



A Caution to Educators: Avoiding a Pedagogy of Poverty Lessons from *Tools of the Mind* Kindergartens

Presented at the Grant Makers for Education meeting, October 25, 2016
Deborah J. Leong, Ph.D. & Elena Bodrova, Ph.D.

The "Pedagogy of Poverty"—a Hidden Barrier to Learning

Poverty presents many risk factors that can increase the likelihood that young children will be exposed to high levels of stress referred to as “toxic stress.” Extremely high levels of stress associated with families living in poverty can affect children's ability to retain what they learn in school and negatively affect their social and emotional well-being^{1 2 3 4}. There is evidence that these conditions can also influence brain development by adversely affecting the developing brain's circuitry.⁵ The impact of this kind of stress on children is increasingly recognized and discussed by neuroscientists, policymakers, and educators.

Stresses at the family and home level are not the only sources of stress for children living in poverty. Their school environment can be another significant stressor. Many schools serving children in poverty approach teaching and learning differently than schools serving more privileged children. Often under-resourced and in an earnest attempt to meet these children's needs, schools fall back to using instructional practices that create another set of stressors and problems for children. The use of adult-directed, tightly structured and rigid daily schedules, high stakes testing⁶, and a narrow definition of academic success can turn school into another source of stress^{7 8 9}. It may be that efforts to reduce toxic stress by strengthening families and neighborhoods¹⁰ will only be partially effective unless we also address what is happening in school.

These stress-inducing practices are most clearly observed in kindergartens where academic demands have been pushed down from upper grades¹¹. Many schools have *completely eliminated active and child-directed play, previously part of kindergarten experiences*—experiences that are developmentally necessary for all young students. The results of this “schoolification”¹² of kindergarten can be seen in the increase in behavioral problems in classrooms and even suspensions from school of kindergarten-age students¹³.

Kindergarten was not always like this. Recent changes in kindergartens serving low SES populations are due to well-intentioned attempts to narrow the achievement gap between children in poverty and their middle-class peers by providing content in a specific way. This approach, the “Pedagogy of Poverty,” a term coined by Martin Haberman¹⁴ includes a constellation of classroom practices where children at-risk for academic underachievement experience high levels of teacher direction. Drill is the primary instructional technique used with a narrow “one size fits all” focus on informational bits and sub-skills that have to be mastered before higher level content is introduced. There is limited time for exploration and playful learning; and student compliance is valued above student initiative¹⁵. Emphasis is placed on constant assessment of isolated sub-skills (e.g., letter names or letter sounds) and the use of hierarchical ability grouping to organize instruction (low readers together)^{16 17}. There are a number of troubling problems with this pedagogical approach. It erodes children's disposition to learn by increasing child anxiety and destroying confidence one's ability to learn. It fails to integrate



learning theory and developmental understandings of how young children learn pushing children to perform before they are ready¹⁸. This approach also takes a toll on teachers, contributing to teacher stress and burnout, and influencing the quality of their instructional interactions with children^{19 20}. Although this teaching approach has been used for many years, there are no research results to back its success and it has not been effective in narrowing the achievement gap as children progress beyond primary grades^{21 22}.

Neuroscience research is beginning to produce evidence that may partially explain why this method of teaching children living in poverty (or in fact, *all* children) does not help them sustain achievement gains in subsequent grade levels. This research shows that children's diminished motivation under the conditions of the "Pedagogy of Poverty" coupled with high levels of home and neighborhood stress may, in fact, promote learning that is more superficial with fewer neural connections, affecting long-term retention²³. Research on high levels of stress indicate that it actually compromises the child's capacity to learn,^{24 25} and can increase learning difficulties and cause behavioral problems, including the avoidance of activities where the child been unsuccessful. This learning "under extreme stress" is thought to be a contributing factor to the summer learning loss that occurs for many children, who at the end of the school year look like they have mastered content, but when tested the next fall, have forgotten what they learned, leading to an ever-widening of the achievement gap from year to year^{26 27}.

One Proven Alternative: *Tools of the Mind*

We care so much about the impact of the "Pedagogy of Poverty" because we know that there are very effective alternatives, including a curriculum that we co-created, *Tools of the Mind* (Tools). Children born in low SES families are not destined to experience the impact of the "Pedagogy of Poverty" because there are very effective alternatives. The *Tools* Kindergarten program presents one such alternative, standing in direct contrast to the "Pedagogy of Poverty" and kindergarten practices being implemented around the country to promote the educational achievement of children at risk for academic failure. *Tools* kindergarten classrooms are designed to be engaging learning environments where *all* children can achieve; with a focus on children's ability to be self-motivated and learn how to learn—all without the use of stressful or punitive teaching interactions.

Blair and Raver's²⁸ randomized control study in 2014 demonstrated that *Tools* closed the achievement gap in Kindergarten for children from high poverty schools. Children in these schools in spite of starting behind their peers, ended the year with achievement levels similar to the middle-class children in the study. In addition, there were significant gains in children's literacy and math achievement scores compared with a control group. These academic results were demonstrated not just at the end of the study year, but extended into the next year in first-grade as well, when children were no longer in the *Tools* program. As well, *Tools* children showed higher levels of executive functions compared to controls. Executive functions are the abilities associated with the development of the prefrontal cortex and other regions of the brain that work in concert with the prefrontal cortex and have been shown to influence a child's ability to learn, attend, and remember as well as engage in positive social interactions²⁹. The children in *Tools* classrooms did not show the degree of "summer loss" of academic and social-emotional development found in children in the control group. The Blair and Raver study shows that better results can be obtained using a different and more effective approach to teaching.

How is *Tools of the Mind* pedagogy different from “the Pedagogy of Poverty?” What lessons can be learned?

Tools approach has demonstrated that *all* children can learn with an integrated play-based approach that emphasizes the development of executive function skills. All studies to date on the program in preschool and kindergarten have shown that *Tools* students learn as much or more than control groups in “business as usual” conditions. This research included high poverty schools where children in the control condition were more likely to experience teacher-directed instruction with ability groupings and high stakes testing—the same techniques described in the “Pedagogy of Poverty”^{30 31}.

Tools’ example shows that we do not have to have a one-size fit all approach. Instead, we can provide individualized instruction embedded in activities designed to support skill development at multiple levels simultaneously. In *Tools* classrooms, children of different abilities engage in the same learning activity although each child practices the target content skill with scaffolding aimed at his or her individual needs. For example, when children make a book about what they learned, some of them represent their message with a scribble, some draw a few elements of their message, some represent their message with lines standing for words, and others some write letters representing the sounds they hear in words. The teacher works on oral language with the first group, increasing representation with the second, on using letters to represent sounds for the next group and for the last group, more fully representing the sounds in the word using estimated spelling. By using a single well-designed activity that has developmental breadth and individual 1:1 instruction embedded in its design, teachers have an easier time compared to the situation when they have to manage multiple activities each aimed only at one developmental level or one activity aimed only at the average child. Furthermore, because these activities do not sacrifice individualized scaffolding, the pace of instruction in the classroom protects children who need more support from being forced to move on before they are ready, and at the same time, does not unfairly hold children back that are ready to be challenged more.

Tools shows that we do not have to use “drill and kill” approaches to get good child outcomes. Instead, play and playful learning helps children reach and exceed expected outcomes. The use of guided play or playful learning has been shown to be more motivating and effective in other programs as well^{32 33}. Research on *Tools of the Mind* confirms not only the effectiveness of this approach but that make-believe play including literature-based dramatization makes contributions to learning³⁴. In a *Tools of the Mind* kindergarten, children engage in thematic studies from Medieval Europe to the Amazon Rainforest, and dramatize the life and times related to these themes. For example, they learn the ways that a medieval market place is similar to and different from today’s supermarket, making connections with their daily lives as they pretend to live in medieval times. Learning and practicing new concepts through play, and later applying these concepts in their reading and writing results in *all* children, regardless of their socioeconomic status, acquiring large and sophisticated vocabularies that are a hallmark of a *Tools of the Mind* kindergarten. In *Tools of the Mind* classrooms, special time is set aside for children to create props and engage in thematic dramatic play. This integrated approach, with dedicated time for make-believe play, enhances children’s motivation and natural imagination while simultaneously contributing to the development of self-regulation and academic learning.

Tools shows that we do not need to use ability groups to teach but instead children thrive and learn best in a collaborative classroom community where they treat each other with intellectual equity and support each other’s learning. The *Tools of the Mind* classroom is organized to



promote children's ability to help each other learn and build on the idea that all children regardless of their level of achievement have something valuable to contribute to their peers. *Tools of the Mind* builds on each child's strengths and helps him or her learn how to be a good thinking and learning partner. Specific strategies are used to make sure children who do not speak English (ELL/DLL) or who have a learning disability are not isolated from collaboration but can participate as full partners. Part of executive functioning practice is the ability to monitor one's own understanding and that of a peer, as well as using strategies intentionally when learning. These practices are embedded in both *Tools* self-correcting materials and a buddy learning system where children work with all of the other children in the class regardless of academic ability. Activities are designed so that learners with lower skills can provide learners with higher skills accurate and helpful feedback on their learning and vice versa. Children help each other think through "how errors help you learn" regardless of ability level. A supportive learning relationship develops where the child with lower skills is not just being tutored all the time, but provides meaningful feedback to a higher skilled peer. Children learn academic social skills so that children support each other in meaningful ways. The entire learning environment is designed to support the social and emotional competence of the learner so that the stress of learning is managed and does not disrupt the learning process but is handled calmly and positively. (View video clip of *Tools of the Mind* classroom where children of different ability levels are paired together and help each other learn: <https://vimeo.com/217566093/e365df06df>)

Tools of the Mind shows that teachers do not need to choose between high-interest, high-engagement activities and explicit instruction. In *Tools of the Mind* classrooms, teachers use a research-based scope and sequence of skills involved in encoding and decoding to provide explicit instruction in these skills to their students. However, this explicit instruction takes place in the context of activities that are highly engaging. For example, children learn how to read word containing specific word pattern as they "decipher" a secret message left by their favorite story characters. While for the children it is a fun activity where they search for the clues about future adventures of these characters, the messages themselves are strategically designed to have children practice orthographic mapping.

Tools of the Mind shows that by addressing the anxiety and negative emotions associated with learning something difficult and making a lot of mistakes, children can learn how to be self-directed and manage these feelings so that these feelings don't destroy motivation and impede learning. Learning can be frustrating and anxiety provoking for children, especially when they make a lot of errors. Negative feelings about failing develop that can cause children to give up, leading to a downward spiral as children continue to avoid a challenging activity and consequently do not make any progress in their learning. The neuroscience research on executive functioning that informs the *Tools of the Mind's* approach to teaching shows that EFs can help children manage negative emotions related to learning by planning and reflecting on learning behaviors. Examples of *Tools of the Mind* activities designed to promote children's self-regulation are Learning Plans and Learning Conferences. Children create daily plans for learning and have the opportunity on a weekly basis to sit with the teacher and discuss their work. During this time the teacher focuses on how to improve children's strategies to learn and at the same time how to manage their feelings of failure. Children learn how to use errors to correct their understandings and how to practice more effectively. Children set goals that both overcome mistakes and at the same time increase their persistence when obstacles emerge. Learning Plans and Learning Conferences are designed to foster a growth mindset—the belief that you can learn

through hard work and practice. When children have a growth mindset, they realize that when they struggle with learning something, it doesn't mean they aren't smart, but it is a chance to improve their performance. This construct is associated with academic success and learning³⁵. Through the use of Learning Plans and the collaborative classroom, children learn how to learn. (See a video of *Tools* classrooms using Learning Plans: <https://vimeo.com/217566605/39ea400110>)

Tools of the Mind shows that we need not limit children of poverty to restricted experiences, but instead we should honor and scaffold the natural curiosity and desire to learn that exists in all children. A facet of "the Pedagogy of Poverty" is the belief that poor children's ability to learn and interest in content is somehow different from middle class children and that children in poverty relate only to topics with which they have personal experience, so topics like ancient Egypt or the Amazon Rainforest are off the table. In *Tools* we have learned that once children know how to make connections between what is being learned and their own experiences, they can relate to any topic. There is no reason to believe that poor children are different from their middle class peers in their interests and that they cannot pursue these interests when provided background knowledge and support for how to use it. If we limit our expectations, we actually end up shortchanging instead of helping the very children we care so much about.

