by Megan Schlab, an eighth grader at Rawson Saunders School.

IDA supports efforts to provide individuals with dyslexia with appropriate instruction and to identify these individuals at an early age.

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From the President's Desk

The New IDA by Hal Malchow

A transformation is taking place. Slowly, in many small steps, the International Dyslexia Association (IDA) is beginning a rebirth of purpose, growth, and effectiveness.

After a long decline, our membership is growing and by the end of June we expect to report a 20% growth. Instead of budget deficit, we are projecting a year-end surplus, a healthy surplus, for the end of the year. We have overhauled our technology and will soon unveil a new website shaped by a new board member who is one of America's leading experts in internet marketing. There is a new partnership and stronger trust between our national headquarters and our branches. Instead of pursuing too many goals, IDA is now focused on one primary goal, changing how reading is taught in America's classrooms.

This issue's cover art, "Flowers of Warm Colors," was contributed by Megan Schlab, an eighth grader at Rawson Saunders School.

At our board meeting in April, I succeeded Eric Tridas as president of IDA. In a lot of ways, I bring different skills and a different perspective to this job. I am not a dyslexia professional. I cannot speak to the science of dyslexia or the fine points of reading instruction. I am businessman and marketer who came to IDA as the parent of a boy who entered the fourth grade unable to read at all. I am a fundraiser who has worked for organizations such as the Red Cross, the U.S. Olympic Committee, and the Democratic National Committee. But while I am different than Eric in some ways, I share the same vision as Eric and our entire board—to build this organization in membership, to grow our revenues, and to focus our work on putting properly trained reading teachers in the classroom.

The progress we are making is the work of many hands. Under the leadership of Eric Tridas, we began changes that have lifted our organization. Thanks to the trust given to our board by the branches, we reformed our bylaws and have begun building a more balanced board that includes successful business people and entrepreneurs with dyslexia. One great example is John Mayo Smith who is Chief Technology Officer for R/GA, a multi-national corporation with offices in 13 countries. John works on social media for companies that include NIKE and Facebook. Now he is helping us shape IDA's new website and social media strategies to promote our own approaches to reading instruction. We also have a talented and dedicated staff that is working hard to help IDA succeed.

At its last meeting our board took two important steps:

1. We appropriated $250,000 to fund the development of a certification exam that will credential teachers who know how to implement scientifically based and clinically proven practices. The certification exam is the third piece of our reading program. The first was the publication of our *Knowledge and Practice Standards* which defines what scientific research shows us to be the most effective methods of reading instruction. The second part was our program to accredit universities who are preparing their students to enter the classroom with the knowledge and skills to successfully prevent and ameliorate reading problems. Now, at the individual level, we will have an exam that will recognize and recommend teachers who can make a difference for students with dyslexia and all other beginning readers as well.
2. We launched a search for a permanent Executive Director. Kristen Penczek, who has handled this job on an interim basis, has done a terrific job. But it is time to move ahead to fill this position.

As I look to the future, I am so excited to have this opportunity to lead a great organization with one of the most important missions in America today. When America first succeeded in the difficult mission of sending astronauts into space, many of the things they learned had benefits here on the ground. When you solve the toughest problems you benefit others as well. At IDA our leaders helped develop the techniques that could teach reading to students with dyslexia—the most difficult challenge in reading instruction. In the process we learned methods that now benefit every beginning reader. To work on this mission is a gift, for me, and for all of us.

I look forward to working to you and others in our community to continue building a new IDA with a bigger vision, a stronger voice, and accomplishments that can make a difference for students with dyslexia all across America.

Hal Malchow

Hal Malchow
President

Theme Editor's Introduction

Understanding Executive Functions: What Helps or Hinders Them and How Executive Functions and Language Development Mutually Support One Another

by Adele Diamond

This special issue on executive functions (EFs) contains seven articles from five countries (Ecuador, the Netherlands, Switzerland, the United Kingdom, and the United States) and three continents (North and South America and Europe). EFs (also called *executive control* or *cognitive control*) refer to a family of top-down processes needed when you have to concentrate and pay attention, when "going on automatic" or relying on instinct or intuition would be ill-advised, insufficient, or impossible (Diamond, 2006, 2013; Espy, 2004; Hughes, 2005; Jacques & Marcovitch, 2010; Miller & Cohen, 2001; Zelazo, Carlson, & Kesek, 2008). Using EFs is effortful; it is easier to continue doing what you have been doing than to change or to put thought into what to do next, and it is easier to give into temptation than to resist it.

There is general agreement that there are three core executive functions (EFs): *inhibitory control*, *working memory*, and *cognitive flexibility* (Miyake, Emerson, & Freidman, 2000; Diamond, 2013; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Logue & Gould, 2013). From these, higher-order EFs are built, such as *reasoning*, *problem-solving*, and *planning* (Collins & Koechlin, 2012; Lunt et al., 2012).

Inhibitory Control

Inhibitory control (or inhibition) consists of the ability to control one's attention, behavior, thoughts, and emotions to override a strong internal predisposition or external lure, and instead do what is more appropriate or needed (Diamond, 2013; Levy & Wagner, 2011; Macdonald, Beauchamp, Crigan, & Anderson, 2013; Simpson et al., 2012; van den Wildenberg et al., 2010; Watson & Bell, 2013; Wiebe, Sheffield, & Espy, 2012). Having the presence of mind to wait before speaking or acting so we give a considered response rather than an impulsive one, can save us from making fools of ourselves and help us demonstrate the best of which we are capable. Self-control is the aspect of inhibitory control that involves resisting temptations and not acting impulsively. The temptation resisted might be to indulge in pleasures when one should not (e.g., eating sweets if you are trying to lose weight), to overindulge, or to stray from the straight and narrow (e.g., to cheat or steal). Alternatively, the temptation might be to impulsively react (e.g., reflexively striking back at someone who has hurt your feelings) or to do or take what you want without regard for social norms or the feelings of others (e.g., butting in line or grabbing another child's toy). Self-regulation overlaps to a large extent (but not completely) with inhibitory control (see Diamond, 2013).

Inhibitory control at the level of attention (selective attention) consists of staying focused on what you intend to focus on despite distractions (including distracting thoughts or distractions in the environment). Another aspect of inhibitory control is having the discipline to stay on task despite distractions and completing a task despite temptations to give up, to move on to more interesting work, or to have a good time instead. This involves making yourself do something or keep at something though you would rather be doing something else. It is related to a final aspect of self-control (delaying gratification (Mischel, Shoda, & Rodriguez, 1989)) making yourself forgo an immediate pleasure for a greater reward later. Without the discipline to complete what one started and delay gratification, no one would ever complete a long, time-consuming task such as writing a term paper, or later a dissertation, or running a marathon.

Without inhibitory control we would be at the mercy of impulse, old habits of thought or action and stimuli in the environment that pull us this way or that. Thus, inhibitory control makes it possible for us to change and choose how we react and how we behave rather than being unthinking creatures of habit. It does not make it easy. Indeed, we are usually creatures of habit and our behavior is under the control of environmental stimuli far more than we usually realize, but having the ability to exercise inhibitory control creates the possibility of choice and change.

Working Memory

Working memory (WM) involves holding information in mind and mentally working with it (Baddeley, 1992; Baddeley & Hitch, 1994; D'Esposito et al., 1995, 1998; Owen, Morris, Sahakian, Polkey, & Robbins, 1996; Smith & Jonides, 1999; Smith, Jonides, Marshuetz, & Koeppe, 1998). Translating instructions into action plans requires WM, as does updating your thinking or planning, mentally re-ordering a to-do list, considering alternatives, or relating one piece of information to another.

WM is critical for making sense of anything that unfolds over time, for that always requires holding in mind what happened earlier and relating that to what is happening now. Thus, WM is necessary for making sense of spoken or written language whether it is a sentence, a paragraph, or longer. The need for WM in oral language is most obvious because what was said earlier is no longer physically present, so relating that to what you are hearing now must be done in your head using WM. However, WM is also critical for understanding what you are reading because even at the level of a sentence it is rare to see all the words at once; so we use WM to relate what we read

Continued on page 8

earlier to what we are reading now. Reasoning would not be possible without WM: WM is critical for mentally relating information to derive a general principle, to see relations between items or ideas, or to consider alternatives. WM is critical to our ability to see connections between seemingly unrelated things and to pull apart elements from an integrated whole—hence it is critical for creativity because creativity involves disassembling and recombining elements in new ways. WM also enables us to bring conceptual knowledge—not just perceptual input—to bear on our decisions and to consider our remembered past and hopes for the future in making plans and decisions.

WM (holding information in mind and manipulating it) is distinct from short-term memory (just holding information in mind). They are linked to different neural sub-systems (D'Esposito, Postle, Ballard, & Lease, 1999; Eldreth et al., 2006; Smith & Jonides, 1999) and show different developmental progressions (short-term memory develops earlier and faster (Davidson, Amso, Anderson, & Diamond, 2006)).

Cognitive Flexibility

Cognitive flexibility (the third core EF) builds on the other two and comes in much later in development (Davidson et al., 2006; Garon, Bryson, & Smith, 2008). One aspect of cognitive flexibility is the ability to change perspectives—either spatially (e.g., "How would this look if viewed from a different direction?") or interpersonally (e.g., "Let me see if I can see this issue from your perspective."). To change perspectives, we need to inhibit (or de-activate) our previous perspective and load a different perspective into WM (i.e., or activate a different perspective). It is in this sense that cognitive flexibility requires and builds on inhibitory control and WM. Another aspect of cognitive flexibility involves changing how we think about something ("thinking outside the box"). For example, if one way of solving a problem isn't working, we can use cognitive flexibility to try to come up with a new way of attacking or conceiving of the problem.

Cognitive flexibility also involves being able to adjust to changed demands or priorities; take advantage of sudden, unexpected opportunities; overcome sudden, unexpected problems; or even admit you were wrong when you get new information. Suppose you were planning to do X, but an amazing opportunity arose to do Y: Do you have the flexibility to take advantage of serendipity? There is much overlap between cognitive flexibility and creativity, task switching, and set shifting. Cognitive flexibility is the opposite of rigidity.

As teachers, we can also use cognitive flexibility. When a student isn't grasping a concept, we often blame the student: "If only the student were brighter, he [or she] would have grasped what I'm trying to teach." We could consider a different perspective, however: "What might I do differently? How can I present the material differently, or word the question differently, so this student succeeds?"

Given what has been said above, it is hardly surprising that EFs are core skills critical for cognitive, social, and psychological development, mental and physical health, and success in school and in life. EFs are critical for *school readiness* (even more critical than IQ or entry-level reading or math; Blair, 2002; Blair & Razza, 2007; Carlson & Moses, 2001; Hughes & Ensor, 2008; Kochanska, Murray, & Coy, 1997; Morrison, Ponitz, & McClelland, 2010) *success in school from the earliest grades through university* (in both language arts and mathematics; Alloway & Alloway, 2010; Borella, Carretti, & Pelgrina, 2010; Duncan et al., 2007; Fiebach, Ricker, Friederici, & Jacobs, 2007; Hamre & Pianta, 2001; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; McClelland et al., 2007; Nicholson, 2007; Savage, Cornish, Manly, & Hollis, 2006; St Clair-Thompson & Gathercole, 2006), *career success* (Bailey, 2007), *making and keeping friends* (Hughes & Dunn, 1998), *marital harmony* (Eakin et al., 2004), and *good health* (Crescioni et al., 2011; Cserjési, Luminet, Poncelet, & Schafer, 2009; Hall, Crossley, & D'Arcy, 2010; Miller, Barnes, & Beaver, 2011; Moffitt et al., 2011; Perry et al., 2011; Riggs, Spruijt-Metz, Sakuma, Chou, & Pentz, 2010).

In This Issue

One article in this special issue focuses on inhibitory control (Borst & Houdé), two papers focus primarily on working memory (Gathercole & Holmes; Gordon-Pershey), and one focuses on cognitive flexibility (Huizinga, Smidts, & Ridderinkhof). Two articles in this special issue address how EFs can support early literacy (Roebers & Jäger; Raver & Blair). Two articles focus more on how language can support the early development of EFs (Gordon-Pershey; Tobar). Four of the articles in this issue offer clear, concrete suggestions for educators and parents (Tobar; Gordon-Pershey; Huizinga and colleagues; Gathercole and Holmes).

"The Relative Importance of Fine Motor Skills, Intelligence, and Executive Functions for First Graders' Reading and Spelling Skills" by Roebers and Jäger confirms what many early educators have noticed—that early motor skills, especially fine motor skills, are predictive of school readiness and a child's readiness to learn to read. What early educators had perhaps not recognized so readily and might be interested to learn from Roebers and Jäger is that a) the reason early fine motor skills appear to be predictive of readiness for the rigors of schooling and the demands of reading is that those require EFs (when EFs are entered into analyses, the relation between fine motor skills and academic achievement or cognitive skills drops out) and b) EFs and fine motor skills are even more predictive of early math achievement than early literacy achievement (see also Blair, Knipe, & Gamson, 2008; Blair & Razza, 2007; Bull & Lee, 2014; and Gilmore et al., 2013). Roebers and Jäger end with a call for appreciating the importance of physical activities and games for building EFs and aiding school achievement.

In her contribution to this issue, "The Influence of Sleep and Exercise, Emotions and Stress, and Language on the Development of Executive Functions: Implications for Parents and Early-Years Educators," Tobar briefly reviews factors that can aid or impede the development of, or ability to use, EFs. Oral language (talking to oneself) is an extremely important aid to fragile EFs. EFs might be fragile because they are still immature, are deteriorating (as they do with aging), the brain has sustained an injury (say, in an accident or fall), or a person has not gotten enough sleep or exercise. As Tobar points out, physical, social, and emotional health are critical for cognitive health, especially good executive functioning. You may have noticed that you think less clearly and have weaker self-control when you are tired or stressed. If children's physical, emotional, or social needs are not met, their EFs and school performance will suffer. Tobar offers advice on the importance of addressing the different needs of each child and how to do it.

In Gordon-Pershey's contribution to this issue, "Executive Functioning and Language: A Complementary Relationship That Supports Learning," she points out that EFs and language skills have a recursive relation to one another: Each is important for and supports the other. EFs provide the cognitive foundation for the growth of language skills and language can be used to scaffold, support, and improve executive functioning. Gordon-Pershey provides a rich panoply of language-based strategies to help students succeed in academic contexts through exercising better EFs.

