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Supporting Online Material for

Preschool Program Improves Cognitive Control

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Additional details for each section of the *Science* Education Forum appear below in the same order as those sections appear in the forum itself.

re: EXECUTIVE FUNCTIONS (EFs) DEFINED

Definitions of EFs and discussion of their relation to self-regulation and IQ are provided here. There are many definitions of EFs. Most experts agree that the three abilities listed in the *Science* Education Forum (inhibition, working memory, and cognitive flexibility) are components of EFs. The literature often discusses these as the core EF abilities (e.g., *1, 2*) and an influential factor analysis of many EF studies reported these as the three core factors underlying all EFs (though the authors named the factors slightly differently, calling them inhibition, updating, and shifting, respectively (*3*)). Some neuroscientists, however, especially those influenced by neural network or computational modeling, would subsume inhibition and even cognitive flexibility under working memory *(4, 5)*. Many people further subdivide these three core abilities into, for example, inhibition of attention and inhibition of action (*6, 7*) or verbal and visuo-spatial working memory (*8, 9*).

Planning, problem-solving, and reasoning are aspects of EFs, though some (especially those from a neuropsychology background (*10, 11*)) consider them foundational, whereas others (such as ourselves) consider them to be derived or built-up from the three core abilities listed above. EF skills depend critically on prefrontal cortex (*12-14*).

Inhibitory control is the ability to resist a strong inclination to do one thing in order to do what is most appropriate or needed. Examples would be resisting the natural inclination to turn out of a skid and instead turn into it, or, to resist driving along your habitual route to work at the point where you need to veer off to get where you want to go before work. Other examples include resisting temptations to play and instead finishing your school work or chores, resisting the luscious chocolate dessert and instead going for the fresh fruit if you want to lose weight, resisting saying something socially inappropriate and saying the polite remark instead, suppressing attention to what your neighbors are saying so that you can concentrate on what the teacher is saying, and generally not giving in to your first impulse and giving a more considered response instead.

The ability to inhibit attention to distraction makes possible selective, focused, and sustained attention. The ability to inhibit a strong behavioral inclination helps make discipline and change possible. (To change, to get out of a behavioural rut, requires inhibition of the strong tendency to continue doing what you've been doing.) Inhibition, thus, allows us a measure of control over our attention and our actions, rather than simply being controlled by external stimuli, our emotions, or habitual behavior tendencies. The concept of inhibition reminds us that it is not enough to know something or remember it. A young child may know what he or she should do, and want to do that, but not be able to do it because of insufficiently developed inhibitory control (*15, 16*).

Working memory is the ability to hold or maintain information in your mind's eye and to mentally work with or manipulate that information. Examples of working memory would be doing mental arithmetic, relating one idea to another, updating the contents of what you are holding in mind, or, as on our Dots task, mentally translating the abstract rule you are holding in mind into the concrete motor response that it implies on each trial. Working memory is also the ability to hold information in mind despite distraction (such as holding a phone number in mind while you pause to listen to what someone has to say) and to hold information in mind while you do something else (such as holding a phone number in mind while talking about something else before dialing). The information loaded into working memory can be newly learned or retrieved from longterm storage. Working memory by its very nature is fleeting, like writing on a misty glass.

The ability to hold information in mind makes it possible for us to remember our plans and others' instructions, consider alternatives and make mental calculations, multi-task, and relate the present to the future or past. It is critical to our ability to see connections between seemingly unconnected items, and hence to creativity, for the essence of creativity is to be able to disassemble and re-combine elements in new ways.

Cognitive flexibility is the ability to nimbly adjust to changed demands or priorities. Considering something from a fresh or different perspective, switching between perspectives, adjusting to change, and 'thinking outside the box' are the essence of cognitive flexibility. Cognitive flexibility builds on inhibition and working memory but adds an additional element.

The relation between EFs and self-regulation. There is a good deal of overlap between EFs, especially its inhibitory component, and self-regulation, though there are also nuanced differences (*2*). EF researchers have generally focused most on cognition, in non-emotionally charged situations, using objective, behavioral measures. Researchers focusing on self-regulation have generally focused more on social situations, often with strong motivational components, and more often relying on parent or teacher report. Also, emotions are not simply things to be inhibited, and exuberance and excitement are to be encouraged as well as kept within reasonable bounds. Self-regulation incorporates encouraging helpful, healthy emotions as well as controlling disruptive ones. The concept of executive functions instead has emphasized cognitive control.

The relation between EFs and IQ. There is little overlap between EFs and most of what IQ tests emphasize (i.e., "crystallized" intelligence," e.g., memory of previously learned facts (*17-19*)). Patients in whom the frontal lobe has been removed usually score in the 80's or 90's, i.e., within the normal range, on such IQ tests (*20, 21*). There is much overlap, however, between EFs and "fluid intelligence" (i.e., reasoning and problem-solving (*22, 23*)). Standard IQ tests typically require some reasoning and problem-solving, which is why IQ scores usually decline 20 points if the frontal lobe is removed, but scores stay within the normal range because IQ tests tend to emphasize crystallized intelligence (*20, 21*).

re: SIGNIFICANCE

EF skills are also important for school success. Working memory and inhibitory control independently predict math competence in preschoolers (see Table S1) and are important for reading acquisition (see Table S1). EF abilities stay closely associated with academic achievement throughout school (see Table S1). In a meta-analysis of six large, longitudinal studies, including two nationally representative samples of US children, Duncan and colleagues found that children's attentional control skills when they entered kindergarten predicted math and reading scores as children progressed through school (*24*).

Table S1. Examples of studies that found that working memory and/or inhibition are important for language and/or math skills in preschool and in later school years.

	Working Memory	Inhibition
Preschool		
Language Skills	(*1*, *25*)	(*1*, *26*)
Math Skills	(*1*, *27*, *28*)	(*1*, *26*, *27*)
Later Grades		
Language Skills	(*29*, *30*, *31*, *32*)	(*29*, *31*, *33*)
Math Skills	(*32*, *34*, *35*, *36*)	(*35*, *37*, *38*)

Poor EFs are associated with social and mental health problems. The cost of social problems reflecting poor self-control, such as crime, incarceration, and lost productivity, is staggering (*39*). Teacher burnout from dealing with out-of-control children is skyrocketing (*40)*. EF deficits are seen in a great many disorders (e.g., addictions (*41-44*), obsessive compulsive disorder (*45-48*), Attention Deficit Hyperactivity Disorder (*49-54*), depression (*55-59*), schizophrenia (*60-64*), and more). The incidence of medicating children for poor inhibitory and attentional skills is increasing exponentially (400% more children were prescribed ADHD medication in 1999 than only 5 years before (*65*).

Poor EFs are associated with economic disadvantage. Kindergarten children at risk because of economic disadvantage are disproportionately behind in EFs relative to other cognitive skills and relative to children from middle-income homes (*66-68)*. Hence improving EFs is particularly urgent for at-risk children.

re: THE STUDY

Details on the two curricula, their implementation, teacher training, monitoring of teacher fidelity, and demographic characteristics of the children assigned to the two curricula are provided here. Implementation of the Tools of the Mind (Tools) curriculum and the school district's new curriculum that taught literacy in a balanced way (dBL) began when this urban school district in the Northeast opened a new publicly funded preschool program for the state's poorest 3- and 4-year-olds. In response to a court order mandating free high-quality preschool in low-income areas, the school district advertised its new free pre-K program. Parents were encouraged to sign up. From that sign-up list, children were randomly assigned to Tools or dBL. All new classrooms created in the district were included in this study. A state formula for identifying areas of greatest need (lowest income, lowest home ownership, etc.) determined which districts were eligible for this new program. Among those low-income districts, the district where this study occurred was among the poorest and most homogenous.

Both curricula involved new, high-quality programs instituted at the same time. Quality standards were set by the state, such as student : teacher ratios of ≤15:2, head teacher should have a B.A., and a 6-hour school-day. The same books, furniture, toys, and materials went to all classrooms, as did the same amount of in-classroom coaching support, number of professional development hours, and teacher stipends for attending workshops. Stratified random assignment of teachers and assistants minimized confounds due to key teacher characteristics (e.g., education level and years of teaching experience). All teachers, regardless of assignment, received $100 in classroom supplies for participating in the study.

Tools of the Mind (Tools)

Tools is an evidence-based curriculum developed by educational psychologists, Elena Bodrova and Deborah Leong (*69-71*), based on Luria's (*72*) and Vygotsky's (*73*) theories and practical insights on higher mental functions and how a comprehensive system of activities promotes EF development. In Tools, techniques for supporting ("scaffolding"), training, and challenging EFs are interwoven in almost all classroom activities throughout the day. Thus, while children are learning language skills or math, for example, they also receive training in EFs. EFs are approached from a variety of different angles in a variety of different activities.