The lesson from the *Tools of the Mind* approach to teaching children from low SES families is that the "Pedagogy of Poverty" is NOT the best way to ensure that these children succeed in school. The overall results show that emphasis on the development of executive functions, and on play and playful learning can reduce or eliminate school-related stress, increase achievement, and change the trajectory of learning gains for young children that will continue into the next grade. Most important, it makes school a place where children enjoy learning, feel successful, and achieve.

¹ Arnsten, A. F. (2009). Stress signaling pathways that impair prefrontal cortex structure and function. *Nature Reviews Neuroscience*, 10, 410-422

² Blair, C. (2012). Treating a Toxin to Learning. *Scientific American Mind*, 23, 64-67.

³ Blair, C., & Raver, C. C. (2012). Child development in the context of adversity: Experiential canalization of brain and behavior. *American Psychologist*, 7(4), 309-318.

⁴ National Scientific Council on the Developing Child. (2010). Persistent fear and anxiety can affect young children's learning and development: Working Paper 9. Retrieved from www.developingchild.net website

⁵ Shonkoff, J. P. (2015). The neurobiology of early childhood development and the foundation of a sustainable society. *Investing against Evidence*, 55.

⁶ Feeney, S., & Freeman, N. K. (2014). Standardized testing in kindergarten. *YC Young Children*, 69(1), 84.

⁷ Burts, D., Hart, C. H., & Charlesworth, R. (1990). Observed activities and stress behaviors of children in developmentally appropriate and inappropriate kindergarten classrooms. *Early Childhood Research Quarterly*, 7(2), 297-318. doi:doi:10.1016/0885-2006(92)90010-V

⁸ Stipek, D., Daniels, D., Galluzzo, D., & Milburn, S. (1992). Characterizing early childhood education programs for poor and middle-class children. *Early Childhood Research Quarterly*, 7(1), 1-19.

⁹ Segool, N. K., Carlson, J. S., Goforth, A. N., Von Der Embse, N., & Barterian, J. A. (2013). Heightened test anxiety among young children: elementary school students' anxious responses to high-stakes testing. *Psychology in the Schools*, 50(5), 489-499

- ¹⁰ Sandel, M., Faugno, E., Mingo, A., Cannon, J., Byrd, K., Garcia, D. A., ... & Jarrett, R. B. (2016). Neighborhood-level interventions to improve childhood opportunity and lift children out of poverty. *Academic pediatrics*, *16*(3), S128-S135.
- ¹¹ Bassock, D., Latham, S., Rorem, A. (2016). Is kindergarten the new first grade? *AERA Open*, *1*(4), 1-31.
- ¹² Organisation for Economic Cooperation and Development (OECD) (2006). Starting Strong II. Paris: OECD
- ¹³ Stipek, D., Daniels, D., Galluzzo, D., & Milburn, S. (1992). Characterizing early childhood education programs for poor and middle-class children. *Early Childhood Research Quarterly*, *7*(1), 1-19.
- ¹⁴ Haberman, M. (1991). The pedagogy of poverty versus good teaching. *Phi Delta Kappan*, *74*(4), 290-294.
- ¹⁵ Haberman, M. (1991). The pedagogy of poverty versus good teaching. *Phi Delta Kappan*, *74*(4), 290-294.
- ¹⁶ Ritchie, S., & Gutmann, L. (2014). *FirstSchool: Transforming PreK–3rd Grade for African American, Latino, and Low-Income Children*. New York: Teachers College Press.
- ¹⁷ Stipek, D. (2004). Teaching practices in kindergarten and first grade: Different strokes for different folks. *Early Childhood Research Quarterly*, *19*(4), 548-568. doi:doi:10.1016/j.ecresq.2004.10.010
- ¹⁸ Haberman, M. (2010). 11 Consequences of Failing to Address the ‘Pedagogy of Poverty. *Phi Delta Kappan*, *92*(2), 45-46.
- ¹⁹ Pakarinen, E., Kiuru, N., Lerkkanen, M. K., Poikkeus, A. M., Siekkinen, M., & Nurmi, J. E. (2010). Classroom organization and teacher stress predict learning motivation in kindergarten children. *European Journal of Psychology of Education*, *25*(3), 281-300
- ²⁰ Friedman-Krauss, A. H., Raver, C. C., Morris, P. A., & Jones, S. M. (2014). The role of classroom-level child behavior problems in predicting preschool teacher stress and classroom emotional climate. *Early Education and Development*, *25*(4), 530-552.
- ²¹ Jackson, Lori A. "Observing children's stress behaviors in a kindergarten classroom." *Early Childhood Research & Practice*, vol. 11, no. 1, 2009. *Academic OneFile*, go.galegroup.com/ps/i.do?p=AONE&sw=w&u=auraria_main&v=2.1&id=GALE%7CA200919474&it=r&asid=f04b14df28e5e255784c83c14efbd8d6. Accessed 14 Nov. 2016.
- ²² Stipek, D., & Greene. (2001). Achievement motivation in early childhood: Cause for concern or celebration? In S. Golbeck (Ed.), *Psychological perspectives on early childhood education: Reframing dilemmas in research and practice* (pp. 64-91). Mahwah, NJ: Erlbaum.
- ²³ Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*(1), 3-10.
- ²⁴ Blair, C. (2012). Treating a Toxin to Learning. *Scientific American Mind*, *23*, 64-67.
- ²⁵ Ursache, A., Blair, C., & Raver, C. C. (2012). The promotion of self-regulation as a means of enhancing school readiness and early achievement in children at risk for school failure. *Child Development Perspectives*, *6*(2), 122-128.
- ²⁶ McGarry, M. V. (2013). *Summer Slide: The Need for Summer Intervention for Low Income Elementary School Students*. Retrieved from <https://repository.wlu.edu/handle/11021/24080> Accessed 14 Nov. 2016
- ²⁷ Gershenson, S. (2013). Do summer time-use gaps vary by socioeconomic status?. *American Educational Research Journal*, *50*(6) 1219-1248 0002831213502516.
- ²⁸ Blair, C., & Raver, C. C. (2014). Closing the Achievement Gap through Modification of Neurocognitive and Neuroendocrine Function: Results from a Cluster Randomized Controlled Trial of an Innovative Approach to the Education of Children in Kindergarten. *PLOS ONE*. doi:DOI: 10.1371/journal.pone.0112393
- ²⁹ Center on the Developing Child at Harvard University (2011). Building the Brain’s “Air Traffic Control” System: How Early Experiences Shape the Development of Executive Function: Working Paper No. 11. <http://www.developingchild.harvard.edu>
- ³⁰ Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool Program Improves Cognitive Control. *Science*, *318*, 1387-1388.

-
- ³¹ Barnett, W. S., Jung, K., Yaro, D. J., Thomas, J., Hornbeck, A., Stechuck, R., & Burns, S. (2008). Educational effects of the Tools of the Mind curriculum: A randomized trial. *Early Childhood Research Quarterly, 23*, 299–313.
- ³² Weisberg, D. S., Hirsh-Pasek, K., & Golinkoff, R. M. (2013). Guided play: Where curricular goals meet a playful pedagogy. *Mind, Brain, and Education, 7*(2), 104-112.
- ³³ Toub, T. S., Rajan, V., Golinkoff, R. M., & Hirsh-Pasek, K. (2016). Guided Play: A Solution to the Play Versus Discovery Learning Dichotomy. In *Evolutionary Perspectives on Child Development and Education* (pp. 117-141). Springer International Publishing.
- ³⁴ Blair, C., & Raver, C. C. (2014). Closing the Achievement Gap through Modification of Neurocognitive and Neuroendocrine Function: Results from a Cluster Randomized Controlled Trial of an Innovative Approach to the Education of Children in Kindergarten. *PLOS ONE*. doi:DOI: 10.1371/journal.pone.0112393
- ³⁴ Elliot, A. J., & Dweck, C. S. (2013). A conceptual history of the achievement goal construct. *Handbook of competence and motivation* (pp. 52-72.): Guilford Publications

THE EARLY YEARS

Preschool Program Improves Cognitive Control

Adele Diamond,^{1*} W. Steven Barnett,² Jessica Thomas,² Sarah Munro¹

Executive functions (EFs), also called cognitive control, are critical for success in school and life. Although EF skills are rarely taught, they can be. The Tools of the Mind (Tools) curriculum improves EFs in preschoolers in regular classrooms with regular teachers at minimal expense. Core EF skills are (i) inhibitory control (resisting habits, temptations, or distractions), (ii) working memory (mentally holding and using information), and (iii) cognitive flexibility (adjusting to change) (1, 2).

Significance

EFs are more strongly associated with school readiness than are intelligence quotient (IQ) or entry-level reading or math skills (3, 4). Kindergarten teachers rank skills like self-discipline and attentional control as more critical for school readiness than content knowledge (5). EFs are important for academic achievement throughout the school years. Working memory and inhibition independently predict math and reading scores in preschool through high school [e.g., (3, 6, 7)].

Many children begin school lacking in EF skills (5). Teachers receive little instruction in how to improve EF and have preschoolers removed from class for poor self-control at alarming rates (8, 9). Previous attempts to improve children's EF have often been costly and of limited success (10–12). Poor EFs are associated with such problems as ADHD, teacher burnout, student dropout, drug use, and crime (2). Young lower-income children have disproportionately poor EFs (13, 14). They fall progressively farther behind in school each year (15).

The Study

The opportunity to evaluate Tools of the Mind (Tools) and another curriculum arose when a low-income, urban school district

agreed to randomly assign teachers and children to these two curricula. Our study included 18 classrooms initially and added 3 more per condition the next year. Quality standards were set by the state. All classrooms received exactly the same resources and the same amounts of teacher training and support (2). Stratified random assign-



"Buddy reading." Two preschoolers engaged in Tools activity. The ear line-drawing held by one guides her attention (2).

ment of teachers and assistants minimized confounds due to teacher characteristics.

EF-training curriculum: Tools. The Tools curriculum (16) is based on Vygotsky's insights into EF and its development. Its core is 40 EF-promoting activities, including telling oneself out loud what one should do ("self-regulatory private speech") (17), dramatic play (18), and aids to facilitate memory and attention (19). Tools teachers spent ~80% of each day promoting EF skills. Tools has been refined through 12 years of research in preschools and kindergartens. Only when EFs were challenged and supported by activities throughout the day did gains generalize to new contexts (2).

District's version of Balanced Literacy curriculum (dBL). The curriculum developed by the school district was based on balanced literacy and included thematic units. Tools and dBL covered the same academic content, but dBL did not address EF development. [For teacher training and fidelity, see (2).]

Participants. Data are reported on 147 preschoolers (62 in dBL and 85 in Tools) in

Cognitive control skills important for success in school and life are amenable to improvement in at-risk preschoolers without costly interventions.

their second year of preschool (average age: 5.1 years in both) who received dBL or Tools for 1 or 2 years. Those who entered in year 2 had attended other preschools for a year. All came from the same neighborhood and were randomly assigned to Tools or dBL with no self-selection into either curriculum. All came from low-income families; 78% with yearly income <\$25,000 (2).

After year 1, so convinced were educators in one school that Tools children were doing substantially better than dBL children that they halted the experiment in their school, reducing our sample of dBL children.

Measures of EF. Outcome measures (the Dots task and a Flanker task) were quite different from what any child had done before. These measures are appropriate for ages 4 through adults, assess all three EF components, and require prefrontal cortex (20–21). They were administered in May and June of year 2.

In all conditions of the Dots task (20), a red heart or flower appeared on the right or left. In the congruent condition, one rule applied ("press on the same side as the heart"). Dots-Incongruent also required remembering a rule ("press on the side opposite the flower") plus it required inhibition of the tendency to respond on the side where the stimulus appeared. In Dots-Mixed, incongruent and congruent trials were intermixed (taxing all three core EFs). Children were given a lot of time to respond [over five times as long as preschoolers usually take (20)].

The central stimulus for our Flanker task was a circle or triangle. Memory demands were minimized by a triangle atop the right-hand key and at the bottom right of the screen, with similar aids for the left-hand circle response. The image to focus on was the small shape in the center; the distractor (or flanker) to be ignored was the larger shape surrounding it. Congruent (e.g., ○ inside ○) and incongruent (e.g., △ inside ○) trials were intermixed. Next came "Reverse" Flanker, where children had to focus on the outside shape, inhibiting attention to the inside, plus flexibly switching

CREDIT: PENNY FARSTER-NARLESKY

¹Department of Psychiatry, University of British Columbia, Vancouver, BC V6T 2A1; BC Children's Hospital, Vancouver, BC, Canada. ²National Institute for Early Education Research (NIEER), Rutgers University, New Brunswick, NJ, USA.