The Raver and Blair article , "At the Crossroads of Education and Developmental Neuroscience: Perspectives on Executive Function," highlights the key roles that EFs play in young children's opportunities for learning in school contexts. The authors then go on to discuss the evidence that children's EFs are shaped by social contexts, including neighborhood and family poverty, parents' and teachers' practices, and educational programs or policies. Family poverty with its associated stresses and strains has a powerful and negative impact on EFs. Home- and school-based interventions are promising approaches for supporting and improving children's EFs across early and middle childhood. Raver and Blair worry that such approaches are but bandages. They make a strong case that to make more than marginal inroads in the dramatic and devastating differences in EFs and school performance by social-economic status (SES) there is no getting around that we must alleviate the financial hardship experienced by economically strapped families by reducing poverty.

In their article, "Change of Mind: Cognitive Flexibility in the Classroom," Huizinga, Smidts, and Ridderinkhof focus on the EF component of cognitive flexibility. They provide an overview of a) the scientific research on cognitive flexibility, b) the importance of exercising cognitive flexibility in the classroom, c) the long developmental progression in children's ability to demonstrate better and better cognitive flexibility throughout childhood and adolescence, and d) practical guidelines and recommendations to help teachers and parents better support children who are suffering with problems with cognitive flexibility.

Susan Gathercole is one of the preeminent authorities on working memory (WM). In "Developmental Impairments of Working Memory: Profiles and Interventions" she and her co-author address WM impairments in a number of developmental disorders, such as specific language impairment. WM impairments are common in children and strongly predict problems in learning and academic progress. WM impairments take a variety of forms. Different profiles of WM impairments are described that partially overlap and are partially distinct. What looks like a WM impairment might actually be a problem in a different function, such as perception. Gathercole and Holmes point out that identifying the cause of WM problems is therefore critical and requires a broad assessment of functions, including, but not limited to, WM. Finally, Gathercole and Holmes discuss multiple, diverse methods for improving academic outcomes in children with WM challenges.

Last but not least, in "Inhibitory Control As a Core Mechanism for Cognitive Development and Learning at School," Borst and Houdé focus on the EF component called *inhibitory control*. Many teachers and educators assume that if children know what they should do, they will do it. Therefore, not solving a problem correctly or not behaving properly is thought to indicate either ignorance and lack of understanding or willful misbehavior and defiance. Thus, for example, Piaget assumed that young children did not understand the principles of number conservation and class inclusion because they failed his tests of those principles. However, as Borst and Houdé demonstrate, often Piaget's measures of cognitive abilities required inhibitory control abilities that are still immature in young children. Young children failed the tests, not because they did not understand the concepts, but because they lacked the inhibitory control to demonstrate their understanding on those tests.

The Borst and Houdé article underscores two general points of considerable importance. One, any test or assessment is only an imperfect indicator of the underlying ability or knowledge it is intended to measure. A child may know much more than he or she can show on a particular test. Queried a different way, a child may be capable of much more sophisticated understanding and advanced ability. Two, development proceeds both by the **acquisition** of knowledge and skills **and** by the increasing ability to **inhibit** inappropriate reactions that can get in the way of demonstrating what is already known. Between knowing the right answer or knowing what correct behavior entails and demonstrating that in one's behavior, another step, long ignored, is often needed. When a strong competing response is present, that response needs to be inhibited. It is not enough to know what is right and to want very much to act accordingly, you must do it, and sometimes an inability to inhibit an inappropriate inclination gets in the way. Adults may not appreciate how inordinately difficult inhibitory control can be for young children because it is so much less difficult for us grown-ups (Wright & Diamond, 2014).

It is hoped that readers will come away from this issue with a better understanding of what EFs are, why people who care about children's ability to read and succeed in school should care about EFs, what factors facilitate or impede EF development, and how EFs not only aid language development but how using language skills can aid EF development.

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__Adele Diamond, Ph.D.__, is a Fellow of the Royal Society of Canada and the Tier I Canada Research Chair Professor of Developmental Cognitive Neuroscience (DCN) at the University of British Columbia. She is one of the founders of the field of DCN and at the forefront of research on executive functions. Her lab examines fundamental questions about how executive functions are affected by biological factors (genes & neurochemistry) and by environmental factors (such as stress or creative interventions). Her work has improved the medical treatment for two disorders and had an impact on early education, improving the lives of millions of children worldwide.

The Relative Importance of Fine Motor Skills, Intelligence, and Executive Functions for First Graders' Reading and Spelling Skills

by Claudia M. Roebers and Katja Jäger

Children's transition into formal schooling constitutes a milestone in their development. Some specific developmental difficulties may only become apparent once children start to read and write. Therefore, it is crucial for professionals working in the educational field to continuously improve their knowledge about individual differences in young children contributing to, or indicative of, children's school readiness. This article presents results from a longitudinal study in which the role of preschoolers' fine motor skills and executive functions (EFs) for later reading and spelling skills were investigated.

Interestingly, when preschool and kindergarten teachers are asked which aspects of young children's early development are markers of their school readiness, they typically list motor skills among the top five factors. Being able to balance on a narrow tree trunk, throw and catch balls, tie one's shoes, thread beads, and draw an accurate line are considered aspects of motor skills that teachers perceive as positively related to children's school readiness. In fact, several studies have confirmed the long-supposed predictive power of motor skills for children's school readiness (e.g., Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010). Why motor skills are indicators of school readiness, however, has remained a largely unanswered question.

For a long time, developmental psychologists agreed with the general idea of Jean Piaget that the underlying mechanism for why individual differences in motor skills might explain substantial amounts of individual differences in early school achievement was that children's general maturational timetable (driven largely by biological factors, i.e., heredity) was critical for the development of both motor and academic skills (Piaget & Inhelder, 1966). From that perspective, motor skills are considered an indicator of maturation and thus mirror children's general, including cognitive, development. Support for that notion came from studies a) showing that motor skills and intellectual skills were substantially linked to each other (at a given time point in development; see, e.g., Davis, Pitchford, & Limback, 2011) and b) revealing one global "growth" factor in development. That is, individual *improvements* in spoken language, mathematical and reading skills, but also in fine and gross motor skills were relatively well explained by one global developmental factor (Rhemtulla & Tucker-Drob, 2011).

However, more recent research suggests that brain development in general or general intellectual skills provide inadequate accounts of the link between motor skills and school readiness. Different groups of researchers around the world have shown that a more specific view is better suited to explain the research findings. For example, in a large-scale study conducted in the Netherlands by Wassenberg and colleagues (2005) with over 1,300 five- to six-year-olds, general cognitive performance was **not** found to be related to either quantitative or qualitative measures of motor performance, arguing against a global relation between cognitive and motor skills. However, they found positive relationships between participants' working memory (storing and processing information), verbal fluency (for example, naming as many animals as possible in one minute), focused and sustained attention, and visual-motor integrative skills (copying geometric forms without using an eraser), and motor performance (gross and fine motor skills). All these cognitive processes (working memory and focused and sustained attention) belong to what are called *executive functions* (EFs; i.e., higher-order, top-down cognitive processes allowing an individual to suppress automatic and dominant but inadequate responses, to maintain a task goal in mind, to manipulate information held in mind, to flexibly shift attention from one aspect of a given task to another, and to quickly adapt to change). The documented links between motor skills and EF thus point to a *specific* relation between motor and cognitive performance in children.

Several other studies support the notion that the link between cognitive and motor skills is specific and driven by shared executive processes. In fact, the links between cognitive skills and motor skills appear to be closer when tasks are new, arguing even more strongly for executive processes in both domains (Roebers & Kauer, 2009) because EFs are needed when things are new or when they change, but not when a task is familiar and well-learned (Chein & Schneider, 2005; Garavan, Kelley, Rosen, Rao, & Stein, 2000; Landau, Garavan, Schmacher, & D'Esposito, 2007). Moreover, Davis and colleagues (2011) found that within the motor domain, on the one side, the link between cognitive and motor performance was driven by fine manual control, independent of a child's age. Within the EF domain, on the other side, closer links to motor skills have been reported for inhibition of automated responses and for working memory compared to other EFs.

Unfortunately, there are methodological limitations in previous studies making it difficult to draw firm conclusions about the precise nature of the link between motor skills and cognitive performance, including academic achievement. Some studies were only cross-sectional, that is, motor skills and cognitive performance were measured at the same time. Out of this kind of studies, conclusions about the relationship between the two variables can be drawn but it is not possible to determine if one variable influences or predicts the other and thus these studies do not shed light on longitudinal relationships. Other studies adopted a longitudinal perspective but then did not simultaneously include measures of EFs **and** general intellectual abilities. Therefore, in our study, we attempted to overcome some of these methodological problems and

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advance our understanding about the motor–cognitive link. Specifically, we wanted to explore whether the assumption of a specific, EF-driven link between motor skills and cognitive skills (both general intellectual abilities and also school achievement in the domains of reading, writing, and mathematics) is more compatible with empirical data than a general cognitive-motor link. This was achieved by simultaneously assessing the children's performance on tests of intelligence and academic skills, motor skills, and EFs. Additionally, we wanted to estimate the *relative* predictive power of motor skills, general intellectual abilities, and EFs for early literacy skills. We focused on reading speed, reading comprehension, and early spelling skills and in the math domain, quantity comparisons, sequences, and addition/subtraction. We included a large sample of children who were five to six years old and in preschool at the beginning of our study, followed them into kindergarten, and then finally assessed their literacy and math achievement at the end of first grade to capture the important transition into formal learning. With regard to motor skills, we targeted fine motor skills, especially manual dexterity, as previous studies have shown that fine motor skills are more important indicators of school readiness than gross motor or balancing skills.

Our Swiss Longitudinal Study

Our sample consisted of 169 children who attended one of over 20 different preschools at the beginning of our longitudinal study. These children were predominately of Caucasian origin and came from lower to upper middle class families. All the children were tested three times: first, at the end of preschool; second, a year later (at the end of kindergarten); then, children made the formal transition into elementary school and were tested a third time at the end of first grade. Over the course of the study, we lost less than 3% of the original sample (usually due to moves).

To quantify individual differences in *fine motor skills*, the three tasks of the manual dexterity subscale of the "Movement Assessment Battery for Children 2" (M-ABC-2; Henderson, Sugden, & Barnett, 2007) were administered. At the first time point, these items consisted of "posting coins into a box with a narrow slot," "threading beads on a lace," and "drawing a trail with a pen." One year later the children had grown into the adjacent age band of the test battery. The items then consisted of "placing pegs into holes," "threading a lace through holes in a board," and "drawing a narrower trail with a pen." Children were instructed to complete the tasks as fast and as accurately as possible.

EFs were measured using three different tasks: a computerized cognitive flexibility task in which families of fish had to be fed according to a rule that required alternating between categories of stimuli (i.e., randomly switching categories between trials), a Fruit Stroop task (children had to use inhibitory control to say the correct color of incorrectly colored fruit, for example, children saw a blue banana and had to respond "yellow"), and a classical working memory task (children had to recall a sequence of differently colored disks in reversed order). More details on these tasks can be found in Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, and Jäger (2014).

Children's intellectual abilities were assessed with *non-verbal, intelligence* tests (the classification-subtest from the culture-fair intelligence test - scale 1 [CFT-1; Cattell, Weiss, & Osterland, 1997] at the first measurement point and the Test of Nonverbal Intelligence [TONI-3; Brown, Sherbenou, & Johnson, 1997] at the second time point as performance on the CFT-1 was approaching ceiling. In other words, the CFT is designed for a younger age group, so most children would achieve a very good result and thus the test would no longer reveal the individual differences of interest to us). Both tests measure children's ability to reason logically, to connect ideas, and to solve non-verbal problems.

Children's early school achievement in the domains of literacy and mathematics were assessed using standardized German school achievement tests. To test spelling, children had to write 22 single nouns (illustrated with one picture each) and write one sentence they heard read aloud. For assessment of their *reading skills*, children were asked to judge the accuracy of a sentence (e.g., "It rains often in the desert"; "A week has seven days") or to search for a match meaning (e.g., choose the picture out of four that matches the written word *moon*). Mathematical achievement was assessed by four subtests of the Heidelberger Rechentest (HRT 1-4; Haffner, Baro, Parzer, & Resch, 2005), including addition, subtraction, continuing a sequence of numbers, and quantity comparisons.

As a first step and to build one broad variable each for fine motor skills, EFs, literacy, and mathematics, respectively, confirmatory factor analyses were performed. With this technique, it is possible to construct one "latent variable" for each domain, which reflects the shared processes that the tasks in a battery tap. The results revealed that the three manual dexterity tasks all belonged and related to one factor (which we shall call *fine motor skills*). The Backwards Color Recall, Fruit Stroop, and Cognitive Flexibility tasks all contributed about equally to the latent variable of EFs, and the scores for spelling, reading speed, and reading comprehension were all related to the same factor (which we shall call *literacy*). Finally, the scores for quantity comparisons, sequences, and addition/subtraction were all found to belong to the latent variable of mathematics. Thus, four major variables reflecting **only** the shared processes of the different tasks emerged and were used for the subsequent analyses.

Next, the global link between intellectual abilities and fine motor skills and their relative contribution to literacy achievement were examined using structural equation modelling. Structural equation modelling is a statistical technique that allows the estimation of relationships between variables and the prediction of specific variables through other variables. Using this technique, a model was drawn mirroring the assumed interrelations and the data from our longitudinal study was entered to test the veracity of this model. As shown by the bidirectional arrows in Figure 1 (a simplified illustration of the model) between children's non-verbal intelligence score and their fine motor skills at preschool, these variables were significantly related at this time point. Moreover, earlier fine motor skills predicted to some extent children's intelligence scores one year later, while earlier intelligence did not significantly predict later fine motor skills and intelligence proved to be relatively stable over one year. Of specific interest is the predictive power of fine motor skills and intelligence for later literacy (depicted in the right-hand portion of Figure 1): Only fine motor skills proved to be a significant predictor of children's ability to read and write one year later and explained 40% of the individual differences in literacy. In other words, when the influence of fine motor skills was held constant, no additional and specific effect of non-verbal intelligence on literacy achievement was found. It may appear that these results support a global relation between motor and cognitive performance and confirm the predictive power of fine motor skills for early literacy but we did not include EFs in this analysis.