Vygotsky proposed that EF skills develop as children engage in specific interpersonal interactions. These include teaching children to use external aids to facilitate their attention and memory(74-76), encouraging use of self-regulatory private speech (77-79), and promoting mature dramatic play (80):

(a) Concrete, external aids. Luria (*81:* p. 30-31) wrote that "all types of human conscious activity are always formed with the support of external auxiliary tools or aids….The development of any type of complex conscious activity at first is expanded in character and requires a number of external aids for its performance, and not until later does it gradually become condensed and converted into an automatic motor skill."

Credit: Morey Kitzman

Figure S1. Two preschoolers engage in "Buddy Reading." The ear line-drawing held by one girl helps her to remember to listen.

During the Tools of Mind activity of "Buddy Reading," all children get a picture book, and are to take turns telling a story that goes with their book to one another in pairs, turning the book's pages and pointing at the pictures as the story progresses. Initially all want to tell their story; none want to listen. The teacher gives one child per pair a drawing of lips and the other a drawing of an ear, explaining that "ears don't talk; ears listen." With the concrete graphic symbol to refer to, preschoolers with the ear inhibit talking, wait their turn, and listen (Figure S1). Children then trade drawings and roles, thus learning to enact the social norms of turn-taking and waiting one's turn. The visual aids remind children who is doing what. After only a few months, the pictures are no longer needed. The listener's role is an active one; that child is supposed to ask the "reader" a question about the book when the reader is finished. Later that becomes internalized by the reader, who asks him- or herself questions about the book to verify comprehension. Thus, typical early childhood classroom activities (e.g., the literacy activity of book "reading") are modified to incorporate EF-promoting strategies and are progressively modified during the school-year to keep challenging EFs at more advanced levels.

Another example is clean-up following center activities, where the need for children to exercise self-discipline is high. Children are expected to clean up quickly and change activities. This is often a time when children forget what they are supposed to do and begin playing with the toys at hand. A clean-up song is used in Tools to help children remember that they have a limited amount of time --only as long as the song lasts -- to clean up.

(b) Regulating the behavior of others. Vygotsky and Luria showed that there is a natural progression from children first using speech to regulate the behavior of others, to then using external and then internal speech to regulate their own behavior, to finally not needing a verbal aid to exercise inhibition and other EF skills (*77*, *82, 83*).

Tools has built that progression into its curriculum and incorporated it into its subject-matter instruction. For example, during a math activity, again done in pairs, one child has a "hand" and counts out objects while the other child checks whether the counting has been correct (the second child serving as a regulator of the first child's performance). The child who is the "checker" waits until the first child finishes counting out the number of objects and then, using a checking sheet, makes sure the answers are correct. This supports self-reflection as well as inhibition. The child who checks inhibits the desire to act until it is his or her turn. The "counter" engages in self-reflection while watching the checking, reflecting on his/her previous answer, thinking about whether it's correct or not (see Figure S2). "Reliving" one's actions by watching someone check is practice in self-reflection on action, a metacognitive aspect of EFs.

Credit: Morey Kitzman

Figure S2. This young girl in Tools is checking to see if her partner counted correctly.

(c) Using private speech to regulate oneself. Vygotsky and Luria considered "private speech" to be a very important mechanism for the development of EFs (*75*, *84*). Vygotsky defined private speech as self-directed speech that is audible. According to Vygotsky (*85*) private speech originates in public (social) speech children address to each other, so for private speech to develop children must have achieved a certain level of development of their public speech.

In Tools, children's use of private speech as a tool for the development of EFs is encouraged and taught in several ways. Teachers model the use of private speech when introducing new activities, especially ones that require constant monitoring of one's actions (such as Scaffolded Writing or Graphic Practice), and encourage children's use of private speech when they engage in these activities. In addition, some Tools activities (such as *Share the News* or *Buddy Reading*) are specifically designed to engage students in public (social) speech with the teacher modeling this speech and children using it to communicate with their peers. Finally, teachers encourage children's use of public speech in make-believe play by engaging them in more extended pretend scenarios.

(d) Using private speech during rule-switching. Since private speech is known to increase as tasks become more challenging, rule-switching in movement games encourages children to increase their use of private speech and practice its use to regulate their behavior. An example of a Tools activity specifically designed to challenge children's emerging EFs is the Pattern Movement game. Children are shown a pattern, such as ABABBA represented by shapes: Triangle, Square, Triangle, Square, Square, Triangle. The teacher assigns specific movements to each shape and the children then enact the pattern as the teacher points to the pattern. Then the shapes are assigned a different set of motor movements and the children have to place a new set of behaviors in working memory and enact them. They have to inhibit the previous set of actions and change to the new actions. This happens three times before the activity ends. Children use private speech to help them remember the changed sets of actions and hold each new set in working memory. For example, when the teacher points to the next shape, children typically say the action associated with it (e.g., "clap") before they do the action (clapping their hands). They are not told to say anything; they spontaneously say it to help themselves act correctly.

(e) Mature, dramatic play. For Vygotsky, engaging in mature, dramatic play was the major mechanism for developing EFs, as all the interactions Vygotsky emphasized can be incorporated there (*80*, *86, 87*).

In Tools, children are taught to think about their play scenario ahead of time (Figure S3, think before acting). Children are taught to plan the play scenario together. They might say, "Let's pretend you're the mommy and I'm the baby. I'll get sick; you'll need to take me to the doctor. She'll be the doctor and give me medicine." The child who'll be Mom might add, "I'll have to drive you there. I'll need a car." After the children agree, they act out the scenario. Then they plan another scenario and play it. Children are taught this planning process in two ways. They draw a general plan for the scenario and role they'll play. The teacher encourages children to think explicitly about their plans in advance and to discuss together who will do what and what will happen when. Second, teachers approach as children are playing and prompt discussion of what the children will do next. As the play scenario evolves, children may plan other things to do within the same role, such as a spaceman who has his spaceship repaired. Two things are going on at the same time here: First, children engage in "thinking as they are talking" (re: Vygotsky's definition of private speech) and they also use the same words in their planning process that they will later use in both their private and public speech during play.

Credit: Morey Kitzman

Figure S3. (**Left and middle**) Children in Tools "writing" in words and drawings their play plans. **(Right)** A child's play plan with his own written description of the play using estimated spelling. It says, "I am going to be the guy that goes into space."

Role-playing (Figure S4) facilitates the internalization of rules and expectations (taxing working memory) and imposes constraints on behavior (taxing inhibition). Children must remember the scenario they chose, what role they chose, and what roles the other children chose. They must inhibit behaviors inconsistent with their role (e.g., the baby cannot suddenly order others around) and they cannot impulsively grab other, non-scenario-related toys, but must honor the plans they agreed on. Children's engagement in play-planning thus encourages their use external means (e.g., pictures) as Tools for effortful attention (attending to their initial plan instead of being driven by the most attractive toy) and the children help regulate one another as they monitor each other's compliance with the rules and assigned roles.

Credit: Sandra Peyser

Credit: Ruth Hensen

Figure S4. Children in Tools engaged in social pretend (or ‘dramatic’) play.

In contrast, in most preschool classrooms (including dBL ones), teachers do not have children plan their play in advance and play is not nurtured intentionally as something that will increase EFs. Often children are allowed to go from center to center as the whim moves them. Play is often seen solely as a social activity or as a way to practice academic skills. The type of play used in Tools requires teachers to help children plan, and stay true to their plans in a way that emphasizes inhibitory control and working memory, while the play scenario evolves and becomes more creative and complex

(f) Tools teachers are also taught general principles. Tools teachers are also taught to realize when an activity is not providing children an opportunity to exercise EFs (such as “choice time” when the teacher makes all the choices) and to modify situations where EFs are likely to break down so that children are helped to maintain self-discipline.

Based on its impact on young children’s learning and development, Tools was named an exemplary innovation by UNESCO in 2001, the first US program and the only early childhood education program at the time to receive that prestigious honor (*70*).