*Author for correspondence. E-mail: adele.diamond@ubc.ca

mindsets and attentional focus. The rules were still “press right for Δ and left for ○.” Again, children were encouraged to take their time and not to rush.

Independently, NIEER administered academic measures to Tools children only. These are described in (2).

Results

We report accuracy rather than speed because, for young children, accuracy is the more sensitive measure (23). We conducted multiple regression analyses with age, gender, curriculum, and years in curriculum as independent variables. Interaction terms were insignificant and were dropped. On Dots-Congruent, which had minimal EF demands, children performed similarly regardless of curriculum, year in a curriculum, or gender, though older children performed better.

When an inhibition demand was added (Dots-Incongruent), Tools children significantly outperformed dBL children (see the figure, left of above). Dots-Mixed taxed all three EF skills and was too difficult for most dBL children: Almost twice as many Tools as dBL children achieved >75% correct on training trials (see the figure, right of above).

Our Flanker task, like Dots-Incongruent, taxed inhibition (with minimal memory or flexibility demands). Tools children significantly outperformed dBL children (figure above). On Reverse Flanker, dBL children performed near chance (65% correct), but Tools children averaged 84% correct (see figure, above). Thus, the most demanding Dots and Flanker conditions showed the largest effects; those effects are socially significant because they are sizeable.

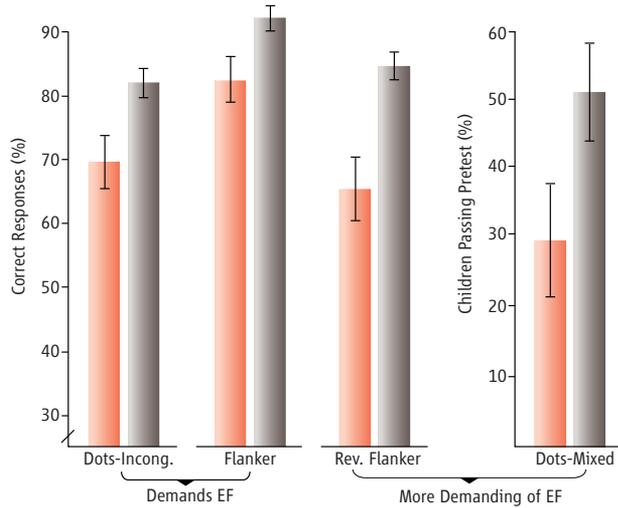
Tasks that were more demanding of EFs correlated more strongly with standardized academic measures. For example, “Get Ready to Read” scores correlated 0.05, 0.32, and 0.42 with Dots-Congruent, -Incongruent, and -Mixed, respectively (2).

Conclusions

Some think preschool is too early to try to improve EFs. Yet it can be done. EFs can be improved in 4- to 5-year-olds in regular public school classes with regular teachers. Being in

Tools accounted for more variance in EFs than did age or gender and remained significant when we controlled for those. These findings of superior scores by Tools children compared with closely matched peers on objective, neurocognitive EF measures are consistent with teachers’ observations (24).

Although play is often thought frivolous, it may be essential. Tools uses mature, dramatic



Tools children (blue) performed better on measures of EF than dBL children (red) did. (A) The dependent measure is percentage of correct responses. Dots-Incongruent, Flanker, and Reverse Flanker tasks are described in the text. (B) The dependent measure is percentage of children passing the pretest for this task. Statistics are reported in the SOM (2).

play to help improve EFs. Yet preschools are under pressure to limit play.

If, throughout the school day, EFs are supported and progressively challenged, benefits generalize and transfer to new activities. Daily EF “exercise” appears to enhance EF development much as physical exercise builds bodies (2).

The more EF-demanding the task, the more highly it correlated with academic measures. Superior academic performance has been found for Tools children in other schools and states, with other teachers and comparison curricula (24, 25). EFs [especially self-discipline (inhibition)] predict and account for unique variance in academic outcomes independent of and more robustly than does IQ (2, 3, 26).

Tools successfully moves children with poor EFs to a more optimal state. It is not known how much it would help children who begin with better EFs.

No study is perfect, and ours is no exception. Before and after measures of EFs, as well as academic measures in dBL children, would have strengthened it. Strengths include random assignment and use of objective measures. No authors or testers had a stake in either

curriculum. Many competing explanations have been ruled out (2).

Most interventions for at-risk children target consequences of poor EFs rather than seeking prevention, as does Tools. We hypothesize that improving EFs early may have increasing benefits over time and may reduce needs for costly special education, societal costs from unregulated antisocial behavior, and the number of diagnoses of EF disorders [e.g., ADHD and conduct disorder (2)].

References and Notes

1. A. Diamond, in *Lifespan Cognition: Mechanisms of Change*, E. Bialystok, F. Craik, Eds. (Oxford Univ. Press, New York, 2006), pp. 70–95.
2. See supporting online material for more information.
3. C. Blair, R. P. Razza, *Child Dev.* **78**, 647 (2007).
4. M. M. McClelland, F. J. Morrison, D. L. Homes, *Early Child. Res. Q.* **15**, 307 (2000).
5. S. E. Rimm-Kaufman, R. C. Pianta, M. J. Cox, *Early Child. Res. Q.* **15**, 147 (2000).
6. R. Bull, G. Scerif, *Dev. Neuropsychol.* **19**, 273 (2001).
7. S. E. Gathercole, C. Tiffany, J. Briscoe, A. Thorn, ALSPAC team, *J. Child Psychol. Psychiatry* **46**, 598 (2005).
8. T. Lewin, “Research finds a high rate of expulsions in preschool,” *New York Times*, 17 May 2005, p. A12.
9. W. S. Gilliam, *Prekindergartners Left Behind: Expulsion Rates in State Prekindergarten Systems* (Yale Child Studies Center, New Haven, CT, 2005).
10. K. A. Kerns, K. Eso, J. Thompson, *Dev. Neuropsychol.* **16**, 273 (1999).
11. S. M. Dowsett, D. J. Livesey, *Dev. Psychobiol.* **36**, 161 (2000).
12. M. R. Rueda, M. K. Rothbart, B. D. McCandliss, L. Saccamanno, M. I. Posner, *Proc. Natl. Acad. Sci. U.S.A.* **102**, 14931 (2005).
13. K. G. Noble et al., *Dev. Sci.* **10**, 464 (2007).
14. K. G. Noble et al., *Dev. Sci.* **8**, 74 (2005).
15. T. O’Shaughnessy et al., *Remedial Spec. Educ.* **24**, 27 (2003).
16. E. Bodrova, D. J. Leong, *Tools of the Mind: The Vygotskian Approach to Early Childhood Education* (Merrill/Prentice-Hall, New York, ed. 2, 2007).
17. 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.
18. L. S. Vygotsky, *Soviet Psychol.* **7**, 6 (1967).
19. L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes* (Harvard Press, Cambridge, MA, 1978).
20. M. C. Davidson et al., *Neuropsychologia* **44**, 2037 (2006).
21. M. R. Rueda et al., *Neuropsychologia* **42**, 1029 (2004).
22. E. Durston et al., *Neuroimage* **20**, 2135 (2003).
23. A. Diamond, N. Kirkham, *Psychol. Sci.* **16**, 291 (2005).
24. W. S. Barnett, et al., “Educational effectiveness of the Tools of the Mind curriculum: A randomized trial” (National Institute of Early Childhood Education Research, Rutgers University, New Brunswick, NJ, 2006).
25. S. Saifer, paper presented at the 17th Annual Conference of the European Early Childhood Education Research Association, Prague, Czech Republic, 29 August 2007.
26. A. L. Duckworth, M. E. P. Seligman, *Psychol. Sci.* **16**, 939 (2005).
27. This research was made possible by funding to A.D. from HELP (the Human Early Learning Partnership) and National Institute on Drug Abuse (R01 DA19685)

Supporting Online Material
www.sciencemag.org/cgi/content/full/318/5855/1387/DC1

10.1126/science.1151148

Downloaded from www.sciencemag.org on November 30, 2007



Closing the Achievement Gap through Modification of Neurocognitive and Neuroendocrine Function: Results from a Cluster Randomized Controlled Trial of an Innovative Approach to the Education of Children in Kindergarten

Clancy Blair*, C. Cybele Raver

Department of Applied Psychology, Steinhardt School of Culture, Education, and Human Development, New York University, New York, New York, United States of America

Abstract

Effective early education is essential for academic achievement and positive life outcomes, particularly for children in poverty. Advances in neuroscience suggest that a focus on self-regulation in education can enhance children's engagement in learning and establish beneficial academic trajectories in the early elementary grades. Here, we experimentally evaluate an innovative approach to the education of children in kindergarten that embeds support for self-regulation, particularly executive functions, into literacy, mathematics, and science learning activities. Results from a cluster randomized controlled trial involving 29 schools, 79 classrooms, and 759 children indicated positive effects on executive functions, reasoning ability, the control of attention, and levels of salivary cortisol and alpha amylase. Results also demonstrated improvements in reading, vocabulary, and mathematics at the end of kindergarten that increased into the first grade. A number of effects were specific to high-poverty schools, suggesting that a focus on executive functions and associated aspects of self-regulation in early elementary education holds promise for closing the achievement gap.

Citation: Blair C, Raver CC (2014) Closing the Achievement Gap through Modification of Neurocognitive and Neuroendocrine Function: Results from a Cluster Randomized Controlled Trial of an Innovative Approach to the Education of Children in Kindergarten. *PLoS ONE* 9(11): e112393. doi:10.1371/journal.pone.0112393

Editor: Daniel Ansari, The University of Western Ontario, Canada

Received: May 19, 2014; **Accepted:** September 21, 2014; **Published:** November 12, 2014

Copyright: © 2014 Blair, Raver. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability: The authors confirm that all data underlying the findings are fully available without restriction. Data are available from the DRYAD Digital Repository: doi:10.5061/dryad.567pt.

Funding: Support for this research was provided by Institute of Education Sciences grant R305A100058. <http://ies.ed.gov/>. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* Email: clancy.blair@nyu.edu

Introduction

The 30th anniversary of the groundbreaking report, *A Nation at Risk*, serves as a powerful reminder of the persistence and growth of SES-related gaps in achievement [1] and signals the need for a renewed commitment to early learning, particularly for children in poverty. Recent advances in neuroscience suggest that poverty-related gaps in achievement are accompanied by poverty-related differences in brain structure and function [2–4] and differences in the regulation of attention, emotion, stress response physiology, and executive functions important for early learning [5,6]. These findings support the hypothesis that SES-related gaps in academic abilities at school entry are in part attributable to effects of poverty on children's self-regulation development [7–9].

To date, decisions about the most effective ways to foster learning in early childhood have not fully capitalized on advances in the neuroscience of self-regulation: Few interventions or approaches have targeted children's executive functions and self-regulation, despite evidence of the plasticity and malleability of neural and physiological systems that support self-regulation and early learning [10–12].

Research has shown that executive functions, defined as cognitive flexibility, working memory, and inhibitory control are malleable [13,14] and predict academic achievement in children over and above IQ and socioeconomic status [15,16]. Although executive functions are defined by a specific set of cognitive skills, they are one aspect of a larger self-regulation system consisting of multiple components arrayed along a continuum from effortful to automatic [17,18]. As a higher order construct embodying the volitional, active engagement of attention and emotion for the purpose of goal-directed action, executive functions can be understood to regulate activity in lower level neural systems associated with attention, emotion, and physiological responses to stimulation. This top-down influence of executive functions is their hallmark and is frequently emphasized in theory and research on cognitive control [19–22]. The relation of executive functions to lower level systems, however, is reciprocal. Changes in emotional and attentional state in response to stimulation are accompanied by physiological changes as indicated by circulating levels of catecholamines, dopamine and norepinephrine, and the steroid hormone cortisol that influence and can at high levels overwhelm neural activity in prefrontal cortex, the seat of executive function

abilities [23,24]. Although executive functions can and do exert ‘top-down’ influence on lower-level systems, these cognitive abilities are dependent on and controlled by the ‘bottom-up’ influence of these lower-level systems. This is particularly the case for young children in whom executive function skills are just developing. Educational approaches that foster the development of the self-regulation system, including the regulation of attention, emotion, and stress response physiology can be expected to enhance executive functions and thereby promote learning and beneficial educational outcomes.