In the final step of our analyses, we built a model in which EFs were included. We attempted to test whether there is a specific link between fine motor skills and EFs, over and above the effect of general intellectual abilities. Figure 2 depicts a simplified illustration of this model. At the first measurement point fine motor skills, EFs, and non-verbal intelligence were significantly interrelated with an especially strong link between motor skills and EFs. Fine motor skills and EFs proved to be very stable over time. As to the relative importance of fine motor skills and EFs for predicting literacy achievement, only EFs had a significant path to later literacy, explaining 46% of children's differences in literacy. Over and above the effect of EFs on literacy, neither fine motor skills nor intelligence contributed substantially to the prediction of reading and spelling skills. This pattern also held when predicting school achievement from EFs, fine motor skills, and intelligence over a two-year period of time. It is especially surprising how strong the link between EFs and academic achievement turned out to be, given the extended time period between assessing EFs in preschool and assessing academic performance two years later in grade 1.

These same conclusions hold even more strongly for predicting mathematics performance: a) The importance of fine motor skills and of non-verbal, fluid intelligence for the prediction of academic outcomes decreased to non-significance when EFs were taken into account and b) Only EFs proved to be a reliable predictor when fine motor skills, non-verbal intelligence, and EFs were integrated into one model. EFs explained a whopping 74% of children's differences in math performance at the end of grade 1!

Conclusions

Our results seemed to suggest a relationship between motor skills and cognitive performance but when we added EF the picture changed. Including EFs in the analyses allowed us to address the question of whether shared executive processes inherent in motor coordination and in intellectual abilities underlie the relation between the two. The results suggest that the link between fine motor skills and EFs is especially strong but there are also specific processes only shared by non-verbal intelligence and EFs contributing to a significant relation between them, though the relation is weaker than between fine motor skills and EFs. Additionally—although somewhat weaker—the specific link between fine motor skills and non-verbal, fluid intelligence remained significant, confirming—at least to some extent—a more global relationship between motor and cognitive performance.

Of central interest for this article was the question of the predictive power of fine motor skills for early literacy. Holding non-verbal intelligence constant, fine motor skills were found to have pronounced predictive power for school achievement in literacy (β = .59). As an aside, this finding was also true for mathematical achievement, although fine motor skills' predictive power was somewhat smaller (β = .34). This finding supports kindergarten teachers' perceptions that motor skills seem to be an indicator of school readiness. Because the tasks we included were not only tasks of "penmanship" but rather fine motor activities of children's everyday life, the predictive power of manual dexterity skills cannot simply be attributed to similarities between school activities and the requirements of our motor tasks. In addition, we had two indicators of reading (speed and comprehension) that obviously do not involve fine motor skills. Rather, this link between fine motor skills and literacy (as well as mathematics) may be due to the child's ability to master the speed-accuracy trade-off inherent in many fine motor tasks and in many school activities. In other words, fine motor skills, reading, spelling, and mathematics involve fast information processing, accurate monitoring, and sensitively

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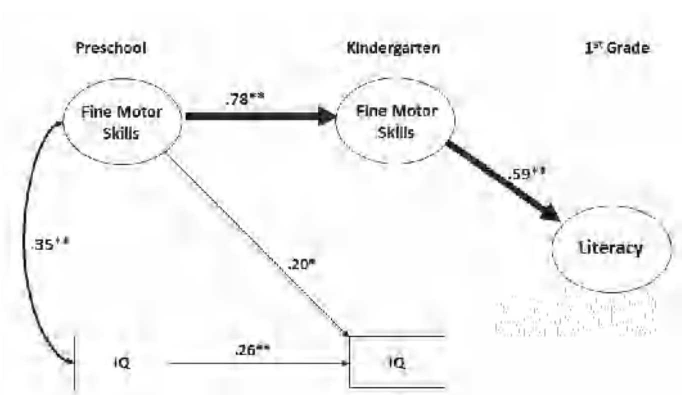

Figure 1. The relations between fine motor skills, intelligence, and literacy (* p < .05; ** p < .001)

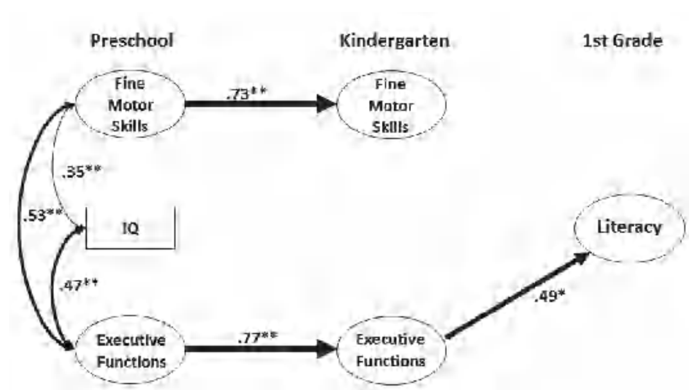

Figure 2. The relations between fine motor skills, intelligence, executive functions, and literacy (* p < .05; ** p < .001)

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adapting one's approach to present demands (e.g., taking one's time and concentrating on accuracy rather than speed for an untimed test). Thus, early fine motor skills may be considered to be an indicator of EFs that will be needed later for the cognitive demands of formal learning, including literacy and mathematics.

The inclusion of EFs into the analysis of predictors of children's early school achievement supported this interpretation. Once the influence of EFs was controlled, fine motor skills were no longer predictive of literacy and mathematics. Put another way, the relationship between fine motor skills and literacy was totally accounted for by the paths between fine motor skills and EFs, and between EFs and literacy. Executive processes such as inhibition of predominant or automated responses and of distraction, working memory, and attentional flexibility can be considered common processes involved in fine motor skills and academic achievement. Thereby, inhibition, working memory, and cognitive flexibility seem to be even more strongly needed for mathematics compared to literacy (74% versus 45% of the variance was explained by EFs in mathematics and literacy, respectively). Possibly, this difference in the predictive power of EFs is mainly driven by an especially important role of working memory for mathematics (Lee & Bull, 2014). In sum, the results of our study indicate that the mechanism underlying the relation between motor skills and academic performance appears to be EFs.

Although many previous studies have demonstrated a substantial role of EFs for early mathematical achievement, relatively few studies have focused on literacy and EFs. Our results show that EFs are also important for children's ability to learn to read and write (see also Monette, Bigras, & Guay, 2011).

Practical Implications

There are several practical implications of these and related findings: Giving children multiple and repeated occasions to be physically active, for example, playing outside, engaging in handicrafts, dance, and exercise in sports are likely to improve not only their motor coordinative skills but also provide opportunities to use and improve their EFs, and, thereby, their academic performance. There is considerable evidence in the literature that better EFs translate into better school performance (Bull & Lee, 2014). Enhancing EF development through all kinds of motor activities seems to be not only an easy way to achieve this goal but it also corresponds to child-appropriate approaches for fostering school readiness. Although the precise mechanisms contributing to this link are still not well specified, we know that the same brain regions are involved in certain motor activities and EFs tasks (Diamond, 2000) and that benefits of physical exercise to the brain regions subserving EFs (including the prefrontal cortex) can be seen on the molecular, cellular, and systems levels (Chaddock, Pontifex, Hillman, & Kramer, 2011; Hillman, Erickson, & Kramer, 2008; Kramer & Erickson, 2007; Voss, Nagamatsu, Lui-Ambrose, & Kramer, 2011). Thus, we can be relatively sure that engaging children in motor activities has a positive impact on children's development and—at young ages—their school readiness.

One may also expect that physical activities as part of interventions may prove to be a useful, child-appropriate, and easy way to improve EFs. Disadvantaged children, or more generally, children with poor EFs, might show the most EF benefits from physical activities and other interventions targeting the improvement of EFs (Diamond & Lee, 2011). But, not all forms of exercise are child-appropriate in terms of inherent game characteristics leading to fun and positive emotions in young children, an aspect that should not be underestimated when working with young children (Diamond, 2010). In a recent study by our own lab, we were able to document positive effects of a short-term (20-minute) child-appropriate physical intervention including different sport games. The post-tests on the participating second-graders showed that the physical activity had improved their inhibitory control (Jäger, Schmidt, Conzelmann, & Roebers, submitted). Such findings are very promising for tailoring evidence-based inventions for children with poor EFs.

In conclusion, the present study offers unambiguous findings and convincing evidence for the assumption that fine motor skills of preschool and kindergarten children are easily observable and signs of their executive function skills. Executive functions are important predictors of early mathematical and literacy abilities and can be positively affected through training but also through many child-appropriate games and activities, including physical exercises.

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Claudia M. Roebers, Ph.D.*, is senior professor for Developmental Psychology at the University of Bern, Chair of the Swiss Graduate School for Cognition, Learning, and Memory, and research group leader at the Center of Cognition, Learning, and Memory of the University of Bern.*

Katja Jäger, M.Sc.*, is assistant lecturer and research assistant in Developmental Psychology at the University of Bern.*

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The Influence of Sleep and Exercise, Emotions and Stress, and Language on the Development of Executive Functions:
Implications for Parents and Early-Years Educators

by Claudia Tobar

Executive functions (EFs) are known to be essential for the growth and development of a human being. Good EFs in an adult predict having a successful job, healthy living, and less possibility of committing crimes (Diamond, 2013; Moffitt et al., 2011). These behaviors certainly appear to be ones that any community and government should promote, as such behaviors benefit public safety, health, and the economy, and reduce the huge costs associated with crime, poor health, and unemployment. How can we help foster such positive behavior in young minds and thus benefit society?

Three core EFs are discussed in this article: inhibitory control, working memory, and cognitive flexibility. These functions are localized in the prefrontal cortex, a part of the brain that matures particularly slowly and does not reach full maturity until one's early twenties (Arnsten, Mazure & Sinha, 2012; Benes, 2006; Luna, 2009; Luna, Garver, Urban, Lazaar, & Sweeney, 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Sowell, Delis, Stiles, & Jernigan, 2001). The development of EFs happens over decades but the early years are crucial. Pineda (2000) suggests that between 6 and 9 years of age there is a peak in development of these functions; also see White (1970) on the 5- to 7-year shift. This peak could be due to developmental and maturation factors as well as the environmental school stimulation that children are exposed to at this age.

Some EFs such as inhibitory control are particularly difficult for young children (Diamond, 2013). Adults tend to have more control over their impulses in their daily activities. However, some children seem more mature for their age, showing more highly-developed EFs. The environmental stimulation for these children might be different, leading to more advanced problem-solving and decision-making skills.

Because, as mentioned above, the development of EFs has been shown to be highly predictive of stable jobs and overall health (Miller, Barnes, & Beaver, 2011; Moffitt et al., 2011), educators and parents have become keenly interested in children developing good EF skills in the early years. There are three principal suggestions presented below concerning factors that influence the development of EFs. Understanding the influence of emotions and stress, sleep and exercise, and oral language in promoting EF development can help educators and parents who seek to provide children with opportunities for better EFs and academic achievement.

Exercise and Sleep

Keeping your body healthy stimulates a healthy mind. Sleep and exercise have been shown to be two physical factors that affect the prefrontal cortex and EFs. For both adults and children, lack of sleep or exercise impairs cognitive performance. For example, in 2003, Sibley and Etnier analyzed the results of 44 studies related to physical activity and cognitive performance to measure the real impact of physical activity in various subjects considering numerous variables. The results showed that performance in all cognitive areas, except memory, significantly correlated with physical activity with an overall effect size of 0.32 (Sibley & Etnier, 2003). With regard to cognitive functions, different types of functions showed varying effect sizes; the highest being perceptual skills, followed by creativity and concentration and, finally, memory (2003). More recently, Hillman (2010) showed that physical activity has a positive effect on cognition, especially on executive control functions (scheduling, planning, working memory, multi-tasking, and dealing with ambiguity). Ploughman (2008) suggests there are three main possible ways physical activity has a positive impact on executive functions. The first relates to the oxygenation of the brain, the second refers to the increase of certain neurotransmitters (notably serotonin and norepinephrine, which facilitate information processing), and the final way is the upregulation of certain neurotrophins in the brain, which means an increase of the cellular component. Examples of the neurotrophins upregulated are basic fibro-blast growth factor (bFGF), insulin-like growth factor (IGF-I), and brain-derived neurotrophic factor (BDNF). In developing brains, these neurotrophins support the survival and differentiation of neurons; whereas in adult brains, they support dendritic growth and expansion and synaptic devices. Hillman (2010) concluded that research suggests that physical activity, especially aerobic, can have a positive effect on multiple aspects of brain function and cognition.

Exercise is an excellent way to keep your cognitive abilities in shape. Studies have been conducted to determine whether a direct causal relationship between exercising and improving EFs exists. However, only a few have shown strong effects (Tuckman & Hinckle, 1986; Lakes & Hoyt, 2004; Manjunath & Telles, 2001). These studies report that some types of exercise have a strong impact on EFs. Activities that combine both exercise and using EFs have shown to be the most effective (Diamond, 2012). Tae kwon do and yoga are two exercise programs that have unified physical activities with mental activation, which is essential to promoting EFs (Lakes & Hoyt, 2004; Manjunath & Telles, 2001). "In particular, the frontal lobe and the executive functions that depend on it show the largest benefit from improved fitness. The positive effects of aerobic physical activity on cognition and brain function are evident at the molecular, cellular, systems, and behavioral levels" (Hillman, Erickson & Kramer, 2008, p. 58). However,

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there is "little evidence of a significant relationship between fitness change and cognitive change" (Kramer & Erickson, 2007, p. 343). Perhaps exercise improves brain function by the way it continually challenges EFs and also brings children joy, pride, and a feeling of social inclusion by making their bodies fit and healthy (Diamond, in press).

Sleep has also been shown to have an influence on cognitive potential. Working memory, one of the three core EFs, is the ability to keep an idea in your mind and work with it. People who have not had enough sleep have a harder time holding their ideas or questions in mind while listening to others and waiting for their turn to speak. Studies performed by Paynea and colleagues have concluded that under certain circumstances sleep can promote false memories over veridical ones, and SWS (slow-wave sleep) can be associated with impairment rather than facilitation of declarative memory consolidation (2009). Moreover, during sleep, we process patterns from our day's learning; we extract the essence of what was learned and find relations between our new learning and past knowledge (also known as "consolidation"). Pace-Schott and colleagues noted the important role of sleep in memory, specifically memory consolidation within multiple memory systems including that of emotional memory (2008). Sleep is the way by which our memories—created by building up the connections among networks of brain cells—are strengthened and unnecessary details are tossed (Stickgold, Winkelman, & Wehrwein, 2004).