District’s version of Balanced Literacy (dBL)

The curriculum developed by the school district (dBL) was based on the idea that literacy should be taught to young children in a balanced way (i.e., through a combination of reading, writing, and listening activities) and in the context of thematic units, such as ‘family’ or ‘transportation.’ The district strove to teach literacy skills in ways that included a balance between large group reading aloud and small group literacy experiences. Children participated in activities designed to help them learn to write their names. Teachers introduced the letters of the alphabet and the sounds that they make. Children had the opportunity to write on their own during play as well as during teacher-led activities. Often the literacy experiences were designed around a theme. For example, if the class were studying apples, children might be given an art experience where they colored or cut out an apple and traced the letter A. The dBL curriculum included all the elements typical of quality early childhood programs including allowing ample time for play (50 minutes in one time block and another 60-70 minutes spread throughout the day).

The dBL curriculum was developed by the district administration over the 3 years prior to the study and the district was proud of the curriculum it had developed. Tools and dBL covered the same academic content, but differed in educational philosophy. Unlike Tools, dBL included no activities that were intentionally designed to promote EF development, though as in many early childhood classrooms, there were activities that naturally led to the practice of EFs, such as songs where children stop and freeze like statues. In dBL classrooms, control was primarily teacher-imposed; children were not expected to regulate each other or themselves.

Teacher training and fidelity

Year 1 began with almost all teachers learning a new curriculum. Tools teachers were trained by Tools trainers; dBL teachers by district trainers. Teacher trainers and coaches for both had the same level of training. All teachers had a 4-day training workshop before school started, then 1-day training workshops in Oct., Jan., and March of Year 1. In Year 2, the opening workshop was 1 day, and the Oct., Jan., and March workshops were a half-day each. Each dBL classroom was visited by a district master teacher, and each Tools classroom by a Tools staff member, every 6 weeks to stabilize practice and suggest improvements.

Teacher fidelity to the assigned curriculum was assessed by two trained observers in Oct., Dec., and Mar. of Year 1. Reliability between the raters was high (never <88%). Their ratings show no overlap between teachers assigned to the two curricula. For example, Tools teachers started out with ratings averaging 60% fidelity to Tools and by March had fidelity ratings >80%. In contrast, on these same items, dBL teachers averaged 20% fidelity to Tools at each timepoint, showing that they seldom presented an activity in the Tools manner (see Figure S5).

All families accepted their child's classroom assignment, but 24% of parents of children in dBL and 9% of parents of children in Tools did not consent to EF testing for their child. The percentage of Tools parents giving consent (91%) was unusually high. The 76% percentage of dBL parents giving consent is close to the average generally found in studies and higher than often found among poor, immigrant families (*26*, *88*).

Participants

The children in the dBL and Tools groups were closely matched in age, ethnicity, income, and mother's education (see Table S2).

Table S2. Background characteristics of the children tested.

	dBL Curriculum	**Tools Curriculum**	
	1 or 2 years	1 year	2 years
Mean age in years (±SD)	5.14 ± 0.34	5.15 ± 0.37	5.12 ± 0.33
Percent Hispanic	93	91	91
Percent male	55	41	51
Percent with family income <$25,000/yr	76	71	86
Percent of mothers whose education was			
Less than high school graduate	24	12	25
High school graduate	33	65	49
Some college	29	18	17
College graduate or more	14	6	9
Number of subjects per group	62	22	63

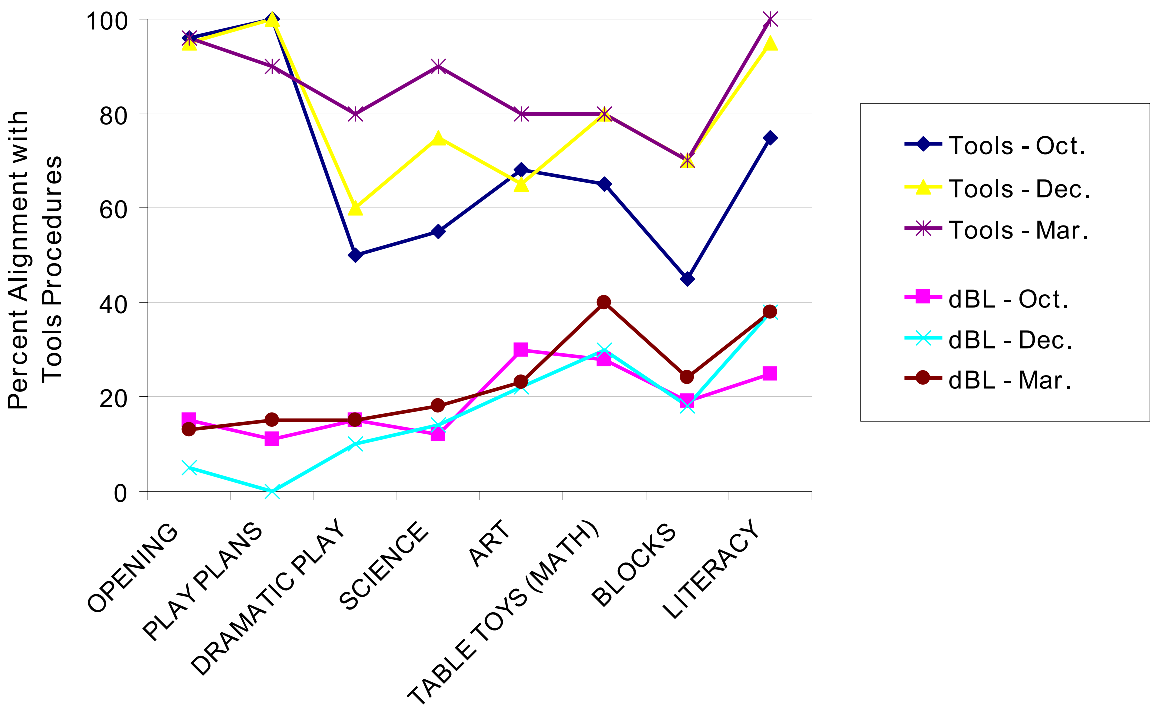

Figure S5. Teacher alignment with the Tools of the Mind curriculum was assessed by two trained raters in Oct., Dec., and Mar. of Year 1.

re: EXECUTIVE FUNCTIONS (EFs) MEASURES

Supplemental information on the EF outcome measures, the Dots task from the Directional Stroop Bttery (*89*) and a Flanker task (*90*), appears here. These measures require activities different from anything the children had done before; to see an effect of curriculum on these outcome measures, children in Tools would have to transfer their EF training to new situations.

In all conditions of the Dots task (*89*, see Figure S6), a red heart or flower appeared on the right or left of the computer screen. Children were given up to 6 seconds per trial in single-task blocks and 10 seconds in the mixed block to respond. That is far longer than preschoolers usually take. For example, in another study when preschoolers were given 2.5 seconds to respond on the same task, they responded in 1.2 seconds on average in the mixed block and in <1 second in the single task blocks (*89*).

In the congruent condition, one rule applied ("press the button on the same side as the heart"). Dots-Incongruent also required remembering a rule ("press the button on the side opposite the flower") but in addition it required inhibiting the tendency to respond on the side where a stimulus appears (that tendency is called the "Simon effect' or spatial compatibility; *91-93*).

In Dots-Mixed, incongruent and congruent trials were randomly intermixed (taxing all three core EFs). Here, two abstract rules had to be held in mind, cognitive flexibility was needed to switch between rules, and inhibition was needed on incongruent and switch trials. In all conditions, mental manipulation of the rules was required to instantiate them (i.e., to calculate whether "same-side" or "opposite-side" meant "press left" or "press right"). Children who err typically remember which rule to use (same- or opposite side) but impulsively respond before allowing themselves enough time to compute whether that means a right or left keypress.

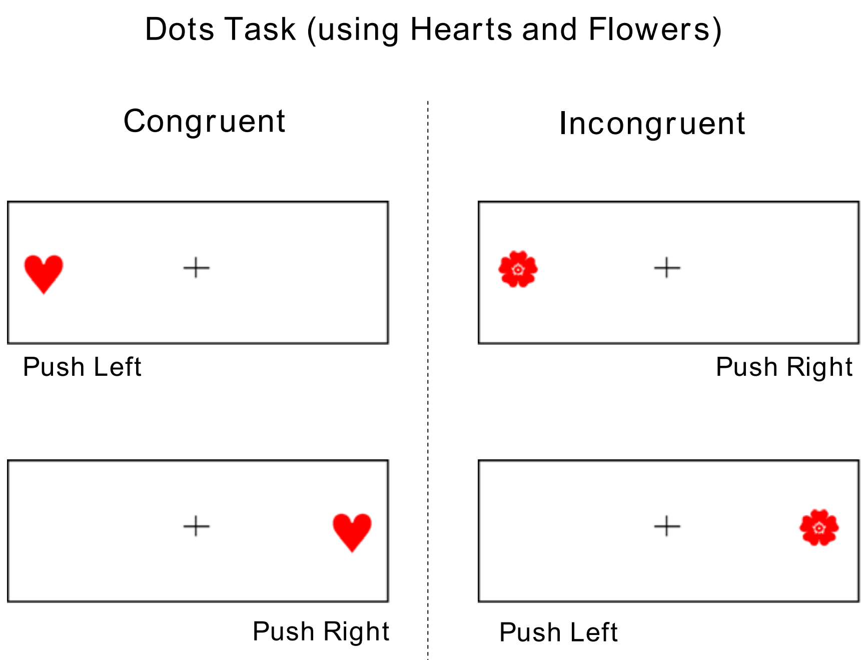

Figure S6. Two trials each of Dots-Congruent and Dots-Incongruent are shown.