Prospective longitudinal research examining relations among early poverty-related adversity and neuroendocrine and neurocognitive function has shown that the stress response can be altered and executive functions compromised for children in severe poverty or facing other early adversity [8,9,25,26]. Few studies, however, have considered ways that the neurobiology of self-regulation can inform educational practice for all children, particularly those from low-income homes [27,28]. Across several clinical interventions targeting small samples of children facing high environmental risk, results provide promising evidence of benefits to executive functions, brain activity, and stress response physiology, primarily as indexed by levels of salivary cortisol, the end product of the hypothalamic-pituitary-adrenal [HPA] axis [29–33]. No prior studies of which we are aware, however, have explicitly built on the neurobiology of self-regulation to test hypotheses about the best ways to structure educational experiences for children.

Here, we focus on kindergarten, an educational opportunity publically available to all age-eligible children within most school districts and 42 out of 50 states, serving over 4 million children annually [34]. Carefully structured opportunities in kindergarten that assist young children in reflecting on knowledge and purposefully and intentionally engaging with learning materials are likely to promote optimal patterns of neuroendocrine and neurocognitive function important for learning. Such opportunities hold substantial promise for reducing or ameliorating poverty-related gaps in school readiness and early school achievement. Accordingly, we hypothesized that educational practices designed to support the development of self-regulation will lead not only to higher academic achievement but will also be associated with beneficial change in measures of children’s attention, executive functions, and stress response physiology. Further, we hypothesized that these effects would be largest for or perhaps even specific to children in high-poverty schools. Children from poverty backgrounds are less well prepared for school both academically and in terms of self-regulation [35,36]. Effective education approaches that focus on self-regulation in combination with academic abilities could provide substantial educational benefits for children facing early disadvantage [37].

Description of the Approach

The aim of this study was to marshal advances in neuroscience research and theory [38,39] to examine the hypothesis that a focus on executive functions and on the regulation of attention, emotion, and stress response physiology that support executive functions can foster children’s educational progress. To meet this aim, we used an experimental research design to test the impact of an innovative educational approach known as Tools of the Mind. This study is the first to examine the kindergarten version of the program. Findings from prior evaluations of the prekindergarten version of Tools of the Mind, however, are mixed. A randomized controlled trial of the prekindergarten version of the program in a high-poverty sample found that the program was effective in promoting executive function abilities [40] with some limited effects on

aspects of children’s academic abilities [41]. Another larger trial of the prekindergarten program with a more diverse sample found no effects on any measures of executive functions or academic outcomes [42].

From a theoretical standpoint, expectations for effects of the Tools of the Mind program on educational outcomes in young children are strong. Building on the fundamental insights of Lev Vygotsky, Alexander Luria, and post-Vygotskian scholars [43–45], the program was developed over 18 years of intensive effort in preschool and kindergarten classrooms across the United States, and other countries including Chile and Canada. The pedagogical approach includes the use of specific tactics to support memory and learning, and the organization of “shared cooperative activity” designed to promote social-emotional as well as cognitive development. Specifically, Tools of the Mind has a coherent focus on executive functions as a primary mechanism through which children make academic progress and develop social competencies. In doing so, the program blends teacher-led scaffolding of a comprehensive curriculum of literacy, mathematics, and science activities aligned with the Common Core Standards with child-directed activities and structured sociodramatic play. In Tools of the Mind, teachers learn how to organize and manage instruction so that children build self-regulation skills through purposeful interactions with classmates. In this way, the program is designed to foster attention and emotion regulation skills in ways that support the development of executive functions and lead to advances in social and emotional competence. Teachers also engage in daily dynamic assessment of children’s development in core areas and provide individualized, differentiated scaffolding [meaning that teachers increase or decrease instructional and emotional support depending on how a child independently performs a specific skill.] Children in Tools kindergarten classrooms also meet with the teacher to create and follow weekly individual Learning Plans and set and review weekly individual learning goals. In these conferences, children “talk through” both correct and incorrect answers leading to the ability to reflect on and correct mistakes. Children reflect on their learning and develop a sense that ability is controllable by effort, and mistakes and errors are something to learn from, rather than to be dismissed or avoided. Such activities support intentionality and planning and are specifically designed to prompt the use of metacognitive strategies and reflective thinking.

There are a number of major differences between Tools and traditional kindergarten. Primary among these is the use intentional make-believe play. To make play an effective educational approach, play in Tools of the Mind classrooms is planned in advance, includes children’s enactment of roles with implicit rules, role speech, and the use of symbolic props [e.g. a block is a loaf of bread, a brick, a phone, etc.]. Play in kindergarten is distinguished from play in preschool through dramatization, meaning that it is tied to stories and literature rather than grounded in children’s everyday experiences. Tools kindergartens first use fairy tales to support the development of high-level dramatization, and then quickly move into chapter books, dramatizing the life and times of the book one chapter at a time. In this way, intentional pretend play serves as a vehicle to develop language, text comprehension, vocabulary skills, and creativity in children.

Another major difference between Tools and traditional kindergarten is the intentional use of peer interaction and teacher scaffolding to support reflective, higher-order thinking skills and to assist children in developing social competence and intrinsic motivation to accomplish academic tasks and goals. Maintaining and building children’s intrinsic motivation to learn instead of

using external rewards [stickers or stars] is a distinguishing feature of Tools. Social interaction within learning activities and games is designed so that children work primarily in pairs with materials that are self-correcting and prompt children to help one another. These interactions are hypothesized to build a classroom community that is conducive to moderate positive emotion arousal, optimal physiological engagement, and thoughtful self-reflection. They are also understood to help children to develop a sense of self-efficacy and an attitude toward the value of task persistence when confronted with difficulties.

Summary

The teaching practices and activities of Tools of the Mind are designed to promote academic learning and ability by broadly focusing on multiple aspects of self-regulation including executive functions, social and emotion regulation skills, the control of attention, and the regulation of stress response physiology. As such, the key question tested in this study is whether the set of classroom practices embodied in the Tools of the Mind program will lead to academic gains as well as gains in a key set of indicators that reflect neurobiological as well as academic benefit. As such, this study tests questions regarding the malleability of neuroendocrine and neurocognitive function in educational contexts as well as academic achievement in response to an innovative educational approach. We test these questions in ways that are designed to have clear implications for educational policy as well as basic science research addressing the best ways to reduce or eliminate the school readiness gap associated with poverty in a large and diverse sample.

Methods

Ethics Statement

All research procedures and protocols including participant recruitment materials were reviewed and approved by the University Committee on Activities Involving Human Subjects at New York University. Parents of participating children provided written consent and all participating children provided verbal assent.

Participants and Procedures

School districts were contacted by research and program personnel and recruited into the study. Twelve districts with a total of 29 schools agreed to participate. Schools signed a memorandum of understanding in which they agreed to accept random assignment to the treatment or control group, to remain in the assigned condition for two years, to facilitate data collection, and if randomly assigned to the treatment group to facilitate the training and coaching. Schools were blocked according to district, percent of students eligible for free or reduced-price lunch, school size, state test scores, and number of kindergarten classrooms, and randomly assigned to the treatment [$N = 16$] or control [$N = 13$] group. Block randomization on multiple variables led to small and acceptable differences in the number of schools randomized to the treatment vs. control groups. Most schools included two participating kindergarten classrooms. We made an exception for 2 schools in the participating districts in which all of the district's kindergarten classrooms were housed in one facility. For these two schools, random assignment was at the classroom level and the school was treated as two schools for analysis purposes. The sample included a total of 79 classrooms, $N = 42$ treatment and $N = 37$ control.

Participating schools ranged from 5% to 92% of students eligible for free or reduced-price lunch. Approximately 15% of the

schools in the sample are considered high-poverty schools as defined by the National Center for Education Statistics [46] as schools with greater than 75% of students eligible for free or reduced-price lunch. Approximately 50% of the schools in the sample are considered low-poverty schools, meaning that less than 25% of students are eligible. The remaining schools ranged from 27% to 68% of students eligible for free or reduced-price lunch.

We attempted to recruit six children per classroom in each of the two years of the study. Recruitment was conducted through flyers sent to children's homes and through parent night activities. Parents provided written consent for children to participate and children provided verbal assent. In instances in which more than 6 children in a classroom expressed interest in participation, we enrolled the first 6 children for whom consent forms were returned by parents and assigned all other children with returned consents to a waiting list. Recruitment efforts yielded a sample of $N = 396$ in Year 1 [229 treatment, 167 control] and $N = 363$ in Year 2 [214 treatment, 149 control] for a total analysis sample of $N = 759$. Children in treatment classrooms were no more likely to participate than were children in control classrooms. Approximately 5% of participants [$N = 34$] were lost to follow-up from fall to spring and replaced with participants on waiting lists in classrooms in which more than 6 participants expressed interest in participating in the study or in some classrooms with newly recruited participants. Additionally, 2 new participants were recruited in the spring in classrooms in which fewer than 6 children had been recruited in the fall. All children entering the study in the spring had been in the classroom since the fall. Total sample size was $N = 723$ in the fall and $N = 725$ in the spring. Fall to spring attrition was unrelated to treatment or control group status.

Children were assessed in the fall and spring by trained data collectors at the school in which the child was enrolled. All measures were administered in a standard order. Assessment sessions on average took less than one hour to complete. In both fall and spring, children participated in two test batteries, one of which included measures of executive function, attention, and speed of processing, and the other measures of academic ability and general reasoning and during which 3 saliva samples were collected to assess physiological reactivity to the assessment session. The timing of saliva collection was designed to assess cortisol reactivity to the testing session. Given that the expression of cortisol in saliva generally lags any change in HPA activity by approximately 20 minutes, we collected an initial sample within 5 minutes of meeting the child for the testing session and then collected second [post1] and third [post2] samples at 20-minute intervals. The first sample provides an indication of the child's physiological state in the classroom prior to the testing session rather than a true baseline or resting state and the post1 and post2 samples provide indications of the child's response to meeting the research assistant and participating in the battery.

On average children were seen at the end of October in the fall and at the end of March in the spring. The second assessment session occurred approximately two weeks after the first in both fall and spring. The average number of days between fall and spring assessments was $M = 156$ [$SD = 27$]. The treatment and control groups did not differ in the number of days between the fall and spring assessments.

All participating children were followed up in the fall of the first grade year. Children were seen by trained data collectors in a single session at the school in which they were enrolled and administered measures of academic ability.

Treatment Classrooms

Teachers and teaching assistants in the *Tools of the Mind* classrooms were trained in a 2-year professional development cycle. In Year 1 teachers had 4 workshops spread across the year with a total of 5 days of training [Workshop 1 is 2 days]. Year 2 had 3 training workshops spread across the year with 3 days of training. Each school had a Tools coach that worked with the Tools trainer to provide in-classroom coaching once every other week during Year 1 and then once a month in Year 2. Coaches varied in their experience with Tools. Most were new to Tools and trained with the teachers during Year 1. There were self-reflection forms for the teacher to complete to assist the teacher in thinking about the implementation of different activities and to help the teacher reach better fidelity. Four times a year the Tools trainer would visit classrooms with the Coach to give feedback to the coach. Tools teachers may have attended district-wide professional development, such as health-related training, but they were not trained on any other curriculum during the course of the study.

Control Classrooms

Schools randomly assigned to the control condition continued with 'business as usual' practice. For example, teachers in control classrooms continued with district professional development as ordinarily scheduled through the school. Classrooms in the control schools used a combination of commercial literacy and mathematics curricula and followed state standards for the development of science and social studies curricula, a typical scenario for kindergarten classrooms. Tools and control classroom curricula meet Massachusetts State Standards and are aligned with the Common Core Standards. No classrooms in the control condition contained activities resembling those in the *Tools of the Mind* classrooms. For example, in the control classrooms children's make-believe play was not intentionally nurtured or scaffolded. In traditional, academically-oriented kindergartens, play is commonly relegated to a 10–15 minute free choice time at the beginning and ending of the school day or during recess, and many classrooms no longer have materials to support children's engagement in make-believe play. Most importantly, none of the literacy curricula used in control classrooms promote the use of literature-based make-believe play as a vehicle for teaching new vocabulary and text comprehension. While some of these curricula may suggest using elements of play in literacy activities it is never done in a systematic fashion across different titles and text genres.