Emotions and Stress

Emotions have been a great focus of research in recent years; investigations on their influence on learning have attracted both neuroscientists and educators. Emotional health has been found to be crucial for brain function, and thus for learning. Diamond mentions "more learning occurs in a joyful classroom, where children feel safe, secure and accepted and where they feel the teacher sees them for who they are and genuinely cares" (2010, p. 784). Melhuish and colleagues (1990) found, in their review of early childhood programs around the globe, that what mattered most was not the quality of the materials or the adult to children ratio, but the quality of the relationship between the teacher or caregiver and the children. This safe relationship in the classroom empowers children to push the limits to take risks, to discover the unknown, and make mistakes (Diamond, 2010).

Stress has been shown to be a powerful inhibitor of learning. Stress impairs the functioning of the prefrontal cortex and impairs EFs (Arnsten et al., 2012; Liston et al., 2009). "The prefrontal cortex area in the brain that has evolved most recently, can be exquisitely sensitive to even temporary everyday anxieties and worries" (Arnsten et al., 2012, p. 50). Reducing stress in the classroom reduces teacher burnout, improves the classroom climate, and leads to better academic outcomes (Jennings & Greenberg, 2009). When stress levels rise, levels of neurochemicals such as norepinephrine and dopamine also rise in the prefrontal cortex. With levels of such neurochemicals being too high, network activity diminishes and control over our actions is ceded to older regions of our brain. Our actions become more automatic; less consciously thought through; thus, under stress, it is difficult to make good decisions. The fact that children enjoy attending school and participate in an academic activity with enthusiasm can manifest that EFs are being fostered.

Language and Bilingualism

One of the biggest milestones during the first years of a person's life is the development of language. The acquisition of language has a strong impact on cognitive growth. The possibility of communication allows an individual to improve their thinking and reasoning skills, supporting the development of EFs. The more we promote the development of language at early ages, exposing children to enriched experiences, such as new vocabulary, verbal repetition of daily events and objects, and real life application of words, the more likely they are to have the ability to communicate and exercise self-regulation. EFs will improve and their transition to school will be smoother. In children where exposure to rich language environments is limited, as in the case of children from low socio-economic status (SES) backgrounds, lower levels of EFs, including self-control, and lower levels of literacy are found (Nobel, McCandliss, & Farah, 2007). Work by Noble and colleagues has shown a strong physical brain differences among children with low SES and children who have had access to literacy enriched environments (2006).

Language has generally been studied to explore its communicational implications. Language, however, has another important aspect, which was recognized by Vygotsky in 1962: language can also serve as an internal cognitive process. "Crib speech" was named after the time where children were left alone in their beds or cribs with no visible presence of adults, and they start verbalizing important events of the day, singing and chatting (Nelson, 1989). This speech did not serve a communicative purpose. However, this "private talk" can be significant to language and cognitive development (Vygotsky, 1986). The most prominent well-researched function of "private speech" linked to important EF development is self-regulation and problem solving (Winsler, Fernyhough & Montero, 1997).

Since 1969, Luria identified "inner speech" as having an important impact on regulatory and planning functions. During early years, children seem to benefit from this type of speech when they perform verbal labeling of the objects and actions around them. "Verbal labeling is one of the many methods helping children to redirect their attention to relevant information" (Kray, Eber, & Karbach, 2008, p. 223). During their early years children tend to repeat and verbalize their actions while they are performing them. As we mature we lose this tendency and make it a silent or unconscious labeling of our actions and thoughts, but this routine can be helpful to re-direct attention between task sets and can be especially important for young children to serve as a self-cueing device (Kray, Eber, & Karbach, 2008). This labeling process can also have an impact on our behavior and can serve as action regulation recognition of our actions (Karbach, Kray, & Hommel, 2011). Findings from studies conducted by these same authors reveal that children who verbalized their actions are connecting the relevant aspects of the task, making associations more permanent and powerful (Karbach, Kray, & Hommel, 2011). As a metacognitive strategy, self-explanation can be considered an efficient way to reach greater understanding (Aleven & Koedinger, 2002).

Bilinguals also benefit from "self-explanation" where repeating the foreign word out loud can promote better retrieval of the word in the future using the rote rehearsal method (Kaushanskaya & Marian, 2007, p. 12). Learning another language may also be beneficial for the development of EFs. Research has been performed to demonstrate that learning a new language, especially at early stages in the child's development, may influence children´s language development. The results from several studies performed by Bialystock and Martin on the benefits of early bilingualism in children converge on the same conclusion: bilingualism increases children's control over their attention (2004). Children who are fluent in two languages also seem to have better inhibitory control. As shown by Bialystock (2004), bilinguals have to constantly inhibit one language to prevent ongoing intrusions. Kaushanskaya and Marian indicate that early bilingualism is crucial for modification of the underlying cognitive system by the linguistic experience (2007).

Indeed, even before children are speaking, children regularly exposed to bilingual input appear to be advanced on the EF skills of inhibition and cognitive flexibility (Kovács & Mehler, 2009). "It seems that the bilingual brain gets an exceptional workout and the results are an improved executive functions, which have benefits that extend to other subject areas and into 21st century skills" (Tokuhama-Espinosa, in press, p. 1).

Conclusions

How can we ensure that classroom environments are in fact giving children the opportunity to develop their EFs? There are a few concrete suggestions that both educators and parents can take into consideration to promote EFs according to evidence-based research.

Reducing possible stress inducers helps to create an atmosphere perceived as safe and secure; a place where mistakes are understood and accepted rather than punished. Taking measures to reduce bullying and family distress or possible abuse can help reduce students' stress. Educators can also contribute to a joyous educational experience by promoting errors as a path to success. "Children need to feel safe enough in school to push the limits of what they know, to venture into the unknown, to take the risk of making a mistake or being wrong" (Diamond, 2010).

As a parent or health provider, making sure that sleep and exercise are part of your child's daily habits safeguards healthy mental development. Physical activity should be a regular part of a child's day. Teachers should be cautious when seeing children that are not performing as usual; one of the reasons may simply be sleep deprivation or excessive inactivity.

Language is an important development milestone during early years. Exposure to enriched conversations and learning a new language can enhance EFs. Language not only used for communication but also for enhancing personal mental processes has also shown to promote cognitive development. "Crib talk" or "inner speech" are important language activities by which children develop labeling and associations of the world around them, allowing them to enhance their attention process (Kabach, Kray, & Hommel, 2011; Kray, Eber &, Karbach, 2008). Self-explanation has also been recognized as an efficient metacognitive strategy to reach better understanding (Aleven & Koedinger, 2002).

Fostering EF from the early years of development has shown to have a positive impact in future development. Once again the conclusions stress the rewarding effects of a healthy body on cognitive development. This new feedback from neuroscience should encourage teachers, parents, and early childhood caregivers to be more aware of the environment that will contribute to healthy EFs for the next generation of children who will become the future thinkers, leaders, and citizens of our society.

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Claudia Tobar *is the Director of the Institute of Teaching and Learning (IDEA) at the Universidad San Francisco de Quito, USFQ, in Ecuador. She also teaches at the education department in the undergraduate program. She is Editor in Chief of* Revista Para el Aula*, a magazine from and for teachers. She was the General Coordinator for the Mind Brain Education Congress 2013 organized by IMBES. Claudia holds a masters degree in Special Education and Early Childhood.*

Executive Functioning and Language:
A Complementary Relationship That Supports Learning

by Monica Gordon-Pershey

Executive functions are the mental processes used to perform activities of self-regulation. Examples of everyday self-regulation skills include paying attention, planning, organizing, strategizing, prioritizing, managing time and space, and reasoning (National Council for Learning Disabilities [NCLD], 2013; for a full description see Diamond, 2013). Simply put, executive functioning refers to the thinking processes that govern how individuals choose *what to do*, and when to do it, how to do it, and why to do it. Not so simply, however, the question then becomes *how do individuals get to the point of knowing what to do?*

The answer appears to be that three predominant mental processes facilitate getting to the point of knowing what to do. These processes, known as the executive functions, structure how the mind thinks. One primary executive function is *cognitive flexibility* (meaning, being able to consider alternatives). A second core executive function is *inhibitory control* (the ability to consider when to act and when to *not* act, that is, the ability to choose which actions to exhibit and which to inhibit) (Diamond, 2013).

Although the ability to remember is not in itself an executive function, a third main executive function is *working memory* (Baddeley & Hitch, 1994; D'Esposito, 2002; Smith, 2000). Working memory is the ability to hold information in mind while thinking about it—the use of the so-called "mental sketchpad." Working memory provides a basis for flexible thinking and self-regulation because working memory keeps the current situation in mind long enough for an individual to consider alternatives and inhibit overly quick reactions.

The three main executive functions work together to allow the mind to choose what to focus on and to hold this priority in mind long enough to think about it. At the same time, executive function inhibits involvement in other circumstances that would detract from thinking about the matter at hand. Executive functions are needed to process, understand, and react to information, circumstances, and events.

Executive functioning takes advantage of recall memory, which includes information storage (i.e., remembering and recalling) and integrates past experiences with present contexts. Memories that are recalled help influence decision-making and identifying optimal actions (Kaufman, 2010). If these cognitive processes are present and working appropriately, they guide individuals to knowing what to do.

However, this is not the entire course of the mind's actions. *The human mind must then experience the cognitive processes it generates*. How does the mind experience, for example, that it is remembering? In many cases, the mind uses language to think and reason. The mind makes sense of its resources of memories, choices, and strategies by putting thoughts into words. This process is known as *verbalization*. Verbalized thoughts help to govern actions. Verbalization occurs during speaking and writing and in self-talk, which happens when individuals silently or quietly use inner language to talk to themselves while thinking.

Verbalization is one of the most critical ways by which the mind reasons. Perhaps it is easiest to think about how important it is for the mind to put thoughts into words by considering the rare situations where a person acts before the mind has time to translate its processes into words—for instance, when a parent steps instantaneously between her child and an oncoming car. Sometimes people act without processing thoughts into words. Language is not necessary in order to act. These actions occur by acting on impulse, and they are sometimes lifesaving. Nevertheless, much of the time, acting impulsively, without allowing language enough time to mediate thoughts, results in actions that are not the best course. Most of the time, language is used so that the mind can translate its cognitive resources of working memory, choice making, and past experiences into words, and these words can guide actions.

Academic Learning Involves Verbalization of Verbal Reasoning

The process that the mind uses to consider events and information, to think about circumstances, and to solve problems by using language is known as *verbal reasoning*. Academic learning requires students to have considerable capacity for verbal reasoning and to be able to *verbalize* their verbal reasoning—to put their thinking into words. Although the mind can reason nonverbally and people can think explicitly in images, the bulk of academic learning pertains to demonstration of verbal reasoning.

Schoolwork generally requires that students verbalize aloud or in writing in order to demonstrate that they have learned concepts and skills. A fair proportion of schoolwork involves remembering and recalling verbal information that describes abstract concepts and complicated events that the students have not experienced first-hand. Students are required to reason through this verbal information in order to produce verbal products: they take tests, write papers, work in cooperative groups, give presentations, and complete other school tasks that involve considerable use of language.

In the context of academic learning, with its emphasis on verbal reasoning, the relationship between executive functioning and language is ongoing and complementary. Attention, working memory, information storage, and integration of experiences with present contexts are brought to bear in the ongoing cycles that the student and teacher engage in: thoughts are verbalized; then these verbal messages are thought about some more, and then more verbalization occurs. Studying involves repeated verbal rehearsal of the information to be learned. For students to progress academically, ongoing cycles

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of verbalization of verbal reasoning must be maintained throughout a class period, and then, cumulatively, for days, weeks, and even years.

To demonstrate learning, a student's underlying cognitive skills are operationalized as language output. To *operationalize* a skill means to show how the skill is put to use—to demonstrate by overt evidence that the skill is occurring. The cognitive act of remembering actually becomes the linguistic act of recounting; the cognitive act of understanding is evidenced by the learner's overt demonstration of verbal reasoning, in spoken or written form. Parents, educators, and other service providers can observe what the student does or does not say, but they cannot actually be certain of what the student does or does not know. Overt language provides a window on executive functioning, and possibly serves as the best available proxy for observing how students manage their executive skills. (Other windows onto what students know include their demonstrations of nonverbal responses (as in asking a child to demonstrate a behavior, point, or gesture), and evidence of thinking in images (e.g., "Draw a picture of your answer.") Traditional schoolwork, however, may not offer many opportunities to use nonverbal behaviors to demonstrate the learning of verbal information.)

Success in School (and in Life) Involves Verbalization of Executive Functioning

Students' executive functions are evidenced by their use of language. Reciprocally, learners can use language to regulate how they employ executive functions. Some learners may not have well-developed self-regulation of the cognitive resources that govern attention, working memory, decision making, and identification of optimal action. One strategy for improvement is for learners to use language to bring their executive functions into conscious focus. Verbalization of executive functioning is an important component of *how individuals get to the point of knowing what to do*. Learners can be taught to verbalize the cognitive processes that they need to employ. A common example of this is when parents and teachers ask children to verbalize the choices available in a given circumstance and describe the reasons why one choice would be better than the others. In so doing, the child is given the opportunity to hold both the goal and the prohibitions firmly in mind.

Another component of how individuals get to the point of knowing what to do is to use language to become aware of what they are thinking and feeling. Cognitive flexibility, inhibitory control, and working memory allow for two aspects of thinking that are particularly important for school success: metacognition and social-emotional regulation (Kaufman, 2010). Metacognition regulates *thinking about thinking*. When students reflect on their own thought processes, their levels of emotional arousal are usually not high, so metacognition is called "cold" functioning (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Hongwnishkul, Happaney, Lee, & Zelazo, 2005; Kerr & Zelazo, 2004). When students use executive function to regulate their affect, social-emotional reactions, and related behaviors, levels of emotional arousal are usually somewhat higher, so these functions are termed "hot" (Brock et al., 2009; Hongwnishkul et al., 2005; Kerr & Zelazo, 2004).Two key considerations about language and executive functioning are apparent in both cold and hot contexts. First, learners must be able to use language reflectively to interpret the world and govern their behavioral repertoire. Second, language, when used in the service of executive functioning, can bring about purposeful and independent thinkers. Instruction and intervention can address enhancing how learners use language to demonstrate what they think, know, and are able to do in cold and hot contexts.

Enhancing Metacognition

Metacognition allows learners to think about and describe their own thought processes. Learners' metacognition is visible when parents and educators ask questions that guide learners to reflect upon their learning. Parents and teachers can encourage learners to verbalize the specific language that guides their thinking. These reflective questions encourage cognitive flexibility, in that students can approach a learning task by making a variety of connections among ideas. During reflective questioning, students employ working memory to hold important knowledge in mind and think with care and detail. Students need inhibitory control during reflective questioning to stay focused and organized, and to recall relevant concepts and disregard irrelevant or extraneous thoughts. Learners can reflect upon their learning in many ways, as the following examples illustrate.