All Flanker tasks require focusing on a central stimulus, inhibiting attention to the stimuli flanking it (*94, 95*). For the Flanker task used here, the central stimulus was a circle or triangle (Figure S7). Again, children were instructed to take their time and encouraged not to rush; 12 seconds was allowed per trial. Both the standard and reverse Flanker conditions required selective attention (inhibition) and some memory of the rules (though memory aids were provided). The reverse condition also required inhibition of what they had just practiced and thus the cognitive flexibility to change the focus of attention and stimulus-response mappings.

Thus, the Dots task required inhibition of a behavioral tendency (the tendency to press on the same side as the stimulus) while the Flanker task requires inhibition of an attentional tendency. For both tasks, when the rules switched, children had to inhibit previous stimulus-response mappings and mindsets.

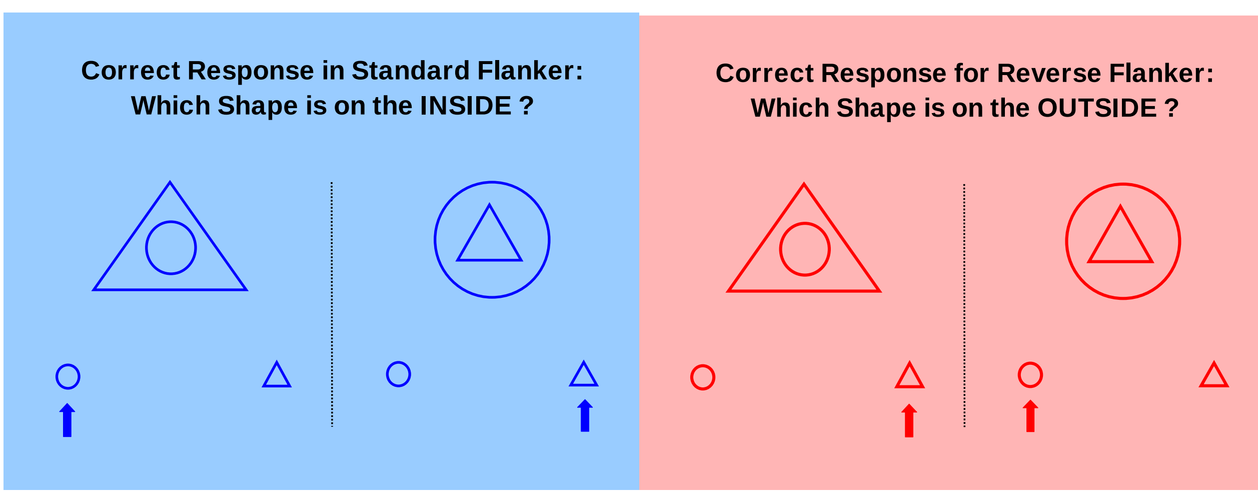

Figure S7. Two trials of the standard flanker and reverse flanker conditions are shown.

re: RESULTS

The results of the statistical analyses appear below.

Dots-Congruent placed minimal demands on EFs. Children performed comparably regardless of curriculum, years in curriculum, or gender, though older children performed better ($F_{3,152}$ = 2.90, p < .04; age: *t*[152] = 2.62, p < .01).

Dots-Incongruent placed a demand on inhibitory control absent in Dots-Congruent. The overall result for multiple regression analysis was: $F_{3,142}$ = 7.06, p < .0001. Children in Tools responded correctly on more trials than did children in dBL (*t*[142] = 2.62, p < .005; β = .28; see Figure 2). Percentage of correct responses by years in a curriculum were 69% for dBL whether 1 year or 2, 78% for children with 1 year of Tools, and 83% for children in their second year of Tools. That linear trend (better performance the more years of Tools) was significant (*t*[142] = 2.27, p < .02). Older children responded correctly on more trials than did younger children (*t*[142] = 4.00, p <.0001; β = .38). Boys and girls performed comparably.

Dot-Mixed placed greater demands on all three core EF skills (inhibition, working memory, and cognitive flexibility) than did the other conditions of the Dots task. Dots-Mixed was too difficult for most children in dBL. Only 29% of them were able to pass the pretest (a prerequisite for proceeding onto testing), though each child was given up to three chances to pass the pretest and were given a great deal of instruction, feedback, and practice. With so few dBL children passing the pretest, too few of them received test trials to be able to do statistical tests on test trial performance. Therefore for the Dots-Mixed condition we used logistic regression to analyze whether the difference in percentage of children passing the pretest (29% in dBL; 51% in Tools) was statistically significant. Indeed it was (Wald = 5.00, p < .02; see Figure 2). The means by years in a program were 29% for dBL both for 1 year or two; 50% for 1 year of Tools and 53% by 2 years of Tools. No significant differences were found by age, gender, or years in a program. All children tested on Dots-Incongruent were also tested on the Dots-Mixed pretest; it is only that many of them did then proceed onto Dots-Mixed testing.

The Standard Flanker task, like Dots-Incongruent, taxed inhibition (with minimal memory or flexibility demands). The overall result for multiple regression analysis was: $F_{3,132}$ = 4.48, p < .01. Children in Tools responded correctly on more trials than did children in dBL (*t*[142] = 2.84, p < .004; β = .31; see Figure 2). Means by years in a program were 82% for dBL whether 1 year or two, 91% for 1 year of Tools and 92% for 2 years of Tools. Older children performed better than younger: *t*[142] = 2.50, p <.01; β = .27). There were no significant differences by gender or by number of years of Tools.

The Reverse Flanker task, like Dots-Mixed, taxed all three core EF abilities. The overall multiple regression result was: $F_{3,132}$ = 4.48, p < .01. Tools children substantially outperformed dBL children (*t*[120] = 3.87, p < .0001; β = .39; see Figure 2 in the *Science* Education Forum). Whereas dBL children performed near chance (65% correct), Tools children averaged 84% correct. Means by years in a program were 65% for dBL whether 1 year or two, 81% for 1 year of Tools and 86% for 2 years of Tools. Thus the most demanding Dots and Flanker conditions showed the largest effects. There were no significant differences by age or by number of years of Tools. Girls outperformed boys: *t*(120) = 2.29, p < .02; β = .24.

Academic measures were administered and analyzed independently by the National Institute for Early Education Research (NIEER). Due to an oversight, those measures were only administered to subjects in the present study who were in Tools. The greater the demand on EFs required by a task condition, the greater the size and number of significant relations between performance on that condition and the standardized, objective academic performance measures independently collected by NIEER. Table S3 presents those data for the three conditions of the Dots task.

Table S3

Correlation of Percentage of Correct Responses on the Dots Task and Academic Performance Measures

	Congruent: No EF required	**Incongruent:** An Intermediate Level of EF Needed	**MIxed:** Most EF required
SRSS (Social Skills Rating Scale) Externalizing subscale	**0.178**	**0.456****	**0.177**
SSRS Internalizing subscale	**0.161**	**0.149**	**0.023**
PPVT (Peabody Picture Vocabulary) raw score	**0.036**	**0.290***	**0.464****
PPVT standard score	**0.034**	**0.275***	**0.444****
IDEA Oral Language proficiency raw score	**0.165**	**0.183**	**0.390***
WPPSI raw score	**0.012**	**0.125**	**0.030**
WCJ (Woodcock Johnson) letter word raw score	**0.091**	**0.166**	**0.068**
WCJ (Woodcock Johnson) letter word standard score	**0.080**	**0.167**	**0.120**
Get Ready To Read raw score	**0.050**	**0.315***	**0.423****
Expressive (EOWPVT) raw score	**-0.037**	**0.272***	**0.383****
Expressive (EOWPVT) standard score	**-0.117**	**0.207**	**0.289***
Expressive standard score new (accts for floor effect)	**-0.086**	**0.242**	**0.329****
WCJ applied problems raw score	**-0.027**	**0.264***	**0.392****
WCJ applied problems standard score	**-0.071**	**0.218**	**0.359****

Table S3. Gray background indicates a significant relation between performance on a condition of the Dots task and an academic measure. There was no relation between performance in the condition that did not require EFs (congruent condition) and any academic measure, but there was a significant relation between scores on academic measures and performance on the EF-demanding conditions, and in every case, the relation was greater with the more EF-demanding condition (mixed condition) than with the less EF-demanding condition (incongruent condition).