Measures

The measures of academic ability included the Applied Problems and Letter-Word subtests from the Woodcock-Johnson III Tests of Achievement [47]. The WJ III is a co-normed set of tests for measuring general scholastic aptitude, oral language, and academic achievement. The validity and reliability of the WJ III Tests of Achievement is well established [48]. To measure fall to spring change and follow-up in the first grade, we used W scores on each of the subtests as these scores are most appropriate for examining individual level change over time [49]. To assess vocabulary ability in the spring and in the first grade follow-up we used the Expressive One Word Picture Vocabulary Test [50] raw score. The EOWPVT is a norm-referenced measure of vocabulary that assesses the child's ability to use words and requires the child to access and retrieve words from memory. The internal consistency reliability of the measure is .98. For the fall [pretest] measure of vocabulary, we used the raw score of the Reading Vocabulary subtest of the Woodcock-Johnson III Tests of Achievement.

The measure of general reasoning was the Raven Colored Progressive Matrices test [51]. The Raven test is a measure of fluid intelligence in which children are presented with a series of plates containing patterns from which a single uniformly shaped piece is missing. At the bottom of each plate, six versions of the missing piece are presented, only one of which correctly fits the pattern. Children were presented with a demonstration trial and then instructed on successive trials to point to the piece that best completes the pattern. Children were presented with one set of 12 plates of increasing difficulty. Total number correct was used for analysis.

Measures of executive function abilities were comprehensive and included assessments of working memory, cognitive flexibility, and inhibitory control. Three measures of executive function were administered on a laptop computer, including the Hearts and Flowers task [52], the Flanker with Reverse Flanker task [40], and the NIH Toolbox version of the Dimensional Change Card Sort task [53]. Children were instructed to respond by pressing one of two designated keys on opposite sides of the keyboard to which small Velcro strips were affixed to cue children to the location of the keys.

On the Hearts and Flowers task, children are instructed to respond by pressing the designated key on the same side as the stimulus when the stimulus is a heart and on the opposite side when the stimulus is a flower. Children are presented with instructional and practice trials, which can be repeated up to three times if necessary, followed by 12 hearts only trials, 12 flowers only trials, and 33 trials on which hearts and flowers are intermixed.

On the Flanker with Reverse Flanker task children are shown a row of five fish that are either blue or pink. When the fish are blue, [the standard flanker block], children are instructed to only pay attention to the middle fish and to press the designated key on the side of the keyboard to which that fish is facing. When the fish are pink [the reverse flanker block], children are instructed to only pay attention to the outer four fish, the flanker fish, and press the designated key on the side of the keyboard to which those fish are facing. On congruent trials, the central fish and the flanking fish are facing the same direction, and on incongruent trials, the central fish and flanking fish are facing in opposite directions. Children are presented with instructional trials and practice trials, which can be repeated up to 3 times and then presented with 50 trials on which congruent and incongruent responses to pink or blue fish are intermixed. In the fall [pretest], children were administered the standard version of the flanker task [54]. In the standard version of the task, the fish are all similarly colored and children respond only to the direction that the middle fish is facing.

On the NIH Toolbox version of the DCCS, children are presented with instructional and practice trials and then complete the standard version of the task, sorting 6 images by color and then by shape. Following this children are presented with 50 mixed trials in which the instruction to sort by color or by shape is presented auditorily.

All computer administered executive function tasks were scored as percent correct responding from which total percent correct and percent correct on incongruent relative to percent correct on congruent trial scores were derived. Reaction time/response latency data were also collected. Latencies less than 200 ms or greater than 3 standard deviations above the mean were excluded. Mean response latencies were calculated for each trial type if at least 60% of trials were valid.

The executive function of working memory was assessed in the spring [posttest] using the Forward/Backward Digit Span task [55]. This task was modeled on Weschsler [56]. Children are

presented with digit strings of increasing length in two-trial sets beginning with two-item sets and progressing through three-, four-, and five-item sets. Children are first instructed to repeat the digits spoken by the experimenter in the order that the experimenter speaks them. Forward digit span continues until the child fails both item sets at a given trial level. The experimenter then asks the child to continue the task but to repeat the digits spoken by the experimenter in reverse order. As with forward span, digit strings of increasing length are presented in two-trial sets beginning with two two-item sets and progressing through two three, four, and five item sets. Testing continues until the child fails both item sets at a given trial level. For both the forward and backward version of the task children are given instructional and practice trials. The task was scored as total number correct items sets. To control for baseline ability in the fall [pretest], we used a z-score composite of percent correct responding on the executive function tasks.

We assessed the ability to control attention in the face of emotional distraction using a Dot-Probe task, a widely used measure of attention bias to emotional stimuli [57]. Children are instructed to respond using the designated key on the keyboard corresponding to the side of the computer screen on which a stimulus [a dot] appears. A fixation cross is presented in the center of the screen for 750 ms followed by two pictures presented simultaneously for 750 ms on the left- and right-hand sides of the computer screen. Pictures included images drawn from the International Affective Picture database. For each pair of pictures, a neutral picture [ex. chair, lamp, cup] was paired with another neutral picture or with an emotionally arousing picture [ex. snakes, wolves, car crash]. Following the picture presentation, a dot either appears in the same location as the emotionally arousing image [congruent trials], in the location opposite the threatening image [incongruent trials], or on either side of the neutral/neutral display [neutral control]. The dot remains on the screen for 5000 ms or until the participant responds. Following instructional and practice trials, forty test trials were presented in a semi-random order that was the same across all participants. Trials with latencies less than 100 ms or greater than 3 standard deviations were excluded from analyses. Mean response latencies were calculated for each trial type if at least 60% of trials were valid. Negative response bias was calculated by subtracting the mean latency to respond to congruent trials from the mean latency to respond to incongruent trials. If participants attend to the emotion image, latencies will be faster for congruent displays and longer for incongruent displays and bias scores will be large and positive. Conversely, if participants are less distracted by the emotion image, the difference between the latencies will be shorter and the difference will be smaller.

Indicators of neuroendocrine function, cortisol and alpha amylase, were obtained through unstimulated whole saliva collected using hydrocellulose absorbent material and expressing sample by centrifugation. Samples were frozen at -20°C prior to being shipped to the laboratory packed in dry ice, and subsequently frozen at -80°C . All samples were assayed for salivary cortisol using a highly sensitive enzyme immunoassay [58]. The test used 25 μl of saliva, had a range of sensitivity from 0.007 to 3.0 $\mu\text{g}/\text{dl}$, and average intra- and inter- assay coefficients of variation less than 10% and 15%, respectively. All samples were assayed in duplicate and the average of the duplicates was used in all analyses. Natural log transformations were applied to the cortisol values to correct for positive skew.

Samples were also assayed for alpha amylase using a commercially available kinetic reaction assay [58]. The assay employs a chromagenic substrate, 2-chloro-p-nitrophenol, linked to maltotriose. The enzymatic action of sAA on this substrate yields

2-chloro-p-nitrophenol, which can be spectrophotometrically measured at 405 nm using a standard laboratory plate reader. The amount of alpha-amylase activity present in the sample is directly proportional to the increase [over a 2-min period] in absorbance at 405 nm. Results are computed in U/ml of alpha-amylase using the formula: [absorbance difference per minute X total assay volume [328 ml] X dilution factor [200]]/[millimolar absorptivity of 2-chloro-p-nitrophenol [12.9] X sample volume [.008 ml] X light path [.97]]. Square root transformations were used to reduce positive skew.

Finally, we included measures of speed of processing to assess potential program effects on this basic aspect of attention and neural efficiency. Measures of speed included a simple reaction time task and a rapid automatized naming task. In the simple reaction time task [35], children were instructed to press the laptop space bar each time a blue dot [7 cm diameter] appeared at random locations across the bottom of the screen. Responses were recorded in milliseconds. The inter-stimulus interval varied between 500 ms and 2500 ms. Children completed a total of 30 trials. Lower scores represent faster processing speed. Trials with latencies less than 200 ms or greater than 3 standard deviations above the mean were excluded from analyses. Mean response latencies were calculated for each trial type if at least 60% of trials were valid. In the rapid automatized naming task [59], children were presented with a sheet of 8.5×11 in paper across which are four rows containing nine color blocks each composed of blue, black, green, red, yellow, and brown squares in pseudo-random order. The child was instructed to name each color in turn quickly but accurately, starting with colors on the top row moving from left to right and row to row until all of the colors have been named. Following demonstration and practice, the child completes the sheet and is presented with a second sheet and instructed to continue naming the colors. The experimenter records the length of time it takes the child to complete the task. Timing is discontinued if the child makes 4 or more errors and the child is considered to have failed the task.

Data Analysis

Means, standard deviations, and numbers of participants with data for each variable in the treatment and control groups for each assessment in the fall and spring of kindergarten are presented in Tables 1 and 2. Follow-up data in first grade are also presented for the academic outcome measures in Table 2. As noted above, fall to spring attrition was approximately 5 percent of cases in the sample overall and 34 participants were replaced and two new participants were added to the sample in the spring. Fall to spring attrition did not differ between the treatment and control groups. A number of variables were also missing some data in the fall or spring for various reasons. For the academic measures, Raven matrices, forward/backward span, and simple reaction time measures, fewer than 5% of children were missing data, generally as a result of fatigue or absence from school and the data are considered to be missing at random. For the computer-administered executive function measures [DCCS, Fish Flanker, Hearts and Flowers] and the Dot-Probe task, missing data were primarily due to children having fewer than 60% valid trials and/or reaction times out of the usable range [e.g., <200 msec.] Missing data for cortisol and sAA were due to insufficient volume of saliva collection or child refusal. Missing cortisol and sAA were also due to refusal of the school principal at one of the participating schools to allow saliva collection from children. Missing data for all variables were unrelated to treatment vs. control status. Analyses were run using full information maximum likelihood estimation to

Table 1. Unadjusted descriptive statistics and sample size for measures of self-regulation and speed of processing in fall and spring of kindergarten.

	Tools of the Mind				Control			
	Fall		Spring		Fall		Spring	
	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]
Dimensional Change Accuracy	351	.65 [.13]	327	.73 [.12]	240	.66 [.13]	235	.73 [.14]
Hearts & Flowers Accuracy	390	.70 [.17]	403	.76 [.17]	273	.69 [.19]	284	.75 [.18]
Flanker Accuracy ^a	346	.74 [.20]	--	--	227	.75 [.21]	--	--
Reverse Flanker Accuracy ^b	--	--	342	.56 [.17]	--	--	234	.55 [.17]
EFs Accuracy z-score Composite	383	-.014 [.77]	399	-.003 [.76]	263	-.004 [.82]	281	-.03 [.82]
Dimensional Change RT msec	339	1083.2 [154]	322	1067.4 [143]	234	1089.6 [145]	233	1077.6 [139]
Hearts & Flowers RT Mixed msec	361	1185.1 [222]	389	1084.3 [209]	247	1181.6 [218]	267	1111.1 [207]
Flanker RT msec ^a	324	1208.9 [209]	--	--	213	1202.8 [202]	--	--
Reverse Flanker RT msec ^b	--	--	329	1420.7 [247]	--	--	224	1438.8 [231]
EFs RT z-score Composite	407	.03 [.85]	413	-.03 [.86]	281	-.02 [.82]	288	.05 [.83]
Backward Span Percent Correct ^b	--	--	416	.25 [.13]	--	--	282	.23 [.14]
Raven Matrices Sum Score	418	8.14 [1.9]	413	8.78 [1.5]	289	7.93 [1.9]	293	8.67 [1.7]
Dot-Probe Negative Bias	305	-14.14 [140]	313	-4.70 [124]	206	-18.47 [159]	229	8.25 [124]
Simple Speed RT msec	417	639.1 [212]	420	529.7 [116]	289	638.4 [199]	295	536.4 [124]
Rapid Color Naming Total Time	348	49.83 [17.7]	373	46.35 [14.4]	241	51.50 [16.4]	258	48.39 [17.2]
Sample 1 log Cortisol ug/dl	348	-2.13 [.69]	364	-2.03 [.60]	254	-2.07 [.65]	279	-2.05 [.60]
Sample 2 log Cortisol ug/dl	349	-2.23 [.68]	366	-2.10 [.57]	249	-2.13 [.67]	279	-2.12 [.61]
Sample 3 log Cortisol ug/dl	335	-2.33 [.67]	353	-2.19 [.55]	235	-2.25 [.67]	272	-2.22 [.62]
Sample 1 sq Alpha Amylase	357	8.02 [3.2]	362	7.99 [3.2]	253	7.80 [3.1]	278	8.25 [3.2]
Sample 2 sq Alpha Amylase	352	8.49 [3.2]	365	8.47 [3.3]	251	8.35 [3.2]	278	8.91 [3.4]
Sample 3 sq Alpha Amylase	342	8.43 [3.1]	355	8.44 [3.3]	233	8.26 [3.1]	268	8.83 [3.2]

^afall [pretest] only.^bspring [posttest] only.

doi:10.1371/journal.pone.0112393.t001

Table 2. Unadjusted descriptive statistics and sample size for measures of academic outcomes in fall and spring of kindergarten.