Cognitive flexibility is enhanced when students develop verbalizations that pertain to how their prior knowledge relates to current learning. Adults can model **metacognitive questions**, so that students learn to verbalize connections among ideas. Adults can teach students to ask themselves questions such as

- *What did I already know that helped me answer today—and how do I know that this was important to remember?*
- *How did I find my answer?*
- *What is my reason for my answer?*
- *What was I thinking of that helped me answer?*
- *What made me say that answer?*
- *When (or where) did I learn that, and why is it important now?*
- *When have I thought about this before, and why is it important now?*
- *Who told me something that helped me answer, and why is it important now?*

Working memory is apparent when students employ **verbalizations to help them self-monitor** their attention to tasks. Verbalizations may include

- *Am I listening attentively?*
- *Am I making sure my mind doesn't wander?*

- *Am I paying close attention to what the teacher is saying?*
- *Have I read and understood the directions?*
- *Am I understanding what I am reading?*
- *Am I sure that I completed every question?*
- *Have I checked for key words, as in questions that say* not *or* except*?*
- *Am I making sure that I understand what I am reading?*

Working memory **verbalizations guide self-regulation**, for example,

- *The teacher has been talking for an hour. What are the important points that she said?*
- *I took notes – what do my notes mean?*

Organizational verbalizations are used for bringing planning and prioritizing into working memory and may include

- *Are my materials organized for school tomorrow?*
- *Do I have homework tonight, and how much time should I plan to do it all?*
- *Have I organized my materials for my homework assignments?*
- *Do I understand the instructions for this paper?*
- *What is the best way to tackle this job?*
- *How do I set up a page so I can take notes during class?*
- *How long will it take to finish my project?*
- *On Thursday, should I tell the teacher that I am going to miss school on Friday for a doctor's appointment and take home my weekend homework?*

Much of self-regulation involves the simultaneous application of cognitive flexibility, working memory, and inhibitory control. **Self-regulatory verbalizations** can help learners keep track of their performance, with queries such as

- *What motivates me?*
- *What is my goal?*
- *How can I keep myself on task?*
- *What can I do if my persistence fails?*
- *How much more work must I do before my break?*
- *After break, how do I make myself get back to work?*

Verbalizations that help self-regulate environmental interactions include

- *Whom can I go to for help?*
- *How am I supposed to act in this situation?*
- *How are the rules in this class different from the rules in my other class?*
- *What does this teacher like students to do – how can I get her to like me?*

In a related way, awareness of context is an important component of the executive functioning needed to self-regulate environmental interactions. Learning about the nuances of different contexts can be very difficult. Adults can assist by providing guidance for **understanding what a context entails**. Queries include

- *What are the rules or conventions of this context?*
- *What brings about success in this context?*

More specifically, adults can provide **context previews**, where they help learners find the answers to questions such as

- *Where will you be?*
- *Who will be there?*
- *What will they be doing?*
- *What will you be doing?*
- *What's an example of a good choice there?*
- *What's an example of a poor choice there?*

Learners can be taught to use **context scans** when they are in unfamiliar settings, for example,

- *What is going on here?*
- *Who is in charge here?*
- *What is my role here (my job)?*
- *What are my other options?*
- *How is this place like (and not like) other places?*
- *How long do I have to stay?*
- *Who can help me—and in what ways do they help?*
- *What can I gain?*
- *What might embarrass me?*

Similarly, context reviews can help learners **think about a context and store important information**. Questions might be

- *Why were you there?*
- *Did you make any good choices?*
- *Did you make any poor choices?*
- *What will you do the same/differently next time?*
- *What did you learn to say there?*

Enhancing Executive Functions to Regulate Social-Emotional Responses and Behaviors

Cognitive flexibility, working memory, and inhibitory control allow individuals to regulate their display of their social-emotional responses. Executive functions underlie the reflectivity and adaptability that are necessary to incorporate social feedback and determine whether to initiate or inhibit behavior.

Learners can use verbalization so that the mind can translate impulses, memories, and choices into words, and these

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words can then guide actions. Learners can use language before, during, and after their actions; language helps them plan, govern, and review what they have done. They can use language to generalize concepts across social and emotional contexts. This may be done by learning social scripts and socially acceptable interaction patterns, by becoming able to predict what others may say and do, and by being able to perceive and interpret the thoughts, feelings, and actions of others.

Verbalizations can pertain to predominantly social or predominantly emotional matters. Social verbalizations guide interactions with others and regulate behaviors such as speaking, sharing, and avoiding. Learners can verbalize their perceptions of social scenarios and their judgments about what to say and do. Role-playing can illustrate the pros and cons of initiating or inhibiting certain interactive behaviors. Adults can **stimulate verbalizations** by asking learners to consider questions such as

- *Why do my actions affect others?*
- *How do I know what the right thing to say is?*
- *What is helpful when interacting with others?*
- *Why do other people act for themselves (and not just do what I want)?*
- *What kinds of words and actions are hurtful?*

Emotional verbalizations enable individuals to initiate or inhibit emotions and reactions to emotions, either as overtly demonstrated or covertly experienced. For example, a school-age child who feels disappointed by losing a game may tell himself that he does not need to cry each time he is disappointed. This child has kept a covert feeling from causing an overt behavior, even if no one else were to see the behavior. Verbalization has helped the child self-regulate.

Learners use language to self-console and to delay gratification. Verbalizations can reinforce adaptability (*Sometimes I can do what I want, and sometimes I cannot, and here's why*) and reflectivity (*I will do that again—and here's why*, or *I will not do that again—and here's why*, or *I will change how I do that—and here's why*).

Learners' social verbalizations and emotional verbalizations demonstrate their cognitive flexibility, working memory, and inhibitory control. Their overt verbalizations openly show the nature and quality of their reflective thinking. From these demonstrations, caregivers can determine the executive functioning capacity that learners bring to a situation and can consider how to guide learners to enhanced levels of executive functioning.

Conclusions

Executive functions are the cognitive processes that activate thought, regulate thinking, learning, and behavior, and help individuals interpret the world, other persons, and themselves. Learners use their executive skills to initiate and inhibit their thoughts and actions. Verbalization—putting thoughts into words—allows learners to use executive functions optimally for the verbal reasoning that is necessary for academic learning. Metacognitive thinking and social-emotional learning and self-regulation are also dependent upon verbalization.

The intent of this article has been to describe how employing verbalization reveals underlying executive functioning and, reciprocally, that verbalization can lead to better conscious use of executive functions. The examples and suggestions provided in this article emphasize the importance of adults explicitly teaching these verbalization skills to learners. Adult guidance is particularly important for learners whose ability to verbalize is limited due to language deficits or language-based learning needs. It may be necessary for these learners to receive overt instruction in using language to enhance executive functioning. Adults who guide school-age children and adolescents to use language purposefully to examine their thinking and reasoning are fostering successful and independent learners.

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***Monica Gordon-Pershey, Ed.D., CCC-SLP**, an Associate Professor at Cleveland State University, Cleveland, OH, co-edited the Summer 2013 issue of* Perspectives on Language and Literacy *titled "Syntax: Its Role in Literacy Learning." A past president of the Northern Ohio Branch of the International Dyslexia Association and a participant in many International Dyslexia Association initiatives, Dr. Gordon-Pershey has authored over 120 papers and presentations on language and literacy and the professional development of speech-language pathologists and teachers.*

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

by C. Cybele Raver and Clancy Blair

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

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

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

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

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

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

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

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

Can EF Be Shaped By the Environment?

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

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

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

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

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

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

Change of Mind: Cognitive Flexibility in the Classroom

by Mariëtte Huizinga, Diana P. Smidts, and K. Richard Ridderinkhof

Daily life is full of changes—a change of plan, an unannounced event, an unexpected problem that needs to be solved, a new environment, or a surprise sudden opportunity. Changes call upon flexibility—one needs to abandon the current direction and adjust one's thoughts or behavior to the new situation. Flexibility is therefore essential for social and goal-directed behavior (Huizinga & van der Molen, 2011), and is considered to be one of the core executive functions (e.g., Miyake et al., 2000). In what follows, we will provide 1) an overview of scientific research into flexibility, which develops during childhood and adolescence; 2) an evaluation of problems with flexibility that children may experience in the classroom; and 3) practical guidelines and recommendations for teachers and coaches on how to deal with such problems.

The following example illustrates how flexibility is put into action in a school situation: Jim, a 12-year-old student, prepared his presentation for today really well. He is looking forward to it and is particularly curious about the reaction of his teacher. When Jim arrives at school, he discovers that there is a substitute teacher, as his regular teacher fell ill. Jim is disappointed and a bit angry, even though he is aware that his own teacher did not fall ill on purpose. Jim then overcomes his initial reaction and realizes that he can enjoy some of the things the substitute teacher is good at, such as telling stories.

Changes in the environment often involve emotional adjustment. Fear, apprehension, sadness, disappointment, or frustration may follow an unexpected change. For instance, Jim in the example above experienced disappointment and even some anger when discovering that his own teacher was not at school. Flexible adjustment to the new situation requires the reappraisal of these negative emotions and a shift to more positive thoughts or feelings (Gross & John, 2003). Jim succeeds by telling himself that his own teacher cannot help falling ill, and that the substitute teacher is also okay because of his talent for telling stories.

As children grow older, they become increasingly more proficient at adjusting to changing circumstances (e.g., Diamond, 2006). They need relatively less time to get used to new situations, and the transition consumes less of their energy. Moreover, they improve on their ability to regulate their emotions. Children gradually learn how to adjust to new circumstances, learn from earlier mistakes, and come up with alternative solutions for a problem. They become increasingly able to distribute attention and meanwhile process different sources of information (Cragg & Chevalier, 2012).

Studying Flexibility

Researchers examining cognitive flexibility often make use of tests that require children to learn certain rules. These tests look like card sorting games where children are asked to pay attention to, for example, the shape or the color of the pictures. As soon as children have learned (and mastered) a rule, a new, different rule is introduced. Subsequently, the children need to switch between the two rules alternatively. The ability to switch between rules indicates a child's ability to think flexibly. Thus, researchers examine children's ability to learn (and master) rules and their ability to switch between these rules (Crone, Bunge, van der Molen, & Ridderinkhof, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molen, 2006).

Complex tests. A classic test to examine cognitive flexibility is the Wisconsin Card Sorting Task (Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtis, 1993). In this task, a person is presented with playing cards with pictures of different shapes (stars, squares, circles, or triangles). The pictures on the cards differ in color (red, yellow, blue, or green) and number of items (one, two, three, or four figures). The cards can be sorted in three ways: according to shape, number, or color. The person is asked to sort the cards, without being told these sorting rules in advance. Now the person needs to infer the correct sorting rule by trial and error, based on the experimenter's feedback. After each sort, the experimenter tells the person whether a sort was correct or incorrect. The first sort is always correct, whatever sorting rule the person used is accepted. For the next several trials, this sorting rule will be the rule to be adhered to. After ten consecutively correct sorts, however, the experimenter changes the sorting rule without informing the person about the rule change. The experimenter merely tells the person that the sort was incorrect, and feedback on subsequent card sorts is based on the new sorting rule. The person now needs to adjust his or her behavior by leaving the initial (and now incorrect) sorting rule and searching for a new sorting rule. The adequacy of flexible switching among sorting rules is indexed by counting the number of attempts to find a new sorting rule, the number of correct changes to a new sorting category, or, alternatively, the number of card sorts in which the person *perseverates* in sorting according to the previously correct sorting rule (i.e., the number of card sorts in which the person keeps repeating the now incorrect sorting rule). A number of studies have shown that children of about 7 years of age are able to do the Wisconsin Card Sorting Task, but they find the task very difficult (Chelune & Baer, 1986; Cragg & Chevalier, 2012). It takes them quite long to find the new sorting rule. They have difficulty letting go of a sorting rule once they have discovered it. Children of about age 12 perform much better on the Wisconsin Card Sorting Task: they need less time to find a sorting rule and find it easier to let go of a rule. Thus, 12-year-olds are better able to flexibly switch compared to 7-year-olds. Research also shows that children of about age 15 perform as well on the Wisconsin Card Sorting Task as young do adults of about age 21. Thus, the ability to flexibly switch among multiple different rules develops until mid-adolescence.

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In rudimentary form, cognitive flexibility manifests itself in children as young as about 2 ½ to 3 years old (Brooks, Hanauer, Padowska, & Rosman, 2003; Perner & Lang, 2002). Four-year-olds begin to show an understanding that one can sort cards with a blue car and a red flower following two different sorting rules: color or shape (Zelazo, 2006). In a computer test modified for children age 5 to 8 years (Luciana & Nelson, 1998), after a number of correct sorts, the child automatically proceeds to the next difficulty level; when the task becomes too difficult, it self-terminates. Five-year-olds are able to find a sorting rule and adjust their behavior accordingly. Six-year-olds are also able to apply a new sorting rule to the same pictures that they already responded to with a different sorting rule in previous levels. Children age 7 to 8 years are even more proficient: They are better able to learn and apply rules and to more quickly and accurately adjust their behavior to new circumstances.

Task switching. Research with tests such as the sorting tasks discussed above is associated with a number of drawbacks. These tasks not only require cognitive flexibility but also other abilities such as counting, concept formation, working memory, and the ability to inhibit a previously correct response. Thus, these tasks do not comprise pure measures of cognitive flexibility. In an attempt to circumvent such problems, during the past years, new—more process-pure—tasks have been developed to measure cognitive flexibility. These so-called "task-switching" tests are computer based and aimed at children of about 6 years and older (see Cragg & Chevalier, 2012).

The idea behind this task-switching paradigm is simple. As in card-sorting tasks, the child has to learn two rules: Respond either to the color or to the shape of the figures. However, which rule should be applied is not to be inferred from feedback, but is indicated by a cue that appears on the screen before the color/shape figure on each trial. Once the child has learned both rules separately, the child is required to switch between those two rules. A series of color trials is followed by a series of shape trials, which is again followed by a series of color trials, and so on. The sequence of trials consists of trials where the task is repeated (task-repetition trials) and trials on which the task changes (task-switch trials). The ability to flexibly switch between tasks can be examined by comparing reaction times and accuracy on task-repetition trials and task-switch trials.