SRSS: *Social Skills Rating Scale.* Rating scale done by the child's teacher of classroom behaviors indicative of self-regulation. Externalizing subscale measures behaviors such as aggressive acts and lack of temper control. Internalizing subscale measures anxiety and sadness. Correlations are provided of the relation between EFs and lack of externalizing and internalizing behaviors (the only 2 subscales administered).

PPVT : *Peabody Picture Vocabulary Test-III* (PPVT-III). The PPVT measures an individual's level of receptive vocabulary in standard English (*96*). To get a baseline of standard English oral vocabulary this assessment was administered to all children regardless of their home language.

Expressive: *Expressive One-Word Picture Vocabulary Test – Revised* (EOWPVT) (*97)*. The EOWPVT is a norm-referenced assessment of an individual's expressive vocabulary in standard English. To get a baseline of standard English expressive vocabulary this assessment was administered to all children regardless of their home language.

WPPSI: The Wechsler Preschool and Primary Scales of Intelligence (WPPSI). Only the peg test from the WPPSI was administered.

WCJ Letter Word: *Woodcock Johnson Test of Achievement, Letter-Word Identification Test.* This test measures an individual's ability to use symbols, letters or words (ascending level of difficulty). This assessment was administered in either English or Spanish, depending on the language the subject was most comfortable speaking.

WCJ Applied Problems: *Woodcock Johnson Test of Achievement, Applied Problems Test.* This test measures a subject's skill in analyzing and solving practical mathematical problems. Many problems include extraneous information which the subject must then have to decide to use or discard in a calculation (*98*). This assessment was administered in either English or Spanish, depending on the language the subject was most comfortable speaking.

Get Ready To Read: *Get Ready to Read* is a screening tool designed to check a 4–year-old's progress in developing early literacy skills. This tool correlates with measures of language and letter knowledge (*99*).

IDEA: *IDEA Oral Language Proficiency Test* (*100*). This test assesses the receptive and expressive language skills of Spanish speaking children; therefore it was administered to about 70% of the students in our sample. Scores reflect students' responses to items representative of common Spanish language speech patterns.

re: DISCUSSION

Why was there so little effect from the number of years of Tools?

Tools is so different from traditional teaching approaches that it takes a year of training and iterative feedback before teachers become proficient at teaching the Tools curriculum. Ratings of teachers' fidelity to Tools by mid-Year-1 were still only 60% (though by March they had climbed to 80%; see Figure S5). Hence, the first year of Tools implementation was imperfect, and that is probably why we found little difference by whether a child had 1 or 2 years of Tools. It is no surprise that performance on the EF measures did not vary by whether children had 1 or 2 years of dBL, since the children did not differ by age and received no special EF training.

Why do children in Tools show impressive gains in EFs? Why have others reported important gains in their academic performance?

Intermediate variables may well mediate, or contribute to, to these effects. For example, Tools classrooms are less stressful for both teachers and students. They have a more positive, happy climate (*101*). Because of Tools techniques for managing difficult times, scaffolding children's emerging EFs, and continually improving children's EFs, situations where children's EFs are likely to fail are minimized. After a year of experience with the Tools curriculum, teachers have few negative interactions with children and children stay on task better. After children have had a year of Tools, Tools teachers rarely need to intervene to keep children on task or to redirect inappropriate behavior, and no longer need time-out as a disciplinary strategy. Stress and anxiety impair EFs and academic performance (*102-104*). Perhaps children in Tools perform better in part because their training in EFs is inherently fun (they get to do activities they enjoy) and because their improving EFs reduces the stress-level in class and the need for teacher-imposed discipline.

While teacher enthusiasm was lower for Tools than for dBL at the outset, over the course of the study that probably changed as it was so evident that children in Tools were doing well. While the Tools curriculum can take credit for initial gains by the children, perhaps additional gains were enhanced by the gathering teacher excitement over the children's progress.

Children's improving EFs, and reduced need for teacher-imposed discipline, also meant that teachers could spend more time on instruction. Perhaps children in Tools show the academic gains reported in part because teachers could spend more time on instruction.

Better EFs, and training in social norms such as turn-taking, also makes for better interpersonal interactions with peers and teacher; such social benefits might also amplify the positive effects of Tools. A large number of Tools activities aid social development. Children do a great deal of interacting with one another and often alternate in taking the roles of the giver and receiver of help or instruction (as in Buddy Reading and Math Checking, for example). Tools teachers are explicitly instructed to make sure that children talk to different children -- that friends do not always talk with friends. Various techniques are used to make sure that children play with and interact with every other child in the classroom. Tools teachers are trained to try to make sure that there are no loners, outcasts or cliques. We know that socio-emotional development aids and supports academic development and contributes importantly to positive classroom climate.

Children in Tools also expressed more self-confidence during testing. When they initially failed practice trials, they expressed confidence that they could do what was required: "I can do this. I'm sure I can do this."

All the children in the current study came from low-income homes. Would more advantaged children show similar gains? Thus far, Tools has only been evaluated with children from low-income homes (though it is currently being implemented in a handful of programs with more economically advantaged children). It is unclear if and how much Tools will help more advantaged children. Tools children showed EF performance in our study comparable to more privileged children (*89*). In general, gains of any intervention are greater in raising below-par scores to par than in raising at-par scores to superior levels.

Both curricula in the current study were implemented with well-educated teachers, excellent materials, and good student: teacher ratios. Would the results be similar for poorly resourced classrooms?

Tools success appears to be independent of classroom resources. Both Tools and dBL in our study were implemented with well-educated teachers, excellent materials, and good student: teacher ratios. The outcomes from using Tools in more poorly resourced classrooms appears to be similar. Tools is being used in Head Start preschools in several States where teacher qualifications are not as high yet the preliminary results seem to be comparable (*105*). A version of *Tools* with a focus on literacy (called *Scaffolded Early Literacy)* has been shown to produce positive effects on student achievement across a variety of settings including *Even Start* programs (which typically have fewer resources and lower staff qualifications than other Early Childhood programs) and was nominated as an exemplary program by the National Staff Development Council and National Education Association (*106*).

However, there do appear to be certain minimal requirements for Tools to succeed. Resources and teacher qualifications are of a less importance than the teacher-child ratio or administrators' support (*105, 107*).

Weaknesses of the current study

Though our groups were well-matched and randomly assigned, our study would have been stronger had there been before and after measures. Lacking pre-intervention measures and lacking academic measures on children in dBL classrooms, we were unable to test here whether improving EFs improves academic performance, though other studies have demonstrated that (*101*, *104*).

Strengths of the current study

Objective, neurocognitive measures were used. Outcome measures were linked to specific neural circuits and were dissimilar from any activities in either curriculum. The curricula were evaluated by people with no stake or involvement in either curriculum. Many competing explanations for our results can be ruled out:

Tools children did not perform better because they were older, more economically advantaged, or had more highly educated mothers; the groups were well matched on these. Both groups came from the same neighborhood and ethnic group. Teachers for both groups had similar education levels and years of teaching, and received equal amounts of training and support. Random assignment of teachers and students reduced the likelihood of selection bias in who chose to teach either curriculum or which parents chose to enroll their children in one or the other curriculum or any other systematic differences between the groups except those caused by curricula. Neither program had more or better resources; materials and even furniture were matched. The same academic subject matter was covered in both programs. A new program can show better outcomes than an older one just because it is new, but both programs here were new. It is not that teachers came in expecting Tools children to do better. Indeed, there was considerable initial resistance to Tools because (a) teachers tended to disagree with the need to support and intervene in play in the way that Tools does and (b) scaffolding children's own EFs, rather than externally imposing control, initially seemed inefficient and some teachers feared it was asking too much or that they would lose control of the classroom.

re: CONCLUSIONS

EF skills can be improved in preschoolers.