	Tools of the Mind						Control					
	Fall K		Spring K		Fall First		Fall K		Spring K		Fall First	
	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]
Applied Problems W Score	408	434.08 [17.1]	410	446.08 [16.6]	393	458.40 [19.1]	282	432.58 [17.9]	289	443.49 [18.2]	268	456.44 [17.6]
Letter-Word W Score	416	370.16 [31.1]	413	404.66 [32.1]	396	434.04 [33.3]	288	370.44 [31.2]	290	403.22 [29.9]	268	430.81 [30.2]
Picture Vocabulary Sum ^a	417	12.32 [2.1]	--	--	--	--	290	12.01 [2.1]	--	--	--	--
EOWPVT Raw Score ^b	--	--	417	71.73 [16.9]	397	76.93 [20.9]	--	--	297	69.09 [17.1]	270	72.53 [22.1]

^afall [pretest] only.^bspring [posttest] only.

doi:10.1371/journal.pone.0112393.t002

adjust for potential bias in the estimates resulting from missing data.

We analyzed the data using multilevel models with children nested within schools, the unit of random assignment. We bootstrapped clustered standard errors [B = 1000] to provide asymptotic refinement and more consistent estimates of standard errors [se] given that the data are hierarchically nested in a small number of clusters [N = 29] and variances may be heteroskedastic [60,61]. For all analyses, treatment versus control group status was included as a binary indicator along with the pretreatment [fall] measure of the outcome variable and child-level [age, sex, parent education, pre-treatment cognitive ability] and school-level [percent free or reduced-price lunch, size of kindergarten enrollment] covariates. By including the pretreatment measure of each outcome as a predictor, the test of the coefficient [b] for the treatment versus control group comparison indicates whether Tools of the Mind was associated with greater change from the pretreatment measure in the fall. To make this comparison of fall to spring change explicit, we also examined a change score as the outcome variable, subtracting the fall measure of the outcome from the spring measure and using this as the dependent variable. Given the redundancy of results for these analyses with those we report when adjusting for the pretest measure, we do not report them but make them available from the first author upon request. For all analyses, we first tested the main effect of treatment [Tools of the Mind vs. Control] on the outcome, and then tested the interaction of treatment with the school-level variable, percent of children eligible for free or reduced-price lunch, to determine whether effects were larger in high-poverty schools.

In the two-level model predicting student outcomes, child posttest score on a given assessment [denoted by Y_{ij}] was predicted at level 1 from a vector of child-level predictors including the child's pre-treatment score on the outcome assessment and child-level covariates.

$$Y_{ij} = \beta_{0j} + \sum_{q=1}^q \beta_{qj} X_{qij} + r_{ij}$$

Test of the effect of the treatment on child posttest score was included in the second level of the model as a binary indicator T_{1j} [treatment = 1, control = 0] to account for the nesting of participants within schools, the unit of random assignment. School level covariates were also included in the model as a vector of predictors W_{sj} at level 2.

$$\beta_{0j} = \gamma_{00} + \gamma_{01} T_{1j} + \sum_{s=1}^S \gamma_{0s} W_{sj} + u_{0j}$$

For outcome assessments with three time points, namely, measures of cortisol and alpha amylase, and mathematics and reading ability with first grade data included, we added a within-person level to the model, in addition to child and school levels. In these models we examined treatment effects on the linear slope as well as the intercept. For the prediction of math and reading outcomes, the intercept was set at the last time point, first grade.

Effect sizes were calculated as the covariate adjusted model parameter estimate for the binary treatment versus control comparison divided by the pooled standard deviation for the outcome. This provides an estimate of the covariate adjusted mean difference between groups in standard deviation units. Effect sizes

were calculated for all treatment effects observed in two-level models, whether main effects or interactions with school poverty. Effect sizes for the interaction effects were calculated with school percent free or reduced-price lunch equal to 1. Effect sizes were not calculated for treatment effects in three-level models given uncertainty as to how to best to make this calculation.

Results

We ran analyses on a number of dependent variables to address a theoretically coherent and interrelated set of research questions. We report results of all analyses below, first reporting the test of the main effect of treatment and then the test of the interaction of treatment with the school-level poverty indicator, percent of students eligible for free or reduced-price lunch. As a preliminary step in the analysis and check on randomization, we examined treatment and control group differences on all variables assessed in the fall of kindergarten to determine if differences between the groups were present at baseline. No differences were observed.

A primary question of interest to both education and neuroscience communities is whether the Tools of the Mind program led to significant improvements relative to the control group in children's neurocognitive and neuroendocrine functioning. Our analysis suggests that the answer is largely yes: Children in classrooms implementing Tools of the Mind did significantly better than children in the control classrooms on a measure of working memory, the backward digit span task, $b = 0.02$, $se = .01$, $p < .05$, $ES = .14$. The effect size [ES] estimate and 95% confidence interval for the estimate for this comparison and for all outcomes included in the analysis are presented in Figure 1. This effect was observed in the sample as a whole and was not larger in high-poverty schools.

Children in classrooms implementing Tools of the Mind also had significantly faster mean reaction time than did children in control classrooms on a composite of inhibitory control and rule switching computer administered executive function tasks including the DCCS mixed trials, the Hearts & Flowers mixed trials, and the Flanker with Reverse Flanker total score, $b = -20.62$, $se = 12.63$, $p < .05$, $ES = .12$. This effect indicates that children receiving the Tools of the Mind program were better able to cope with cognitive interference and subsequent slowing of responding on these tasks. The analysis of this composite also indicated that the effect of treatment on reaction time tended to be larger in high-poverty schools, $b = -75.7$, $se = 55.9$, $p = .10$, $ES = .48$. Figure 2 presents the ES estimate and 95% confidence interval for this comparison and for all outcome variables in high-poverty schools. We did not observe an overall effect of Tools of the Mind on accuracy [percent correct responding] on this executive function composite. The effect of the program on accuracy on the executive function composite, however, was large in high-poverty schools although not statistically significant using the conventional threshold, $b = .039$, $se = .029$, $p < .10$, $ES = .31$.

A further effect of the curriculum on the control of attention in the face of interference was also seen on a task in which emotionally arousing stimuli are interspersed among neutral images and are either congruent or incongruent with a cued response location. On this task, the Dot-Probe, we did not observe an overall effect of Tools of the Mind but found that the effect of the program on this outcome was specific to high-poverty schools. Children receiving Tools of the Mind in high-poverty schools exhibited reduced interference from the emotional image on response latency on incongruent relative to congruent trials, referred to as negative bias, $b = -102.2$, $se = 47.01$, $p < .05$,

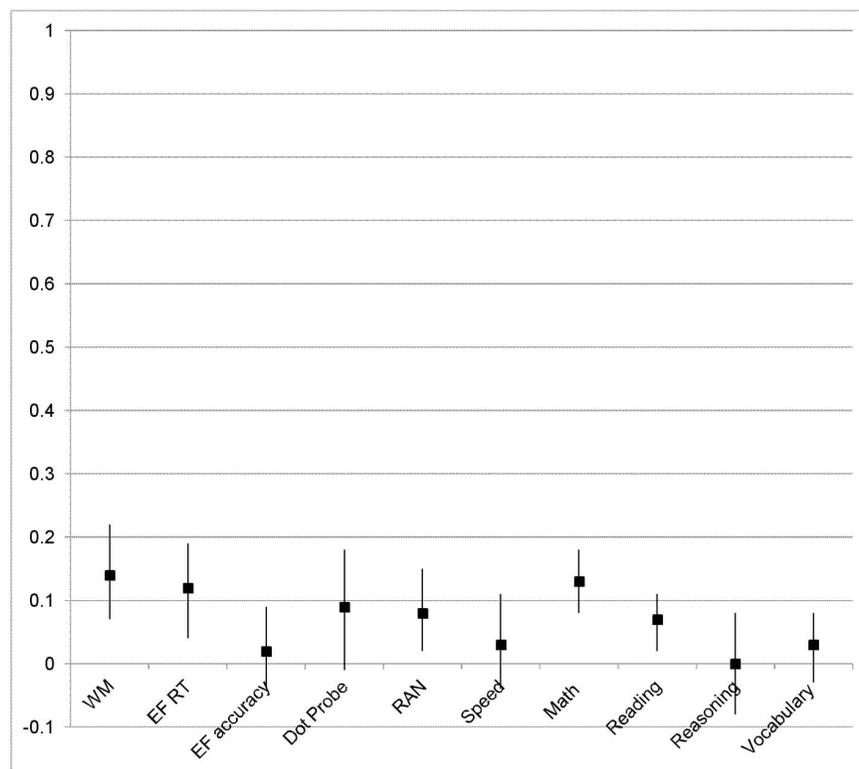


Figure 1. Effect size estimates for main effects of Tools of the Mind versus Control group comparisons at the end of kindergarten.

Error bars represent effect sizes at $\pm 1SE$.

doi:10.1371/journal.pone.0112393.g001

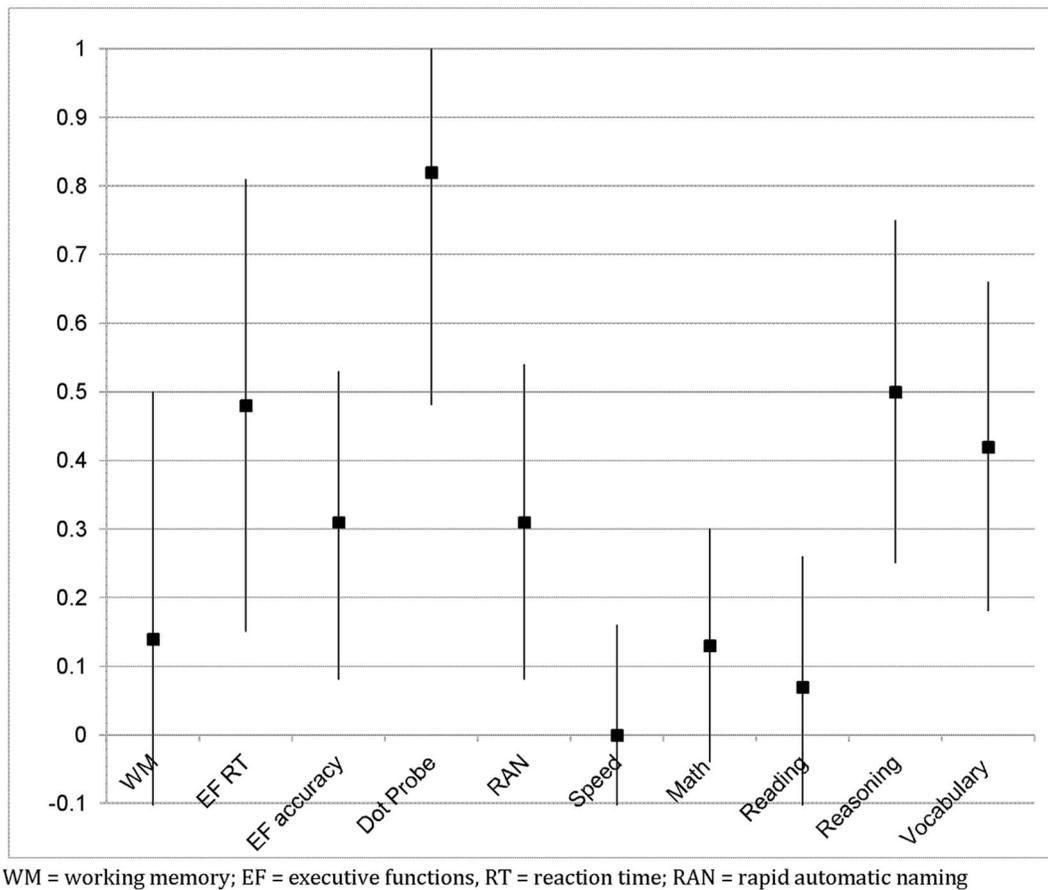


Figure 2. Effect size estimates for Tools of the Mind versus Control group comparisons in high poverty schools at the end of kindergarten. Error bars represent effect sizes at $\pm 1SE$. doi:10.1371/journal.pone.0112393.g002

ES = .82 [Figure 1b]. The effect of the curriculum on the Dot-Probe task was not seen, either in the sample overall or in high-poverty schools for attention as assessed by a simple reaction time task. The test of the effect of Tools of the Mind on the rapid automatized naming task, a measure of speeded responding, however, indicated that children in Tools of the Mind classrooms were more efficient at processing information, $b = 1.44$, $se = .97$, $p < .05$, $ES = .08$. This effect of the treatment was larger, although not conventionally statistically significant, in high-poverty schools, $b = 4.36$, $se = 4.04$, $p < .20$, $ES = .28$.