Research with adults typically shows that responses on task-switch trials are slower and less accurate compared to task-repetition trials (Monsell, 2003). This difference is referred to as "switch costs" (or "local switch costs") and provides an index of the ability to flexibly switch from one rule to another rule. Research with the task-switching paradigm in children is fairly recent (Davidson et al., 2006; Huizinga et al., 2006). The outcomes show that switch costs of 7-year-olds are larger compared to switch costs of 11-year-olds, which are larger than switch costs of 15-year-olds. Switch costs of 15-year-olds do not differ from switch costs of young-adults. Thus, based on the outcomes of research with the task switching paradigm, cognitive flexibility appears to develop until mid-adolescence.

Problems with Flexibility

Adjusting behavior to changing circumstances is not easy. This is particularly true when a change occurs unexpectedly, such as when a plan for a picnic in the park needs to be canceled because of unanticipated rain. Children respond differently to (unexpected) changes. Some children tend to get angry, while others adjust smoothly to the new situation. Some children resist change or need more time to adjust, while others are excited by the change and readily engage in exploration of new circumstances.

Individual Differences. The way in which a child manages the need to switch depends on the nature of the change itself, and how the child values the change. For instance, relatively minor and neutral changes (e.g., "we are out of pasta, so today we'll have pizza for dinner") will usually have less impact than relatively major changes (e.g., changing schools) or, in the eyes of the child, sensitive changes (e.g., "today you should wear your green sweater because your favorite blue Thomas-the-Train shirt is in the laundry"). As noted above, as they grow older, children become more proficient at adjusting to new circumstances. In addition, as the brain develops, the capacity to process new information improves (Crone & Ridderinkhof, 2011), children become progressively more competent at grasping and overseeing a new situation, and hence accommodate more easily.

Some children experience severe difficulties in adjusting to new situations, and big or small changes are equally adverse to them. Any change is distressing for them. These children prefer to keep things the way they are and stick to their routines. Their ability to respond flexibly usually stays worse than their peers even when they become older. Such children can be perceived by others as rigid, strict, or stubborn.

Typical Problems. Tables 1 and 2 illustrate behavior that is typically seen in children and adolescents experiencing problems with flexibility. Note that every typically developing child shows inflexible behavior every now and then. It is the frequency of the behavior that is important. The greater the degree and frequency of inflexible behavior, the more it interferes with daily activities. When a child is stressed or under pressure (e.g., during an exam period, or when there is a quarrel) a normally more flexible child might be inflexible because under stress or pressure all executive functions, including flexibility, are impaired (e.g., Arnsten, Mazure, & Sinha, 2012). In children experiencing problems, most incidences of changing circumstances (either small or more substantial changes) result in uneasy, insecure feelings. The following suggestions demonstrate how children experiencing problems with flexibility can be supported. These suggestions apply to daily life at school.

Remedial Action

The suggestions below are intended to help students who experience problems with flexibility to function and deal with those issues more smoothly in the classroom. (These suggestions derive from an analysis based on Dutch classroom situations, which are not unlike those in the United States, as presented in Smidts & Huizinga (2011a)). The goal of these suggestions is to ensure that the student obtains insight into tasks or routines, including daily and weekly tasks, ranging from routines in learning school-related skills to the planning and completion of assignments.

Keeping to daily and weekly routines. Children experiencing problems with flexibility function best in an environment that is predictable, constant, and consistent. Therefore, following routines is of great importance for these children. In general, routines that are tailored specifically to an individual child are easier to manage at home than at school. Nevertheless, several methods exist for teachers or coaches to help a child function more optimally in a school environment. The following suggestions are intended to render the classroom environment as predictable as possible for students that have trouble adjusting to new circumstances.

- Use a calendar, and display it at visible locations in the classroom, for instance next to the door. Stickers or pictograms can be used for children who cannot yet read fluently.
- Prepare students for today's activities. Pick a quiet moment in the morning to visit with a child at his or her desk and explain what's on today's program.
- Announce a change of activities in advance (e.g., "We'll start with arithmetic in ten minutes.") A while later, repeat the announcement (e.g., "Don't forget, five minutes left before arithmetic.").
- Try and arrange materials systematically within the classroom and use easily visible labels.
- Make clear appointments with a student. Sometimes it helps (also for class-mates) to print the appointments and display them visibly in the classroom.
- Avoid too many changes at once. For instance, when an intern will be visiting next Monday, and next Thursday's class will be shorter than usual, don't announce these messages both at the same time. Spreading out these messages makes them easier to digest.

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TABLE 1. Behaviors Indicative of Problems with Cognitive Flexibility in Children

Problem Behavior	Example
Needs relatively more time to get used to unknown situations.	Attending school for the first time or change of schools, a birthday party, going to the dentist for the first time.
Has difficulty with new people.	Behaves detached or clingy in the presence of unknown visitors, a new teacher, a different baby-sitter, the doctor.
Gets upset when something in the environment changes.	New furniture at home, or a change of location of the furniture, when stuff normally stored in one specific spot (shoes, toys, books) is moved.
Has difficulty stopping ongoing behavior to change and do something different.	Gets confused when it is announced that it is time to go home or when the classroom needs to get cleaned up to start a new activity.
Gets frustrated when others disobey regulations or behave unexpectedly.	Gets angry when the neighbor does not take off his shoes when he enters the house or when a cousin only wants to paint pink flowers when it had been 'agreed' they would both make a drawing of a farm.
Has difficulty getting used to a change in daily routine.	Gets upset when picked up from school by foot instead by car or when groceries still need to be picked up after school, contrary to the daily routine.

TABLE 2. Behavior Indicative of Problems with Cognitive Flexibility in Adolescents

Problem Behavior	Example
Has difficulty coming up with alternative solutions for a problem.	Gets stuck when needs to come up with a way to get to school after finding out that buses are on strike.
Gets upset in new situations or a new environment.	Gets angry about a new teacher or change of room.
Resists change of plans.	Panics when a plan that was made earlier unexpectedly changes: "We first have to pick up your new glasses before we visit grandma and grandpa."
Resists change of routine.	Becomes irritated when dinner is ready later than usual.
Has difficulty accepting disappointment or a reprimand.	Stays frustrated for a long time when something does not work out, for example, a difficult homework assignment.

Providing instructions and helping with assignments. The way in which a child receives instructions to a large extent determines if she or he will understand the goal and the type of assignment. For a student having problems with switching, it helps to indicate in advance which steps are important for completing the assignment (without giving away too much information). The essence lies in reducing the complexity of the task and providing the student with an analysis of what she or he needs to do. The goal of the following suggestions is to provide instructions as clearly as possible to a child experiencing problems with adjusting to new circumstances.

- Try to be as specific as possible about the assignment: What is the goal, what exactly is expected from the child?
- Provide ample examples of comparable assignments.
- Provide insight into general strategies for solutions, such as approaches that have previously been applied successfully. ("Remember, how we solved … last week? The current assignment is similar. Like last week, we will do … again. But we'll do it slightly differently this time, so that …").
- Try to make the assignment as clear as possible by breaking it down into small chunks of information. Eventually, make a checklist of the independent pieces.
- Make templates for repeating or similar assignments.

The goal of the following suggestions is to support a student when working on the assignment.

- Provide extra time for new assignments.
- Provide as much positive feedback as possible ("Go on, you are doing well, keep up the good work") while avoiding negative feedback ("You completed four different tasks already, well done! Try and do one more" rather than, "There are six tasks that you still haven't finished, so try a little harder").
- Help a student remember the individual steps of the assignment and their sequence ("When you finish this, then you can proceed with …").
- Analyze together with the student what went well and where there's room for improvement. Try to get him or her back on track with step-by-step instructions.

Build on school-related skills. Many school-related activities call for flexibility in one form or other, such as changing perspective. For example, when working on a writing assignment, one may need to find different words that share the same meaning. When getting stuck during arithmetic, one needs to discover and try out alternative solutions. Both cases require flexible adjustment. The suggestions below are aimed at helping children with difficulties adjusting to new circumstances with school-related activities.

- Practice writing from the student's perspective ("Describe how you rode a bicycle in front of your home. What did you do? What happened?")
- Practice writing from someone else's perspective ("How would your neighbor describe your bike ride?")
- Be clear about the topics that will be covered during an exam or quiz.
- Give children practice with the different kinds of tests before they are given the actual test.
    - What does a question aiming at knowledge look like? How will the topic of the question be introduced? What will you ask of the student exactly?
    - What does a question aiming at insight look like? How is the topic introduced? What will you be asking of the student?
    - What does a question aiming at practical application look like? How is the topic introduced? What will you ask of the student?

Summary

Social and goal-directed behavior in classroom situations requires a child to think and behave in a flexible manner. New situations may call upon a change in thoughts or behavior. When the current situation changes, a child is required to adjust to the new situation. This often involves adjusting, or regulating, emotions. Young children are less able to adapt to a new situation, as this skill is not fully developed until mid-adolescence. The more flexible someone is, the less time and energy it takes to get used to a new situation. Problems with flexibility become observable when a child needs more time to adjust to a new situation relative to other children, or when changes cause feelings of discomfort within a child. Predictability and routine are essential for children experiencing problems with flexible adjustment. The results of empirical research on the development of children's flexibility will foster practitioners' tools to provide tailor-made interventions for children with difficulties adjusting to new situations.

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***Mariette Huizinga, Ph.D.**, is Associate Professor in Educational Neuroscience at the ‘LEARN!’ Research Institute (Department of Educational Neuroscience), at the VU University Amsterdam. The main focus of her research is on the development of self-regulation and socio-emotional development in relation to school performance.*

***Diana Smidts, Ph.D.**, works as a pediatric psychologist at the outpatient clinic of the department of Clinical Child and Adolescent Studies at Leiden University, The Netherlands. Her interests are in disorders of childhood that have an impact on the brain, including both developmental and acquired disorders.*

***Richard Ridderinkhof, Ph.D.**, is Professor in Neurocognitive Development & Aging and Chair of the Dept. of Developmental Psychology at the U. Amsterdam. His work focuses on the cognitive and neural mechanisms of decision-making and action control, and how these may be enhanced through training, motivational factors, affect induction, pharmacological intervention, or deep-brain stimulation.*

Developmental Impairments of Working Memory: Profiles and Interventions

by Susan E. Gathercole and Joni Holmes

Impairments of working memory (WM) are a feature of many of the most common cognitive disorders and have been suggested to contribute to many of the associated learning difficulties (McLoughlin & Leather, 2013; Rose, 2009). Understanding the origins of these problems is a vital step toward identifying ways of effectively supporting the struggling child. In this article we review recent developments in this field that have the potential to advance therapeutic and educational practice to improve learning outcomes for individual children.

WM provides the temporary storage of information necessary to support many everyday cognitive activities. This system involves the coordination of high-level executive control of attention with temporary storage, providing the ability to work with the items while they are in temporary storage. According to one influential model (Baddeley, 2000; Baddeley & Hitch, 1974), higher-level control is provided by the limited-capacity central executive. This is supplemented by specialized verbal and visuo-spatial stores, often referred to as short-term memory (STM).

The subcomponents of WM act in concert to provide consciously accessible representations of recent events that are vital to a wide range of cognitive abilities including mental arithmetic (Adams & Hitch, 1997), following instructions (Yang, Gathercole, & Allen, 2013), and the comprehension of language (Cain, Oakhill, & Bryant, 2004). Failures of WM are closely associated with inattentive and distractible behavior both in children and adults (Gathercole, Alloway, Kirkwood, Elliott, Holmes, & Hilton, 2008; Kane et al., 2007). This may reflect the loss of crucial task-relevant information from WM needed to guide goal-directed mental activity.

Profiles of Working Memory Impairments

Three profiles of impairment and their links with patterns of learning difficulties are described below.

Deficits in Verbal WM

Verbal WM is assessed by tasks such as reading span (a test in which the participant reads each of a succession of sentences and then attempts to recall the final word of each in the same sequence) and backward digit span (involving the immediate recall in reverse order of a sequence of spoken or written digits). Such tasks depend both on the storage of verbal material (STM) and the attentional control of working memory (Alloway, Gathercole, & Pickering, 2006; Kane et al., 2004). Deficits on these measures and also on verbal STM tasks have been widely reported in groups with Specific Language Impairment (SLI) (Archibald & Gathercole, 2006; Montgomery, 2000). The magnitude of the deficits in complex WM tasks is often greater than would be expected on the basis of the verbal STM problems alone (Majerus, Heiligenstein, Gautherot, Poncelet, & Van der Linden, 2009). One possible reason for this is that the low quality of the temporary memory representations in STM requires executive involvement even in simple storage tasks. This may lead to even greater problems in complex tasks that place simultaneous demands on both the storage of verbal information and other processing too, which then must compete for limited executive resources (Archibald & Gathercole, 2006).

Deficits in Visuo-Spatial WM

A disproportionate impairment in WM for nonverbal information such as patterns, movements, and other detailed physical features has recently been reported for children with dyscalculia, a condition characterized by impaired mathematical abilities but age-typical reading (Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2013). However, domain-general impairments of WM are more typical of children whose academic learning difficulties extend across both reading and mathematics difficulties. There may therefore be two distinct pathways through WM to impaired mathematical learning.

General Deficits in WM

Some children have deficits extending across verbal and visuo-spatial WM, and these have been widely interpreted as arising from an impairment in the executive control of WM. Domain-general deficits of WM are characteristic of many children with ADHD (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and can also be detected through screening in the general school population (e.g., Archibald & Joanisse, 2009). Children with this profile are at high risk for poor academic progress in reading and mathematics (Gathercole, Pickering, Knight, & Stegmann, 2007; Swanson & Sachse-Lee, 2001).

Causes of WM Impairments

There is no single WM disorder, but multiple patterns of impairments that overlap across different specific learning difficulties many of which, such as reading difficulties and attention deficit and hyperactivity disorder (ADHD), co-occur. WM profiles provide important clues to the underlying cause of the child's cognitive problems but are not in themselves

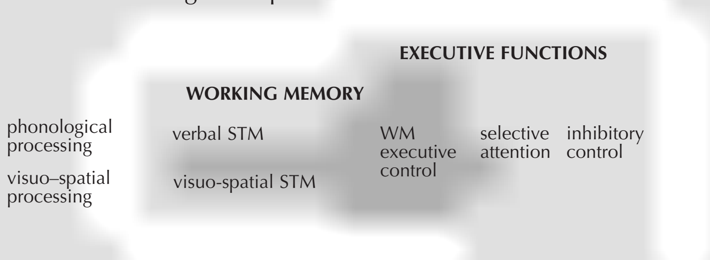

Figure 1. Working memory in its broader cognitive context. For the purposes of illustration, executive functions shown are restricted to working memory, selective attention, and inhibitory control.

sufficient to pinpoint the core deficit. This is because, as shown in Figure 1, working memory is an integral part of a broader cognitive system. It receives inputs from perceptual systems that process phonological and visuo-spatial material, and the quality of these inputs will inevitably have an impact on the quality of their representations in WM. For example, poor perceptual processing skills will lead to deficient storage in verbal STM, which will limit the ability to perform more complex verbal WM activities that depend in part on this system.