Markedly better EF performance was found in at-risk 5-year-olds after 1-2 years of exposure to the Tools curriculum compared with closely matched peers. Tools exposure accounted for more variance in EFs than did age or gender, and remained significant controlling for those. These findings of superior performance on objective, neurocognitive measures of EFs in at-risk children in *Tools* are consistent with independent findings that, on questionnaire measures, teachers rate children in *Tools* higher on EFs (*101*).

It was on the most demanding EF conditions (Dots-Mixed and Reverse-Flanker) that children in *Tools* shone most compared to their peers. On Reverse Flanker, for example, children with EF-training were correct on almost 25% more trials than children without EF-training. On Dots-Mixed, less than a third of preschoolers without EF-training could demonstrate performance in accordance with task rules, whereas over half of *Tools* children could. These differences are socially significant in that they are substantial. The easier EF conditions (Dots-Incongruent and Flanker) showed significant, but smaller, group differences.

Some have felt preschool too early to try to improve EF skills. We show here that EFs can indeed be improved in preschoolers. Although EF skills and prefrontal cortex show very long developmental progressions and are not fully mature until the early 20's (*108-112*) just because PFC is not fully functional, does not mean that it is not functional at all. Indeed, it is functional even in infants (*110*, *113-115*).

To improve EFs in preschoolers does *not* require costly interventions.
The Tools program studied here was implemented in regular public-school classrooms by regular teachers, not specialists. No computers or other technical equipment were used. No more individualized attention was required than occurs in a regular classroom. The materials used were simple, inexpensive, and readily available.

The relation of EFs to academic performance.
The more EF-demanding the outcome measure, the more highly it correlated with independently acquired, objective measures of academic performance. This is consistent with much else. Superior academic performance has been found for *Tools* programs with other children and teachers, in other schools and states and with different comparison conditions (e.g., *101*, *104*). Disadvantaged children in Tools have consistently met or exceeded state and national standards on mandated literacy and math assessments -- an extraordinary accomplishment for at-risk children. In a separate random-assignment study by NIEER, *Tools* children showed substantially more growth in language and literacy than comparison children (*101*).

Our results are consistent with the strong impressions of teachers and administrators where both new programs, dBL and Tools, were introduced into the same school. They had never seen children so attentive and showing such sustained work activity in preschool as in Tools classrooms. Behavior problems prevalent in dBL classrooms were absent in Tools classes. The school felt it unethical to deprive half the children of a program that seemed so superior, so all dBL classrooms were switched to Tools.

That improving EFs should improve academic performance is also consistent with findings that EFs account for unique variance in academic outcomes (phonemic awareness, letter knowledge, and especially mathematics; see Table S1) independent of, and more strongly than, general intelligence, and with findings that self-discipline (inhibiting temptations) predicts academic performance more robustly than does IQ. In Duckworth and Seligman (*116*), self-discipline accounted for over two times more variance than IQ in final grades. The authors concluded, "[D]iscipline influences achievement more than talent does." (p. 944).

When the lead author of (*1*) was interviewed, he elaborated the important points that often children do not succeed in school, not because they are dumb, but because they have poor EFs: "Not only is executive function pivotal for academic success, it's amenable to training. Preschool curricula that focus on development of these skills and self-regulation are needed in a big way. There is a federal push to learn our numbers, our letters and our words, but a focus on the content, without a focus on the skills required to use that content, will end up with children being left behind" (*117*).

Our findings are consistent, as well, with those showing that Montessori education improves EFs and academic performance on standardized tests of reading and math (*118*). We hypothesize that Montessori practices improve academic performance in part because they improve EFs.

The importance of mature, dramatic play.
Play is often thought to be frivolous -- time away from building academic skills, rather than a vital part of early education. Indeed, preschool teachers are under increased pressure to limit playtime to provide more time for instruction. Yet, few activities so challenge children to exercise EFs as does mature, social pretend play.

If throughout the entire school-day EFs are supported and progressively challenged, benefits generalize and transfer to new activities.

Tools and dBL were similar in a great many respects. They differed primarily in that only Tools built an EF component into almost every school activity. Superior performance on the outcome measures used here required generalization and transfer of EF skills to new situations, quite different from anything any of the children had done before. When Tools children failed early practice trials, they often used verbal mediation (learned in Tools) to help themselves to succeed.

Tools has been refined through 12 years of research in preschools and kindergartens to determine what worked best. Initially it was tried as an add-on to existing curricula. Children improved on what they practiced in that module, but the benefit did not transfer. Only when EFs were challenged and supported by activities throughout the day did gains generalize to new contexts.

This finding concerning generalization of EF skills is consistent with other findings showing that if children this age continually exercise inhibition and cognitive flexibility by inhibiting one language when using another and flexibly switching between languages, their performance on non-linguistic EF tasks is 1-2 years ahead of monolingual peers (*119-122*), but not if second-language use is confined to a class. If the brain is to develop properly, children need the appropriate challenges and opportunities. If a neural system is repeatedly exercised, it, like a muscle, will function more optimally. Daily EF "exercise" appears to enhance and accelerate EF development much as physical exercise improves our bodies.

Possibilities: Might the widening achievement gap between the economically advantaged and disadvantaged result from a negative feedback loop beginning with poor initial EFs? Might rates of students dropping out of school or getting expelled, teacher burnout, crime, drug addiction, and diagnoses of ADHD and conduct disorder be reduced if children are helped early in life to improve their EF skills?

Low-income children tend to have poorer EFs than more economically advantaged children and tend to fall progressively farther behind over the school years (*123*). We propose that those two facts are related and correctible. We hypothesize that helping at-risk children improve their EF skills early might be critical to closing the achievement gap and reducing societal inequalities.

Poor EFs leads to problems paying attention in class, completing assignments, and inhibiting impulsive behaviors. A child who feels frustrated by not being able to concentrate or not being able to remember instructions may decide school is not worth the effort or is a place of failure. School is less fun because compliance with school demands is harder and because one's behavior so often elicits negative responses from teachers. Teachers come to expect poor self-control and poor work, and the children come to hold more negative self-perceptions of themselves as students. People withdraw from situations where they have negative experiences and which threaten their feelings of self-worth (*124*). Hence, children who begin school with poorer EFs, would be expected to become increasingly resistant to school and schoolwork, put less effort and self-investment into school, and it is no surprise that they drop out at much higher rates (*125*).

Children who have better EFs, on the other hand, are likely to be praised for their good behavior, find schoolwork easier, enjoy school more, and want to spend more time on their lessons. Their teachers enjoy them and a self-reinforcing positive feedback loop is created. The powerful self-fulfilling prophecy effects of one's own and others' perceptions of, and expectations for, oneself are well known (*126-131*). Thus, we hypothesize that the benefits from early EF training could well increase over time as the positive feedback loop picks up steam, so that longterm benefits could greatly exceed short-term effects. Children who have learned to regulate their behavior and attention are better students, teachers enjoy them more, and that positive feedback loop can lead, we believe, to increased gains over the years. What happens in later grades can reinforce children's early experiences or undermine them, but all things being equal, children who get started on a more promising trajectory will end up better. Preventing negative feedback loops before they start holds far more promise than trying to reverse problems once they've been allowed to develop.

Thus, we predict that improving young children's EF skills can improve their longterm acquisition of academic skills, school success and retention, job prospects and success, and can reduce the incidence of crime and drug addiction, and the disparity in achievement between rich and poor.

We further predict that children who go through a preschool program that directly scaffolds and challenges the development of EFs will be less likely to be diagnosed with disorders of EFs (such as ADHD or conduct disorder) because the program will have taught them to exercise self-control and emotion-regulation. The recent explosion in the diagnoses of ADHD might be due, in part, to some children never learning to exercise inhibitory control and self-discipline. Some children are strongly biologically predisposed to hyperactivity; training in self-regulation alone would not be sufficient for them. Many children, however, are mis-diagnosed with ADHD because they never learned to exercise self-regulation. Hence, we propose that early EF training can reduce the incidence of ADHD and conduct disorder.