Of further interest, analyses revealed significant impacts of Tools of the Mind on measures of children's stress response physiology that were specific to high-poverty schools. No main effect of treatment was observed. Levels of cortisol and alpha amylase were assessed through saliva samples collected at three time points over one data collection session [baseline, 20 mins post, and 40 mins post]. Controlling for the time of day of data collection, a three level model with observations nested within participants nested within schools indicated that salivary cortisol levels declined significantly in both groups, $b = -.19$, $se = .03$, $p < .001$, across the testing session but that overall levels were higher, $b = .25$, $se = .07$, $p < .05$, among children in the classrooms implementing Tools of the Mind in high-poverty schools. Similarly, salivary amylase levels increased significantly over the testing session in both groups, $b = .48$, $se = .14$, $p < .001$, but were significantly lower, $b = -1.62$, $se = .38$, $p < .05$, among children in

the classrooms implementing Tools of the Mind in high-poverty schools.

Finally, as hypothesized, the analysis demonstrated that Tools of the Mind substantially benefited children's academic progress relative to the progress of children in the control schools [Figures 1 and 2]. Children in classrooms implementing Tools of the Mind showed significantly higher academic ability than did children in control classrooms on a measure of mathematics, $b = 2.10$, $se = .94$, $p < .05$, $ES = .13$. This effect of Tools of the Mind on mathematics in the sample overall was not significantly larger in high-poverty schools. In contrast, a large effect of treatment on vocabulary was specific to children in high-poverty schools, $b = 8.34$, $se = 4.30$, $p < .05$, $ES = .43$. The specific effect of the curriculum in high-poverty schools was also seen on a measure of general fluid intelligence or reasoning, the Raven colored matrices test, $b = -0.75$, $se = .42$, $p < .05$, $ES = .46$.

Follow-up data in the first grade on children participating in the study [see Table 2] indicated that an initially non-significant main effect of the Tools of the Mind program on reading ability, $b = 2.00$, $se = 1.42$, $p < .10$, $ES = .07$, increased and became significant, $b = 3.32$, $se = 1.45$, $p < .05$, $ES = .14$. The sustained effect of the program was also observed for vocabulary and extended to all children receiving Tools of the Mind, not only children in high-poverty schools, $b = 2.16$, $se = 1.14$, $p < .05$, $ES = .10$. Some sustained effect of the program was also observed for mathematics to some extent, $b = 1.36$, $se = 1.01$, $p < .10$, $ES = .07$, however, the effect of Tools of the Mind on achievement

in mathematics was somewhat reduced from that seen at the end of kindergarten. Notably, the effects of the program on progress in reading, vocabulary, and mathematics were detected when controlling for both the pre [fall] and post [spring] measures of the outcome in kindergarten, indicating an effect of the curriculum over and above that seen at the end of kindergarten. These findings indicate that the significant improvement in learning in children in the Tools of the Mind classrooms relative to the control classrooms continued into the first grade. This effect of the curriculum on growth in child academic ability is readily illustrated for reading, for which we have the same measure at all three time points. A three level model with measurement occasion nested within participants and participants nested within schools indicated a positive treatment effect on the slope for reading ability, $b = 2.24$, $se = .83$, $p < .01$ [Figure 3], indicating faster growth in reading ability in the treatment group relative to the control group.

Discussion

The results of this field-based experiment demonstrate that the Tools of the Mind program, which focuses broadly on the development of self-regulation as key to early learning, led to improvements in neuroendocrine and neurocognitive function as well as significant improvements in academic abilities. These findings indicating positive effects of Tools of the Mind on children's executive functions and attention as well as on indicators of stress response physiology help to empirically confirm the responsiveness to experience of these aspects of children's development as well as substantiate the relevance of an educational approach that builds on the neurobiology of self-regulation. No prior study of which we are aware has shown widespread effects of a focus on self-regulation on multiple interrelated aspects of children's early development in an educational setting using an experimental design. A small number of experimental studies implementing programmatic activities to support self-regulation development have shown effects on stress response physiology as indicated by cortisol [31] and on the control of attention both behaviorally and in terms of brain activity [32]. Our study, however, is the first to comprehensively assess and

document treatment-related differences in neuropsychological and psychophysiological measures as well as academic outcomes in a typically occurring educational context.

The fact that these broad experimental effects were observed in response to an innovative program focused on self-regulation development suggests that the approach embodied in Tools of the Mind is effective at engaging children and assisting children in making academic progress. As noted above, prior findings of the prekindergarten version of the program have been mixed. It may be that kindergarten represents an optimal time during which the activities contained in Tools of the Mind can support and foster self-regulation skills and abilities in children. Executive functions and the control of attention enable children to focus on and process information more efficiently while higher levels of cortisol and lower levels of amylase provide evidence of physiological support for engagement. Although stress physiology is complex and lower levels of cortisol and higher levels of alpha amylase are generally desirable at rest, elevated cortisol under conditions of moderate stress and engagement is associated with a higher level of cognitive ability [62,63]. Moderate cortisol elevations, taking into account diurnal variation, promote memory and learning and facilitate energy utilization and storage [64,65]. Although sustained diurnal elevations in cortisol are injurious to the organism and indicative of chronic stress, our findings are not consistent with an interpretation in which the relative elevations we observed in children are indicative of increased stress in Tools of the Mind classrooms. Notably, levels of salivary cortisol significantly declined, and levels of sAA significantly increased during the approximately 50 minute assessment session in both groups. On average, children in the sample did not exhibit any indication of the sustained elevated levels of salivary cortisol that are reported in research on children in preschool settings [66–68]. Research on stress response physiology in children in elementary education settings is rare and only one other study to our knowledge, with a middle income sample of preschoolers, has examined change in salivary cortisol and sAA using a protocol similar to ours [69]. Consistent with our findings, in that study, lower cortisol across the assessment session was associated with behavior regulation difficulties as rated by teachers and higher

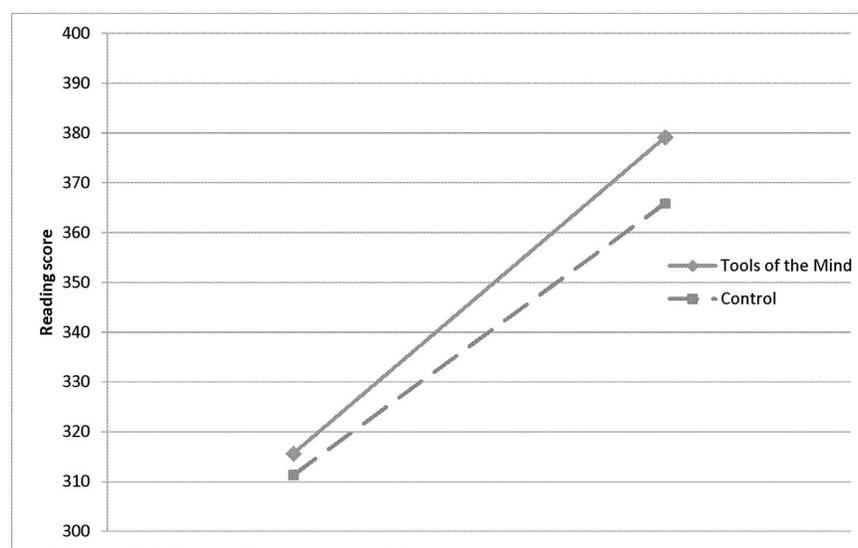


Figure 3. Effect of the Tools of the Mind curriculum on growth in reading (linear slope) from the beginning of kindergarten through the fall of first grade, $b = 2.24$, $se = .83$, $p = .001$.
doi:10.1371/journal.pone.0112393.g003

levels of sAA were associated with greater difficulty delaying gratification.

Perhaps most importantly, a number of the effects we observed, including effects for salivary cortisol and alpha amylase, are specific to high-poverty schools. Recent research has highlighted the neurobiological and cognitive costs associated with exposure to poverty-related adversity. Our findings highlight that children in high-poverty schools demonstrate significant neurobiological and academic benefit when provided with an educational approach that provides scaffolded support for self-regulation. The indication that such an educational approach can work to overcome deficits in school readiness associated with poverty has substantial implications for school reform and anti-poverty efforts. As well, the indication that academic gains associated with the curriculum are sustained and increase over time into the first grade for all children contributes to the profound expectation that effective early education can work to reduce the achievement gap and thereby help to reduce growing social and economic inequality in the United States while also providing benefits to all children's learning.

Addressing inequities in educational opportunity associated with poverty is a national priority. Educational disadvantages associated with poverty are present prior to kindergarten [70]. By improving children's skills at the outset of their educational careers, our findings suggest that effective child-directed educational approaches such as Tools of the Mind can perhaps go a long way toward fulfilling the promise of free and universal public education by equalizing opportunity for children to succeed despite initial disadvantage. By working to level the playing field for children at school entry, effective kindergarten education can be expected to lead to reduced social and economic burden associated with poverty. Long term follow-ups of model early intervention programs of the 1970s and 1980s indicate that these high quality educational programs resulted in greater academic achievement, school completion, and employment, and reduced grade retention, special education, arrest, and incarceration among program recipients [71]. These findings are complemented by longitudinal findings from a birth cohort of children in Dunedin, New Zealand indicating that self-regulation in childhood, measured between ages 3 and 11 years is a powerful predictor of well being in adulthood [72]. In sum, programs that can improve self-regulation in children can be expected to have long-term benefits.

Although the case is clear for initiating anti-poverty programs as early as possible, far in advance of kindergarten entry, kindergarten represents an excellent window of opportunity for implementing the child-focused approach embodied by Tools of the Mind. Educational practice increasingly emphasizes academic content in kindergarten, and children of kindergarten age are for the most part ready to engage with that content. There is, however, surprisingly little research and policy emphasis on kindergarten effectiveness. This is despite the indication that a high quality kindergarten experience may uniquely influence later educational and life outcomes. Evaluation of the kindergarten class size experiment in Tennessee known as Project Star indicated that students randomly assigned to kindergarten classrooms with fewer students had higher academic achievement at grades, 4, 6, and 8 [73] and that assignment to a higher quality kindergarten

classroom was associated with higher rates of college attendance and higher earnings in adulthood [74]. Although much of the discussion in early education focuses on prekindergarten, increased attention to kindergarten, and also the first three elementary grades, can broaden understanding of the goals of early education and the best ways in which to support children's learning.