Phonological processing deficits have been extensively documented in SLI and dyslexia (Bishop & Snowling, 2004), and provide a plausible explanation for the associated verbal WM impairments. However, it cannot be assumed that impaired phonological inputs are invariably the cause of verbal WM impairments. In some cases, the deficit may originate specifically within WM. Direct testing of phonological processing abilities is therefore vital to establish whether verbal memory problems are the consequence of perceptual processing difficulties.

As Figure 1 shows, interactions between WM and the broader cognitive system extend beyond the interface with perception. The attentional control of WM is part of a broader network of executive functions mediated by frontal networks in the brain. Other functions include selective attention, inhibitory control, set switching, and planning (Miyake et al., 2000; Pennington & Ozonoff, 1996). Weak or inefficient frontal networks will disrupt multiple executive functions, including the executive component of WM. A domain-general deficit in WM is therefore not in itself sufficient to conclude that the source of the performance impairment originates within the memory system.

Broad impairments of WM characterize many children with ADHD and also some individuals with low WM identified through community screening (Archibald & Joanisse, 2009; Gathercole, Alloway et al., 2008). Could their problems be a consequence of more pervasive executive function deficits? Evidence on this issue is mixed. Studies of children with general deficits in WM, reported impairments in shifting between response sets and planning, but not in inhibitory control (St Clair-Thompson, Stevens, Hunt, & Bolder, 2011) or teacher ratings of other aspects of executive control (Gathercole, Alloway et al., 2008). In children with ADHD, the greatest executive function impairments are found in WM, planning and response inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Thus, problems in the executive control WM appear to lack specificity and are associated with impairments in at least some other executive functions. This raises important issues concerning the extent to which learning difficulties are consequences of problems in working memory *per se*, or in the broader network of executive functions.

Interventions for WM Problems

The past decade has seen an explosion of interest in whether working memory can be enhanced through intensive training regimes that adapt continuously to maintain challenge as performance improves through repeated practice. In adults, WM performance shows sustained improvement after adaptive training, and is associated with changes following training in the fronto-parietal network serving WM (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Westerberg & Klingberg, 2007).

The Cogmed® WM Training (CWMT) program employs intensive adaptive training of multiple visuo-spatial and verbal working memory tasks over 25 days. Suitable for children from 4 years, it is effective in boosting performance both on the trained activities and on other similarly structured tasks (Klingberg, 2010). These gains have been found to persist for up to a year after training in children with ADHD (Chacko et al., 2013; Dunning, Holmes, & Gathercole, 2013; Klingberg et al., 2005) and in children with low working memory (Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009). However, the functional gains following CWMT are disappointingly limited. Gains are largely restricted to tasks similar to the trained activities, with little evidence of more consistent transfer either to tasks approximating more closely to classroom activities that tax WM or to educational attainments in key areas such as reading and mathematics (Diamond, 2011; Dunning et al., 2013; Melby-Lervag & Hulme, 2013).

Another approach is to encourage children to use effective mnemonic strategies that might relieve the pressure on relatively low memory capacities. St Clair Thompson and colleagues (2010) reported promising findings using the Memory Booster program to teach typically developing five- to eight-year-old children to use strategies such as rehearsal, visual imagery, creating stories, and grouping. It is also valuable to target the classroom environment of the child with poor WM more broadly to minimize the adverse educational consequences of WM overload (Elliott, Gathercole, Alloway, Holmes, & Kirkwood, 2010). A key step is boosting teacher understanding of WM involvement in classroom learning and of practical issues such as the warning signs of WM failure (failing to see multistep tasks through to completion, inattention, and distractibility). When these warning signs are detected, the WM loads of classroom activities can often be reduced. This can be achieved by reducing the length or complexity of verbal information to be remembered (e.g., breaking down multistep instructions or having the children write down things they need to remember). External memory aids for the child (such as digital audio recorders or personalized mini whiteboards) can also be useful, as well as practice in using mnemonic strategies in areas of strength (Archibald & Gathercole, 2006). Further information on classroom-based approaches is provided by Gathercole and Alloway (2008).

For children with core WM deficits, the most promising approach may be to combine intensive training, strategy training, and classroom-based support. For other children, such as those with verbal WM deficits associated with phonological processing difficulties, training may be of less value as it fails to address the likely underlying deficit of analyzing and representing phonological forms. Instead, phonologically based training is a priority (Hulme & Snowling, 2009) and may indeed boost verbal WM (Melby-Lervag & Hulme, 2010). However, these benefits will take time to accrue and may not be sufficient to enable children with phonological deficits to match the WM capabilities of their typical peers. This will cause continuing problems in meeting the high memory

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demands of the classroom and is likely to result in inattentiveness and difficulties in following instructions (Gathercole, Darling, Evans, Jeffcock, & Stone, 2008), as well as problems in language understanding (Pimperton & Nation, 2012). Classroom-based support and strategy training may therefore be valuable adjuncts to phonological training for these children.

Overview

Impairments of WM are common and are linked with problems in learning and academic attainment. They take several different forms and may reflect deficits either within WM, in earlier perceptual processes, or in the network of executive functions. A broad assessment of cognitive functions including but not limited to WM is therefore vital. Methods of supporting children with WM problems include intensive training, practice in using mnemonic strategies, and modulating the classroom environment to avoid WM overload. Choice of suitable methods of support is best guided by an understanding of the child's core deficit. Although this deficit will be the priority target for interventions, effective management of WM loads may improve classroom functioning while interventions targeting the core deficits are ongoing.

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Professor Susan E. Gathercole, Ph.D.*, University of Cambridge, is a cognitive psychologist with interests in memory and learning both in typical development and in children with learning difficulties. Her research over the past 30 years has focused on the role of working memory in aspects of learning including language and reading. Susan is the Director of the MRC Cognition and Brain Sciences Unit at Cambridge and is currently investigating the underlying causes of working memory impairments and methods including cognitive training for overcoming them.*

Joni Holmes, Ph.D.*, is a research scientist for the MRC Cognition and Brain Sciences Unit, Cambridge, UK. Her interests include the overlap between working memory, attention, and executive function processes in children and adults. Joni is currently developing and evaluating targeted interventions to overcome core deficits that predispose individuals to cognitive developmental disorders.*

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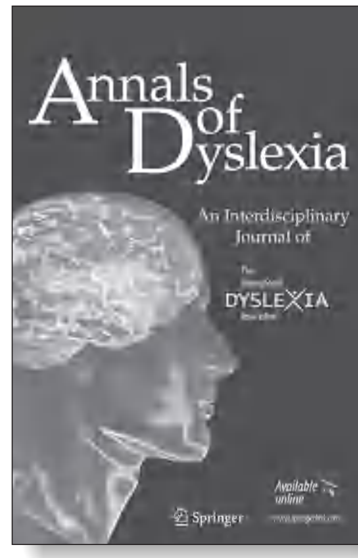

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Inhibitory Control As a Core Mechanism for Cognitive Development and Learning at School

by Grégoire Borst and Olivier Houdé

We present new findings here suggesting that some systematic difficulties on classic Piagetian logic problems and in school are due to problems with the component of executive functions known as inhibitory control. Examples of the kinds of cognitive challenges that might require inhibitory control in school are a) whether to use a singular or plural tense verb when the subject of a sentence is "the friends of my sister" or "the dog of the neighbors" or b) whether to add or subtract when told, "Jamie has $5. That is twice as much as Jean has," and asked, "How much does Jean have?"

In one of Jean Piaget's famous problems, the number-conservation task, two rows with an identical number of objects were presented with the objects in the two rows in one-to-one correspondence. When the children acknowledged that the two rows possessed an identical number of objects (i.e., initial equivalence), one of the rows was transformed in length but not in number (e.g., the objects were spread farther apart). Children were then again asked whether the two rows had an identical number of objects. Children before the age of 7 tend to say that the longer row contains more objects than the shorter row (Piaget, 1954, 1983). According to Piaget, how children of different ages respond to this problem reveals a fundamental shift (i.e., a new stage) in the logical structure of children's minds.

In Piaget's constructivist theory, a child achieves an increasingly complex understanding of the physical world by acting on objects around him or her. In this view, cognitive development is linear and cumulative. It is linear because children will acquire, with age, knowledge of increasing complexity. It is cumulative because new mental structures build upon earlier ones; prior structures are not replaced but transformed.

However, by studying infants' gazes rather than their actions (or motor "schemes") as Piaget did, researchers have shown that Piaget underestimated the cognitive abilities of infants. For instance, infants appear to be able to perceive numerical invariance in situations similar to the one presented in Piaget's number-conservation problem, in which length and number conflict (Antell & Keating, 1983). If infants have rich knowledge of physical and mathematical principles as numerous studies have demonstrated (e.g., Spelke, 2000; Wynn, 1992), why then do older children commit systematic errors in Piagetian problems that are supposed to test the same knowledge that infants demonstrate they have?

Such findings led some to suggest that cognitive development should not be viewed as linear but as non-linear and dynamic (Siegler, 1999). Accepting that theoretical framework, our neo-Piagetian model (Houdé, 2000) postulates that at each age and in each context, children and adults potentially have access to heuristics and logico-mathematical algorithms to solve a problem. *Heuristics* are shortcut strategies for reaching judgments. They enable one to reach a decision quickly with minimal effort, but at the cost of occasionally generating the wrong solution (Gilovich & Savitsky, 1996; Shah & Oppenheimer, 2008). *Algorithms*, on the other hand, are slow and effortful. They involve applying analytical strategies that can be relied on to produce a correct answer (Kahneman, 2011). In any unfamiliar context, heuristics and algorithms compete. Children and adults prefer using perceptual or cognitive heuristics because they are so easy and fast (Houdé, 2000). Inhibition of the temptation to rely on those heuristics by the prefrontal cortex and interrelated structures is critical to avoid errors in situations in which a misleading heuristic competes with a logical algorithm for generating the answer (Houdé, et al., 2011; Houdé, et al., 2000; Poirel, et al., 2012). This ability to inhibit misleading heuristics is directly related to maturation of the prefrontal cortex, and brain imaging studies have demonstrated that the prefrontal cortex undergoes a prolonged maturation from infancy to adolescence (e.g., Casey, Tottenham, Liston, & Durston, 2005). Critically, the sequence in which the cortex matures parallels cognitive milestones in cognitive development. Regions critical for primary motor and sensory skills mature earliest, with temporal and parietal association cortices associated with basic language skills, spatial attention, and numerical abilities maturing next; the last to mature is the prefrontal cortex and the inhibitory-control ability it makes possible. This maturational sequence can explain why inhibiting misleading strategies remains challenging throughout childhood and early adolescence.

In what follows, we first present converging behavioral and brain-imaging evidence (i.e., evidence from diverse methods and approaches that support the same conclusion) that success in two classic Piagetian problems (the number conservation and the class-inclusion tasks [defined below]) reflect the ability to inhibit a misleading heuristic and not a new cognitive stage as Piaget hypothesized. Next, we present new findings suggesting that systematic difficulties in school can also be explained by a failure to inhibit knowledge acquired in previous years of schooling.

The Role of Inhibition and Prefrontal Maturation in Resolving Classical Piagetian Problems

How can we explain that children only succeed at Piaget's test of number conservation by about age 7 when infants and younger children understand that irrelevant transformations, such as the length of an alignment, does not affect the number of objects in that alignment (Antell & Keating, 1983; Melher & Bever, 1967; see also Lipton & Spelke, 2003)? Our hypothesis is that children use a set of numerical heuristics during childhood and that in some contexts (such as on Piaget's classic tests) those heuristics are misleading. Failure to inhibit those heuristics leads to systematic errors. In the case of number conservation, we hypothesized that children fail to inhibit the length-equals-number heuristic, a visuo-spatial strategy highly

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reinforced not only in our visual environment but also in mathematics textbooks (e.g., some illustrations used to teach children to count depict increasingly longer horizontal rows of objects to indicate increasing number). To demonstrate that inhibition of the length-equals-number heuristic is needed to succeed at the number-conservation problem, Houdé and Guichart (2001) designed a negative priming paradigm. In the classical negative priming paradigm, participants performed pairs of stimuli. The first stimulus of the pair is called the *prime*; the second one the *probe*. Classically, participants' performance is measured on the second stimuli (i.e., probes). Critically, performance is compared between probes in which the target is a distractor inhibited on the first stimulus (i.e., the test trials) and probes in which the target bears no relation with a distractor inhibited on the prime (i.e., the control trials). The logic of the negative priming approach is thus as follows: If information (or a perceptual or cognitive heuristic) was previously ignored (or inhibited), then the subsequent processing of that information (or the subsequent activation of that heuristic strategy) will be disrupted as revealed by slower or less accurate responses (see, e.g., Borst, Moutier, & Houdé, 2013; Tipper, 2001). For instance, a negative priming effect is observed if participants are slower to identify the central letter on the probe (e.g., HHHCHHH), when preceded by a prime in which the target letter was a distractor (e.g., CCCBCCC) than when preceded by a prime in which the target letter was not a distractor (e.g., VVVBVVV).

In the study by Houdé & Guichart (2001), fourth-graders performed control and test trials. In the second part of each trial (i.e., the probe), two rows in which length and number co-varied (i.e., the longer row contained more objects) were displayed. On control trials, objects were displayed in the first part of the trial (i.e., the prime) in such a way that counting each object was the only appropriate strategy (i.e., the objects were displayed vertically for one row and horizontally for the other row). Thus, the strategy appropriate for the prime did not require inhibition of the strategy appropriate for the probe. Conversely, on the first part of the test trial (i.e., the prime), two rows of different length but with the same number of objects were presented. To respond correctly that the two rows contain the same number of objects, children had to inhibit the length-equals-number heuristic. Thus, the misleading heuristic that had to be inhibited during the first part of each test trial was the appropriate strategy for the second part of each test trial. Comparison of response times on the probe (i.e., the second half of each trial) for test and control trials revealed a clear negative priming effect: Children of 9 years were slower to use the length-equals-number heuristic if during the first part of that trial they had received a Piaget-like number-conservation test item that required that the heuristic be inhibited. Further behavioral studies from our laboratory have shown that children's ability to succeed on Piaget's classic number-conservation task depends on their ability to inhibit the misleading length-equals-number heuristic (Houdé & Guichart, 2001; Houdé et al., 2011; Poirel et al., 2012; for demonstration in adults, see Daurignac, Houdé, & Jouvent, 2006).