References Cited

1. C. Blair, R.P. Razza, *Child Dev.* **78**, 647-663 (2007).
2. A. Diamond, in *Lifespan Cognition: Mechanisms of Change,* E. Bialystok, F. Craik, Eds. (Oxford Univ. Press, New York, 2006) pp. 70-95.
3. A. Miyake *et al.*, *Cognit. Psychol.* **41**, 49-100 (2000).
4. D. Y. Kimberg, M. D'Esposito, M. J. Farah, *Curr. Dir. Psychol. Sci.* **6**, 185-192 (1997).
5. J. B. Morton, Y. Munakata, *Dev. Psychobiol.* **40**, 255-265 (2002).
6. J. T. Nigg, *Psychol Bull.* ***126**,* 220-246 (2000)
7. B. J. Casey, N. Tottenham, J. Fossella, *Dev. Psychobiol.* **40**, 237-254 (2002).
8. A. Baddeley, in *The Cognitive Neurosciences,* M. S. Gazzaniga, Ed. (MIT Press, Cambridge, MA, 1995)
9. J. Jonides *et al.*, in *The Psychology of Learning and Motivation: Advances in Research and Theory,* D. L. Medin, Ed. (Academic Press, San Diego, CA, 1996), vol. 35.
10. M. B. Jurado, M. Rosselli, *Neuropsychol. Rev.* **17**, 213-233 (2007)
11. P. Anderson, *Child Neuropsychol.* **8**, 71-82 (2002).
12. M. D'Esposito *et al.*, *Nature* **378**, 279-281 (1995).
13. M. Petrides, in *Control of Cognitive Processes: Attention and Performance XVIII,* S. Monsell, J. Driver, Eds. (MIT Press, Cambridge, MA, 2000).
14. S. A. Bunge, K. N. Ochsner, J. E. Desmond, G. H. Glover, J. D. Gabrieli, *Brain* **124**, 2074-2086 (2001).
15. A. Diamond, in *Handbook of Developmental Cognitive Neuroscience,* C. Nelson, M. Luciana Eds. (MIT Press, Cambridge, MA, 2001)
16. A. Diamond, J. Gilbert, *Cogn. Dev.* ***4**,* 223-249 (1989).
17. L. S. Siegel, *J. Learn. Disabil.* **23**, 267-269, 319 (1990).
18. A. R. Jensen, *Straight Talk about Mental Tests* (The Free Press, New York, 1981) pp. 62-63.
19. J. Duncan, P. Burgess, H. Emslie, *Neuropsychologia* **33**, 261-268 (1995).
20. D. T. Stuss, D. F. Benson, *The Frontal Lobes* (Raven Press, New York, 1986).
21. D. T. Stuss, D. F. Benson, in *The Frontal Lobes Revisited,* E. Perecman, Ed. (IRBN Press, New York, 1987) pp. 141-158.
22. C. Blair, *Behav. Brain Sci.* **29**, 109-125 (2006).
23. J. Duncan, P. Burgess, H. Emslie, *Neuropsychologia* **33**, 261-268 (1995).
24. G. J. Duncan *et al.*, *Dev. Psychol.* **43**, 1428-1446 (2007).
25. A. M. Adams, S. E. Gathercole, *J Speech Hear Res.* **38**, 403-414. (1995)
26. M. M. McClelland *et al.*, *Dev Psychol*. **43**, 947-959. (2007)
27. K. A. Espy *et al.*, *Dev. Neuropsychol.* **26**, 465-486 (2004).
28 M.. C. Passolunghi, B. Vercelloni, H. Schadee, *Cogn. Dev.* **22**, 165-184 (2007).
29. R. De Beni, P. Palladino, F. Pazzaglia, C. Cornoldi, *Q. J. Exp. Psychol.* **51A**, 305-320 (1998).
30. S.E. Gathercole, C. Tiffany, J. Briscoe, A. Thorn, A. Team, *J. Child Psychol. Psychiatry* **46**, 598-611 (2005).
31. R. Savage, K. Cornish, T. Manly, C. Hollis, *Br. J. Psychol.* **97**, 365-385 (2006).
32. S. E. Gathercole, S. J. Pickering, C. Knight, Z. Stegmann, *Appl. Cogn. Psychol.* **18**, 1-16 (2004).

33. C. J. Riebach, B. Ricker, A. D. Friederici, A. M. Jacobs, *Neuroimage* **36**, 901-911 (2007).

34. P. Barrouillet, R. Lepine, *J. Exp. Child Psychol.* **91**, 183-204 (2005).

35. R. Bull, G. Scerif, *Dev. Neuropsychol.* **19**, 273-293 (2001).

36. L. Swanson, K. Kim, *Intelligence* **35**, 151-168 (2007).

37. G. M. Marzocchi, D. Lucangeli, T. De Meo, F. Fini, C. Comoldi, *Dev. Neuropsychol*. **21**, 73-92 (2002).

38. M. C. Passolunghi, L. S. Siegel, *J. Exp. Child. Psychol.* **80**, 44-57 (2001).

39. G. Atkinson, A. Healey, S. Mourato, *Oxf. Econ. Pap.* **57**, 559-585 (2005).

40. R. P. Hastings**,** *Sch. Psychol. Int.* **24,** 115-127 (2003).

41. M. Lyvers, *Exp. Clin. Psychopharmacol.* **8**, 225-249 (2000)

42. R. Z. Goldstein, N. D. Volkow, G. J. Wang, J. S. Fowler, S. Rajaram, *Neuroreport* **12**, 2595-2599 (2001).

43. R. Hester, H. Garavan, *J. Neurosci.* **24**, 11017-11022 (2004).

44. A. Verdejo-García, A. Bechara, E. C., Recknor, M. Pérez-García, *J. Int. Neuropsychol. Soc.* **12**, 405-415 (2006)

45. R. Penadés *et al.*, *Eur. Psychiatry*. **22**, 404-410 (2007).

46. S. R. Chamberlain *et al.*, *Am. J. Psychiatry* **164**, 335-338 (2007).

47. S. Andrés *et al.*, *J. Psychiatr. Res.* (2007); published online 26 June 2007.

48. S. W. Chang, J. T. McCracken, J. C. Piacentini, *J. Clin. Exp. Neuropsychol*. **29**, 724-733 (2007).

49. R. A. Barkley, *Psychol. Bull.* **121**, 65-94 (1997).

50 A. Diamond, *Dev. Psychopathol.* **17**, 807-825 (2005).

51. R. Martinussen, J. Hayden, S. Hogg-Johnson, R. Tannock, *J. Am. Acad. Child. Adolesc. Psychiatry* **44**, 377-384 (2005)

52. A. McInnes, T. Humphries, S. Hogg-Johnson, R. Tannock, *J. Abnorm. Child Psychol.* **31**, 427-443 (2003).

53. B. F. Pennington, S. Ozonoff, *J. Child Psychol. Psychiatry* **37**, 51-87 (1996).

54. R. Schachar, R. Tannock, M. Marriott, G. Logan, *J. Abnorm. Child Psychol.* **23**, 411-437 (1995).

55. Z. A. Kyte, I. M. Goodyer, B. J. Sahakian, *J. Child Psychol. Psychiatry* **46**, 995-1005 (2005).

56. Y. Paelecke-Habermann, J. Pohl, B. Leplow, *J. Affect. Disord*. **89**, 125-135 (2005).

57. E. J. Rose, K. P. Ebmeier, *J. Affect. Disord*. **90**, 149-161 (2006).

58. G. Christopher, J. MacDonald, *Cognit. Neuropsychiatry* **10**, 379-399 (2005).

59. J. V. Taylor-Tavares *et al.*, *Biol. Psychiatry* **62**, 917-924 (2007).

60. C. Franke, B. Reutrer, L. Schulz, N. Kathmann, *Biol. Psychol.* **76**, 91-99 (2007).

61. D. M. Barch, *Annu. Rev. Clin. Psychol.* **1**, 321-353 (2005).

62. A. Reichenberg, P. D. Harvey, *Psychol. Bull.* **133**, 833-858 (2007).

63. C. Winograd-Gurvich, P. B. Fitzgerald, N. Georgiou-Karistianis, L. Millist, O. White, *Psychiatry Res*. (2007); published online 25 September 2007.

64. P. G. Enticott, J. R. Ogloff, J. L. Bradshaw, *Psychiatry Res*. (2007); published online 2 October 2007.

65. L. M. Robison, D. A. Sclar, T. L. Skaer, R. S. Galin, *Clin. Pediatr.* **38**, 209-217 (1999).

66. K. G. Noble, B. D. McCandliss, M. J. Farah, *Dev. Sci.* **10**, 464-480 (2007).

67. K. G. Noble, M. F. Norman, M. J. Farah, *Dev. Sci.* **8**, 74-87 (2005).

68. M. J. Farah et al., *Brain Res*. **1110**, 166-174 (2006).

69. E. Bodrova, D. J. Leong, *Tools of the Mind: The Vygotskian Approach to Early Childhood Education* (Merrill/Prentice Hall, New York, ed. 2, 2007).

70. E. Bodrova, D. J. Leong, *The Tools of the Mind: A Case Study of Implementing the Vgotskian Approach in American Early Childhood and Primary Classrooms* (International Bureau of Education, UNESCO, Geneva, Switzerland, 2001).

71. E. Bodrova, D. J. Leong, in *Future Direction in Teacher Training,* M. Zaslow, I. Martinez-Beck, Eds. (Brooke Cole, New York, 2006).

72. A. R. Luria, *The Higher Cortical Functions in Man* (Basic Books, New York, 1966).

73. L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processess* (Harvard Univ. Press, Cambridge, MA, 1978).

74. A. Luria, in *The Psychology of Written Language,* M. Martlew, Ed. (Wiley, New York, 1983) pp. 237-277.

75. L. S. Vygotsky, in *The Vygotsky Reader,* R. van der Veer, J. Valsiner, Eds. (Blackwell, Cambridge, MA, 1994) pp. 57-72.

76. L. S. Vygotsky, *The History of the Development of Higher Mental Functions* (Plenum Press, New York, 1997), vol. 4.

77. A. R. Luria, in *The Role of Speech in the Regulation of Normal and Abnormal Behavior,* J. Tizard, Ed. (Liveright Publishing Corp., New York, 1961) pp. 50-96.

78. A. R. Luria, in *Reading in the Psychology of Cognition,* R. C. Anderson, D. P. Ausubel, Eds. (Holt, Rinehart and Winston, New York, 1965) pp. 350-363.

79. L. S. Vygotsky, *Thought and Language* (MIT Press, Cambridge, MA, 1962).

80. L. S. Vygotsky, *Soviet Psychol.* **7**, 6-18 (1967).

81. A. R. Luria, *The Working Brain* (Basic Books, New York, 1973).

82. L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes* (Harvard Univ. Press, Cambridge, MA, 1978).

83. L. S. Vygotsky, *Thought and Language*. (MIT Press, Cambridge, MA, 1986).

84. A. R. Luria, in *A Handbook of Contemporary Soviet Psychology,* M. Cole, I. Maltzman, Eds. (Basic Books, New York, NY, 1969).

85. L. S. Vygotsky, *Thinking and Speech (N. Minick, Trans.)* (Penum Press, New York, NY, 1987), vol. 1.

86. L. E. Berk, T. D. Mann, A. T. Ogan, in *Play-Learning: How Play Motivates and Enhances Cognitive and Social-Emotional Growth,* D. G. Singer, R. M. Golinkoff, K. A. Hirsh-Pasek, Eds. (Oxford Univ. Press, New York, 2006) pp. 74-100.

87. Y. V. Karpov, *The Neo-Vygotskian Approach to Child Development* (Cambridge Univ. Press, New York, 2005).

88. C. Blair, D. Granger, M. Willoughby, K. Kivlighan, Family Life Project Investigators, *Ann. N. Y. Acad. Sci.* **1094**, 263-267 (2006).

89. M.C. Davidson, D. Amso, L.C. Anderson, A. Diamond, *Neuropsychologia* **44**, 2037–2078 (2006).

90. S. Munro, C. Chau, K. Gazarian, A. Diamond, poster presented at the 2006 Annual Cognitive Neuroscience Society Meeting, San Francisco, CA, 10 April 2006

91. C. H. Lu, R. W. Proctor, *Psychon. Bull. Rev.* **2**, 174-207 (1995).

92. J. R. Simon, in *Stimulus-Response Compatibility: An Integrated Perspective,* R. W. Proctor, T. G. Reeve, Eds. (North-Holland, Amsterdam, 1990) pp. 31-86.
93. A. P. Georgopoulos, *Int. Rev. Neurobiol.* **37**, 103-119 (1994).
94. S. Durston *et al.*, *NeuroImage* **20**, 2135-2141 (2003).
95. M. R. Rueda *et al.*, *Neuropsychologia*, **42**, 1029-1040 (2004).
96. L. M. Dunn, L. M. Dunn, *Peabody Picture Vocabulary Test* (American Guidance Service, Inc, Circle Pines, MN, 3rd ed. 1997).
97. R. Brownell, Ed., *EOWPVT Expressive One-Word Picture Vocabulary Test* (Academic Therapy publications, 2000).
98. R.W. Woodcock, N. Mather, in *Woodcock-Johnson Psycho-Educational Battery,* R. W. Woodcock, M. B. Johnson, Eds. (Riverside Publishing, Itasca, IL, 1989).
99. G.J. Whitehurst, C.J. Lonigan, in *Handbook of Early Literacy Research,* S. B. Neuman, D. K. Dickinson, Eds. (Guilford Press, New York, 2001) pp. 11-29.
100. *IDEA Oral Language Proficiency Test* (Ballard & Tighe Publishers, Brea, CA, 1999).
101. W. S. Barnett *et al.*, “Educational effects of the Tools of the Mind Curriculum: A randomized trial” (National Institute of Early Education Research, Rutgers University, New Brunswick, NJ, 2007).
102. A. F. Arnsten, *Science* **280**, 1711-1712 (1998).
103. A. F. Arnsten, *J. Am. Acad. Child. Adolesc. Psychiatry* **38**, 220-222 (1999).
104. J. J. Cerqueira, F. Mailliet, O. F. Almeida, T. M. Jay, N. Sousa, *J. Neurosci*. **27**, 2781-2787 (2007).
105. S. Saifer, paper presented at the 17th Annual Conference of the European Early Childhood Education Research Association, Prague, Czech Republic, 29 August 2007
106. J. Killion, *What Works in the Elementary School: Results-Based Staff Development* (National Staff Development Council, Oxford, OH, 2002).
107. E. Bodrova, D. Leong, J. Norford, D. Paynter, *J. of Staff Dev.*, **24**, 47-51 (2003).
108. J. N. Giedd *et al.*, *Nat. Neurosci.* **2**, 861-863 (1999).
109. N. Gogtay *et al.*, *Proc. Natl. Acad. Sci*. **101**, 8174-8179 (1994).
110. A. Diamond, in *Principles of Frontal Lobe Function*, D. T. Stuss, R. T. Knight, Eds. (Oxford Univ. Press, London, 2002) pp. 466-503.
111. A. W. Toga, P. M. Thompson, E. R. Sowell, *Trends Neurosci.* **29**, 148-159 (2006).
112. L. Lu *et al.*, *Cereb. Cortex* **17**, 1092-1099 (2007).
113. A. Diamond, in *Brain Maturation and Cognitive Development: Comparative and Cross-Cultural Perspectives,* K. R. Gibson, A. C. Petersen, Eds. (Aldine de Gruyter, NY, 1991) pp. 127-180.
114. A. Diamond, M. Prevor, G. Callender, D. P. Druin, *Monogr. Soc. Res. Child Dev.* **62**, 1-207 (1997).
115. A. A. Baird *et al.*, *NeuroImage* **16**, 1120-1126 (2002).
116. A.L. Duckworth, M.E.P. Seligman, *Psychol. Sci.* 16, 939-944 (2005).
117. C. Nicholson, *Scientific American On the Web,* www.sciam.com/article.cfm?id=beyond-iq-kids-who-can-focus-on-task-do-better-math (26 March 2007).
118. A. Lillard, N. Else-Quest, *Science.* **313**, 1893-1894 (2006).
119. E. Bialystok, *Child Dev.* **33**, 636-644 (1999).
120. E. Bialystok, M. M. Martin, *Dev. Sci.* **7**, 325 (2004).

121. E. Bialystok *et al., NeuroImage* **24**, 40-49 (2005).

122. E. Bialystok, D. Shapiro, *Dev. Sci.* **8**, 595 (2005).

123. T. O'Shaughnessy, K. L. Lane, F. M. Gresham, M. Beebe-Frankenberger, *Remedial and Special Education.* **24**, 27 (2003).

124. J. Crocker, *Self and Identity* **1**, 143 (2002).

125. F. Vitaro, M. Brendgen, S. Larose, R. E. Tremblay, *J. Educ. Psychol.* **97**, 617-629 (2005).

126. O. B. Davidson, D. Eden, *J. Appl. Psychol.* **85**, 386-398 (2000).

127. M. J. Harris, R. Rosenthal, *Psychol. Bull.* **97**, 363-386 (1985).

128. N. M. Kierein, M. A. Gold, *J. Organiz. Behav.* **21**, 913-928 (2000).

129. K. J. Kolb, L. Jussim, *Roeper Rev.* **17**, 26-30 (1994).

130. R. Rosenthal, *Am. Psychol.* **57**, 839-849 (2002).

131. D. Trouilloud, P. Sarrazin, P. Bressoux, J. Bois, *J. Educ. Psychol.* **98**, 75-86 (2006).