An additional functional magnetic-resonance-imaging (fMRI) study conducted in our lab showed that a network including regions involved in inhibitory control (such as an area within the prefrontal cortex [the right inferior frontal gyrus] and an area in the posterior parietal cortex) is activated in children who succeed at the number-conservation task but not in children who fail (Houdé et al., 2011). A fMRI follow-up study (Poirel et al., 2012) revealed that the level of activation within the right inferior frontal gyrus was selectively related to the inhibitory control efficiency of children assessed with an adaptation of the Color-Word Stroop task for preschool and school children (Wright, Waterman, Prescott, & Murdoch-Eton, 2003). Even adult brains must inhibit the length-equals-number heuristic to succeed at Piaget's number conservation problems as evidenced by the modulation of the electrical activity (measured by an electroencephalogram) of the prefrontal areas of the brain involved in inhibition of prepotent response (e.g., Daurignac et al., 2006).

Moreover, it seems that failure to inhibit a misleading heuristic may also be at the root of errors observed in the class-inclusion problem designed by Piaget (Inhelder & Piaget, 1964). In this categorization task, ten daisies (subordinate class A) and two roses (subordinate class A') are presented and the child is asked whether there are more daisies or more flowers (superordinate class B). Children younger than 7 years typically respond that there are more daisies. (Note that that is a rather odd question to ask, and if the problem is presented differently much younger children succeed [e.g., Donaldson, 1978; Siegel, McCabe, Brand, & Matthew, 1978]. We are addressing here what is needed to succeed at the problem as Piaget posed it.) Children younger than 7 years err because instead of comparing the superordinate class (flowers) to its subordinate class (daisies), they directly compare the two subordinate classes. According to Inhelder and Piaget (1964), this error reflects that young children lack the conceptual principle needed to grasp the underlying logic of class inclusion (B = A + A'). We have shown that is not the reason they err.

Using a negative priming paradigm, Perret, Paour, and Blaye (2003) found that 9-year-old children were slower to determine in the second part of the trial (i.e., the probe) that there were more daisies than roses (when presented with a picture of ten daisies and two roses and asked whether they were more daisies than roses) after they successfully determined in the first part of trial (i.e., the prime) that there were more flowers than daisies (when presented with a picture of ten daisies and two roses and asked a typical class inclusion question, i.e., Are there more daisies than flowers?). This is consistent with children needing to inhibit direct perceptual comparison of the two subordinate classes (their first inclination) in Piaget's task to compare the overall number of flowers to a subclass of flowers. Using a similar negative priming paradigm, we replicated the results of Perret and colleagues (2003) and also demonstrated the negative priming effect in adults, though of a smaller magnitude than observed in children (Borst, Poirel, Pineau, Cassotti, & Houdé, 2013). Taken together, these results suggest that a) increasing efficiency in solving class-inclusion problems with age might be related to the growing ability to inhibit comparing two subclasses, and that b) the misleading heuristic (directly comparing classes at the same hierarchical level) is still used by adults.

Thus, we found that success on the way Piaget framed number-conservation and class-inclusion problems relies on the same ability to inhibit misleading heuristics. Cognitive development, it would seem, relies not only on the ability to acquire knowledge of incremental complexity (Piaget, 1983) but also on the executive ability to inhibit previously acquired knowledge or prepotent tendencies (e.g., Bjorklund & Harnishfeger, 1990; Dempster, 1992; Diamond, 1991, 1998; Harnishfeger, 1995; Houdé, 2000).

The Role of Inhibition in Overcoming Systematic Difficulties at School

Thus far, we have presented converging evidence that succeeding at classical experimental problems in the lab relies on the ability to inhibit a misleading heuristic. A question is whether failure to inhibit a misleading heuristic can also explain some systematic difficulties children have in the classroom. In a first study (Lubin, Vidal, Lanöe, Houdé, & Borst, 2013), we focused on simple arithmetic word problems. The resolution of such problems remains challenging not only for school children but also for adults (Verschaffel, 1994); although, they involve simple arithmetic operations such as addition and subtraction mastered at a very young age (see Lubin, et al., 2010; Lubin, Poirel, Rossi, Pineau, & Houdé, 2009; Wynn, 1992). For example, children have difficulty with arithmetic word problems such as *Bill has 20 marbles. He has 5 more marbles than John. How many marbles does John have?* Here, the relational term (*more than*) is inconsistent with the arithmetic operation (subtraction) required. Most errors on these types of problems are reversal errors characterized by adding the numbers instead of subtracting them or vice versa (e.g., Stern, 1993).

We hypothesized that solving this type of problem might remain challenging because children fail to inhibit the "add if more, subtract if less" misleading heuristic. To test that, we designed a negative priming paradigm for sixth graders, ninth graders, and adults. On both control and test trials, participants performed pairs of arithmetic problems. In the second part (i.e., probe) of each problem, participants were asked to solve arithmetic problems in which the "add if more, subtract if less" heuristic led to the correct solution (e.g., "*Bill has 20 marbles. John has 5 more marbles than Bill. How many marbles does John have?*"). In the first part of the control trials (i.e., prime), participants solved neutral problems in which inhibition was not needed (e.g., "Bill has 25 pens. John has 10 pens. Who has more pens?") Whereas in the first part of the test trials (i.e., prime), participants solved problems in which the "add if more, subtract if less" heuristic had to be inhibited (e.g., "Bill has 20 marbles. He has 5 more marbles than John. How many marbles does John have?"). All groups were slower to solve a problem in which the "add if more, subtract if less" heuristic led to the correct solution when that solution was preceded by a problem in which this heuristic had to be inhibited, than when it was preceded by a neutral problem in which inhibition was not needed. These negative priming effects observed in children, adolescents, and adults suggest that performing simple arithmetic word problems when the relational term is incongruent with the required arithmetic operation relies not only on the ability to grasp the logic of the problem but also on the ability to inhibit a misleading strategy or inclination. Thus, the increased speed and accuracy with which this type of problem is solved from childhood to adulthood (Verschaffel, 1994) may be directly related to developmental improvements in inhibitory control due to the maturation of the prefrontal cortex and its connections with related brain regions (Johnson, 1999).

Results in two additional studies from our lab on subject-verb-agreement errors in sentences such as "the dog of the neighbors eat" (Lanöe, Lubin, Vidal, Houdé, & Borst, under review) and on mirror errors in reading, for example, confusing *b* with *d* and *p* with *q* (Borst, Ahr, Roell, & Houdé, 2014) provide convergent evidence that a failure to inhibit a misleading heuristic might also be at the root of systematic difficulties in literacy.

Conclusion

Taken together, our behavioral and brain-imaging results suggest that designing pedagogical interventions based on training children to inhibit misleading heuristics might be a way to help them overcome systematic difficulties they face at school in mathematics or literacy. This meta-cognitive training consists of making children aware that there is a trap in certain contexts and that they should inhibit the misleading strategy or inclination in order to overcome systematic difficulties they encounter at school. Pedagogical interventions based on training the inhibition of heuristics (or reasoning biases) not only improve logical reasoning to a greater extent than ones based solely on verbal logic per se (Houdé, 2007; Houdé et al., 2000; Houdé & Moutier, 1996; Moutier & Houdé, 2003) but also help children in the classroom overcome systematic difficulties to a greater extent than traditional curricula (Lubin, A., Lanoë, C., Pineau, A., & Rossi, S., 2012).

Given that executive-function training is especially beneficial for children with lower executive function efficiency (see Diamond & Lee, 2011), it might be critical to implement at school pedagogical interventions designed to improve inhibitory control, namely for children at risk (for instance children from disadvantaged backgrounds: Noble, Houston, Kan, & Sowell, 2012).

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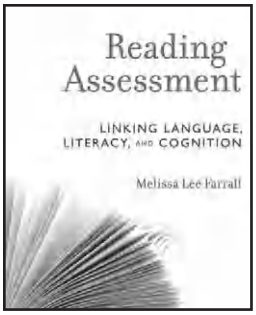
Grégoire Borst, Ph.D.*, is an assistant professor in developmental psychology and cognitive neuroscience at Paris Descartes University. He obtained his Ph.D. in 2004 from the Paris South University. He was a postdoctoral fellow for three years and a research associate for one year at Harvard University in the Stephen M. Kosslyn Lab. His work focuses on the basic properties of visuo-spatial mental imagery and more recently on the role played by mental imagery in the reversibility of operation in Piagetian tasks. Recently, he has started to study the development of executive control efficiency in particular in number and categorization tasks to determine whether inhibition is domain-specific or domain-general at a behavioral and neural level.*

Olivier Houdé, Ph.D.*, received his doctorate in psychology in 1991 from the University of Paris Descartes – Sorbonne and has been a professor there since 1995. He was also a guest professor at the University of Geneva from 1992 to 1995 and a junior member of the Institut Universitaire de France (IUF) from 1997 to 2002. He received his M.Sc. in neuroscience in 1998 from the University of Claude Bernard (Lyon). Using experimental-psychology and brain-imaging techniques, his research deals with cognitive development and learning in children and adults (specifically, the role of cognitive inhibition in strategy selection). He is an exceptional-class professor at the University of Paris Descartes and a Senior member of the IUF since 2007. He is currently Director of the Laboratory for the Psychology of Child Development and Education (Centre National de la Recherche Scientifique (CNRS), Paris-Descartes and Caen Universities, Sorbonne-Paris-Cité Alliance for Higher Education and Research).*

Book Review by Nancy Chapel Eberhardt



Reading Assessment: Linking Language, Literacy, and Cognition

Melissa Lee Farrall

Wiley.

394 pages. Paperback.

Melissa Lee Farrall has contributed a wonderfully readable and useful book to the field of reading assessment. Less a "how to" text, *Reading Assessment: Linking Language, Literacy, and Cognition* is more a "why do" framework. In each chapter, the author has done a masterful job integrating vast amounts of information in a clear, concise, and relaxed style. In so doing, she has provided a comprehensive context for reading assessment that is simultaneously historical, research-based, and practical. This book has the potential to orient the novice evaluator to the science and art of conducting a reading evaluation, while being equally useful for an experienced evaluator as an easy-to-access resource.

Reading Assessment begins with an eloquent and excellent history of the reading theories that have both informed and influenced the field of reading. The author's historical review of language assessment provides the reader with a keen appreciation of evolving procedures and techniques. For example, Farrall discusses Brown's contribution for measuring early language growth (i.e., the mean length of utterance, MLU) as a reflection of a growing understanding of language development. Through examples like this, the reader is reminded of the relevance of evaluation procedures and the fact that the field of reading assessment is evolutionary.

After this foundation, the author tackles the critically important topic of statistics and test development. Farrall explains the two main ways to measure student performance: criterion-referenced tests and norm-referenced tests. The author also discusses topics ranging from mastery and automaticity to percentiles and stanines making clear the importance of understanding the "language of assessment." Whenever possible, graphics convey tons of information in an accessible format. For example, a graphic (Test Scoring Systems and Their Distribution, p. 65) shows the important relationship between percentiles, standard scores, scaled scores, and stanines. Farrall also brings her experienced perspective to these topics, as in her cautionary discussion about the use of grade equivalents, a discussion well worth reading.

Farrall avoids presenting the topic of reading assessment as a formulaic process, but instead offers readers a perspective about what is a complex decision-making process. She stresses the importance of knowledge of each layer of the language pyramid from phonology to pragmatics as the mechanism which permits us to "craft evaluations with meaningful, focused recommendations" (p. 29). The book draws on research to illuminate each of the layers of language. Chapters 9 through 12 focus on each layer in depth, outlining content and pointing to areas that may require assessment as part of a reading evaluation. For instance, in Chapter 9, "Oral Language Assessment," the author integrates detailed literacy content pertaining to word structure (e.g., morphemes), making the case that the evaluator must be knowledgeable about the specific layer of language to understand appropriate assessment techniques and the student's performance during the assessment process. It is in these chapters that Farrall truly links language, literacy, and cognition. At every turn, the author grounds her information in evidence and cites studies that support her recommendations.

The book is replete with features that enhance its readability and utility:

- Frequent use of **graphics** conveys concepts and categories of information. In Chapter 9, for example, Farrall presents the two categories of morphemes—inflectional and derivational—in an easy to understand flowchart.
- Beginning with the chapter on underlying processes (Chapter 10), the author uses **case studies** to illustrate the thought process for test selection and interpretation, as well as to model turning conclusions into recommendations. The case studies do an effective job of putting together many aspects of the evaluation process.
- Inclusion of **tables of evaluation tools** provides an easily utilized reference. For instance, in Chapter 8 on the topic of intellectual assessment, the presentation of a small sample of intelligence tests (pp. 130–136) uses tables to pack an enormous amount of information into a few pages.
- Each chapter concludes with **review questions**, which provide an opportunity for readers to reflect on and apply the information in the chapter. Happily, Farrall also provides an answer key at the end of the book to guide readers in their thinking about the answers.

Throughout the book, Farrall's sense of responsibility to help professionals in the field of reading shines through. Her closing paragraph captures the intent and spirit of the book:

> The teaching profession is unique in its calling and its responsibility; what other profession can claim to reach into the neural systems of young brains to forge links between new and old? As evaluators, we stand at that all-too-critical juncture between teachers and how students learn. Properly equipped with our powers of

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> observation and tools of assessment, we illuminate individual strengths and weaknesses as a foundation for effective instruction. (p. 309)

And so it is that Farrall has helped to inform that juncture in *Reading Assessment: Linking Language, Literacy, and Cognition*. The field of literacy instruction and evaluation is richer and wiser for her contribution.

__Nancy Chapel Eberhardt__ is currently an educational consultant with the 3t Literacy Group. Her experiences include special education teacher, administrator, author of literacy curriculum materials (LANGUAGE!), and professional development provider. Most recently she co-authored RtI: The Forgotten Tier. *The opinions of this reviewer are not necessarily the opinions of the International Dyslexia Association.*

40 York Road, 4th Floor
Baltimore, MD 21204-5202
Phone: (410) 296-0232
Fax: (410) 321-5069
E-Mail: info@interdys.org
Website: www.interdys.org