In conclusion, it is important to point out that results from this experimental evaluation are particularly notable in that the Tools of the Mind educational program is implemented without a high level of additional resources and support and using typical professional development activities. Teachers received typical levels of training and implemented the curriculum with materials that are well within the budget of the average kindergarten classroom. Given mixed findings in prior evaluations, however, further research is needed on the approach and its application across contexts. It will be particularly important in future analyses to identify the program's "active ingredients." This analysis is limited in that it focused only on the examination of the efficacy of the program without attention to fidelity of program implementation or specific program components. This analysis is also limited in that we conducted multiple statistical tests without correction and as a consequence there is the possibility that our results could have capitalized on chance. This concern is mitigated to some extent by the coherence of our findings and by the strong theoretical rationale for examining multiple interrelated aspects of children's development. Further, although findings indicate that effects of Tools of the Mind are large on certain of the dependent variables in high-poverty schools, we had no hypotheses as to why some variables but not others would show this differential effect of the program. Despite these limitations, our findings do suggest that the adoption of readily implementable programs embodying a focus on self-regulation development in kindergarten can be expected to have substantial impact on reducing disparities in educational achievement while boosting early achievement for all children. As such, these findings have implications for educational policy at local and national levels. Specifically, they support the shift among school systems to investment in universal programs and assurance of high quality early education for all from prekindergarten through 3rd grade [see Weiland and Yoshikawa [75] on efforts in Boston MA and the universal early education initiative in New York City as well as ongoing federal early education initiatives.] In contrast to earlier policy emphases on targeted, means-tested intervention supporting income-eligible children through programs such as Head Start, our findings suggest the value added from an integrated model of high-quality early education for all children across the early elementary grades.

Acknowledgments

We wish to thank the participating children, families, schools, and teachers and acknowledge the assistance of a large group of data collectors and research assistants, particularly Mohamed Soliman, Aida Alikalfic, and Caitlin Mauer.

Author Contributions

Conceived and designed the experiments: CB CCR. Performed the experiments: CB CCR. Analyzed the data: CB CCR. Contributed to the writing of the manuscript: CB CCR.

References

1. Reardon S (2011) The widening academic achievement gap between the rich and the poor: New evidence and possible explanations. In: Duncan G, Murnane R, editors. *Whither opportunity*. New York: Russell Sage. 91–116.
2. Hanson JL, Chandra A, Wolfe BL, Pollak SD (2011) Association between income and the hippocampus. *PLoS One* 6: e18712.

3. Gianaros PJ, Marsland AL, Sheu LK, Erickson KI, Verstynen TD (2013) Inflammatory pathways link socioeconomic inequalities to white matter architecture. *Cerebral Cortex* 23: 2058–2071.
4. Sheridan MA, Sarsour K, Jutte D, D'Esposito M, Boyce WT (2012) The impact of social disparity on prefrontal function in childhood. *PLoS One*. 2012; 7(4):e35744. doi:10.1371/journal.pone.0035744. Epub 2012 Apr 26. PMID: 22563395.
5. Blair C, Granger DA, Kivlighan KT, Mills-Koonce R, Willoughby M, et al. (2008) Maternal and child contributions to cortisol response to emotional arousal in young children from low-income, rural communities. *Dev Psychol* 44: 1095–1109.
6. Evans GW (2003) A multimethodological analysis of cumulative risk and allostatic load among rural children. *Dev Psychol* 39: 924–933.
7. Raver CC, Blair C, Willoughby M, Family Life Project Key Investigators (2013) Poverty as a predictor of 4-year-olds' executive function: New perspectives on models of differential susceptibility. *Dev Psychol* 49: 292–304.
8. Blair C, Granger D, Willoughby M, Mills-Koonce R, Cox M, et al. (2011) Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Dev* 82: 1970–1984.
9. Evans GW, Schamberg MA (2009) Childhood poverty, chronic stress, and adult working memory. *Proc Natl Acad Sci USA* 106: 6545–6549.
10. Fisher PA, Gunnar MR, Dozier M, Bruce J, Pears KC (2006) Effects of therapeutic interventions for foster children on behavioral problems, caregiver attachment, and stress regulatory neural systems. *Ann NY Acad Sci* 1094: 215–225.
11. Mackey AP, Hill SS, Stone SI, Bunge SA (2011) Differential effects of reasoning and speed training in children. *Dev Sci* 14: 582–590.
12. Bryck RL, Fisher PA (2012) Training the brain: Practical applications of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science. *Am Psychol* 67: 87–100.
13. Melby-Lervåg M, Hulme C (2013) Is working memory training effective? A meta-analytic review. *Dev Psychol* 49: 270–291.
14. Diamond A, Lee K (2011) Interventions shown to aid executive function development in children 4 to 12 years old. *Sci* 333: 959–964.
15. Blair C, Razza RP (2007) Relating effortful control, executive function, and false-belief understanding to emerging math and literacy ability in kindergarten. *Child Dev* 78: 647–663.
16. Bull R, Espy KA, Wiebe SA, Sheffield TD, Nelson JM (2011) Using confirmatory factor analysis to understand executive control in preschool children: Sources of variation in emergent mathematics achievement. *Dev Sci* 14: 679–692.
17. Blair C, Ursache A (2011) A bidirectional model of executive functions and self-regulation. In: Baumeister R, Vohs K, editors. *Handbook of Self-Regulation*, 2nd edition. New York: Guilford. 300–320.
18. Diamond A (2013) Executive functions. *Annu Rev Psych* 64: 135–168.
19. Fuster J (2008). *The prefrontal cortex*, 4th edition Burlington MA: Academic Press 410 p.
20. Botvinick M, Cohen J, Carter C (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends Cogn Sci* 8: 539–546.
21. Duncan J (2001) An adaptive coding model of neural function in prefrontal cortex. *Nat Rev Neurosci* 2: 820–829.
22. Miller EK, Cohen JD (2001), An integrative theory of prefrontal cortex function. *Annu Rev Neurosci* 24: 167–202.
23. Arnsten AFT (2009) Stress signaling pathways that impair prefrontal cortex structure and function. *Nat Rev Neurosci* 10: 410–422.
24. Ramos BP, Arnsten AFT (2007) Adrenergic pharmacology and cognition: Focus on the prefrontal cortex. *Pharmacol Ther* 113: 523–536.
25. Kim P, Evans GW, Angstadt M, Ho SS, Sripada CS, et al (2013) Effects of childhood poverty and chronic stress on emotion regulatory brain function in adulthood. *Proc Natl Acad Sci* 110: 18442–18447.
26. Pears KC, Fisher PA, Bruce J, Kim HK, Yoerger K (2010) Early elementary school adjustment of maltreated children in foster care: The roles of inhibitory control and caregiver involvement. *Child Dev* 81: 1550–1564.
27. Berkman ET, Graham AM, Fisher PA (2012) Training self-control: A domain-general translational neuroscience approach. *Child Dev Perspect* 6: 374–384.
28. Bruce J, McDermott JM, Fisher PA, Fox NA (2009) Using behavioral and electrophysiological measures to assess the effects of a preventive intervention: A preliminary study with preschool-aged foster children. *Prev Sci* 10: 129–140.
29. Brotman LM, Gouley KK, Huang KY, Kamboukos D, Fratto C, et al. (2007) Effects of a psychosocial family-based preventive intervention on cortisol response to a social challenge in preschoolers at high risk for antisocial behavior. *Arch Gen Psychiatry* 64: 1172–1179.
30. Dozier M, Peloso E, Lewis E, Laurenceau JP, Levine S (2008) Effects of an attachment-based intervention on the cortisol production of infants and toddlers in foster care. *Dev Psychopathol* 20: 845–859.
31. Fisher PA, Stoolmiller M, Gunnar MR, Burraston BO (2007) Effects of a therapeutic intervention for foster preschoolers on diurnal cortisol activity. *Psychoneuroendocrinology* 32: 892–905.
32. Neville HJ, Stevens C, Pakulak E, Bell TA, Fanning J, et al. (2013). Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proc Natl Acad Sci USA* 110: 12138–12143.
33. Rueda MR, Rothbart MK, McCandliss BD, Saccomanno L, Posner MI (2005) Training, maturation, and genetic influences on the development of executive attention. *Proc Natl Acad Sci USA* 102: 14931–14936.
34. National Center for Education Statistics. Available: nces.ed.gov/programs/coe/indicator_tea Accessed 2013 May.
35. Fitzpatrick C, McKinnon R, Blair C, Willoughby M (2014) Do preschool executive function skills explain the school readiness gap between advantaged and disadvantaged children? *Learn Instr* 30: 25–31.
36. Noble KG, McCandliss BD, Farah MJ (2007) Socioeconomic gradients predict individual differences in neurocognitive abilities. *Dev Sci* 10: 464–480.
37. Raver CC, Jones SM, Li-Grining C, Zhai F, Bub K, et al. (2001) CSRP's impact on low-income preschoolers' pre-academic skills: Self-regulation as a mediating mechanism. *Child Dev* 82, 362–378.
38. Nelson CA, Sheridan MA (2011) Lessons from neuroscience research for understanding causal links between family and neighborhood characteristics and educational outcomes. In: Duncan G, Murman R, editors. *Whither opportunity*. New York: Russell Sage. 27–46.
39. Blair C, Raver CC (2012) Child development in the context of adversity: Experiential canalization of brain and behavior. *Am Psychol* 67: 309.
40. Diamond A, Barnett WS, Thomas J, Munro S (2007) Preschool program improves cognitive control. *Sci* 318: 1387–1388.
41. Barnett WS, Jung K, Yarosz DJ, Thomas J, Hornbeck A (2008) Educational effects of the Tools of the Mind curriculum: A randomized trial. *Early Child Res Q* 23: 299–313.
42. Wilson S, Farran D (2012) Paper presented at the Society for Research on Educational Effectiveness Spring 2012 Conference. March 8, 2012. (Washington, DC).
43. Bodrova E, Leong DJ (2007) *Tools of the Mind: The Vygotskian Approach to Early Childhood Education* (Merrill/Prentice Hall, New York, ed 2).
44. Bodrova E, Leong DJ (2001) *The Tools of the Mind: A case study of implementing the Vygotskian approach in American early childhood and primary classrooms* (International Bureau of Education, UNESCO, Geneva, Switzerland).
45. Bodrova E, Leong DJ (2006) The development of self-regulation in young children: Implications for Teacher Training. In: Zaslow M, Martinez-Beck I, editors. *Future directions in teacher training*. New York: Brooks-Cole. 203–224.
46. Aud S, Hussar W, Planty M, Snyder T, Bianco K, et al. (2010) *The Condition of Education 2010* (NCES 2010-028). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.
47. Woodcock RW, McGrew K, Mather N (2001) *Woodcock-Johnson Tests of Cognitive Abilities and Tests of Achievement* (Riverside, Rolling Meadows, IL, ed. 3).
48. Woodcock RW, McGrew K, Mather N, Schrank F (2003) *Diagnostic Supplement to the WJ III Tests of Cognitive Abilities* (Riverside, Rolling Meadows, IL).
49. Jaffé LE (2009) Development, interpretation, and application of the W score and the relative proficiency index (Riverside, Rolling Meadows, IL, Woodcock-Johnson III Assessment Service Bulletin No. 11).
50. Brownell R (2000) *Expressive One-Word Picture Vocabulary Test Manual* (Academic Therapy, Novato, CA, ed 3).
51. Raven JC (1956) *Colored Progressive Matrices* (Psychological Corporation, San Antonio, TX).
52. Davidson MC, Amso D, Anderson LC, Diamond A (2006) Development of cognitive control and executive functions from 4–13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia* 44: 2037–2078.
53. Zelazo PD, Bauer PJ (2013) National Institutes of Health Toolbox Cognition Battery (NIH Toolbox CB): Validation for Children between 3 and 15 Years. New York: Wiley.
54. Fan J, McCandliss BD, Sommer T, Raz A, Posner MI (2002). Testing the efficiency and independence of attentional networks. *J Cogn Neurosci* 14: 340–347.
55. Rudel RG, Denckla MB (1974) Relation of forward and backward digit repetition to neurological impairment in children with learning disabilities. *Neuropsychologia* 12: 109–118.
56. Wechsler D (1997) *Administration and Scoring Manual for the Wechsler Adult Intelligence Scale* (The Psychological Corporation, San Antonio, TX, ed 3).
57. Kujawa AJ, Torpey D, Kim J, Hajcak G, Rose S, et al. (2011) Attentional biases for emotional faces in young children of mothers with chronic or recurrent depression. *J Ab Child Psych* 39: 125–135.
58. Salimetrics. State College, PA. Available: www.salimetrics.com.
59. Denkla MB, Rudel RG (1976) Rapid “automatized” naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia* 14: 471–9.
60. Brownstone D, Valletta R (2001) The bootstrap and multiple imputations: Harnessing increased computing power for improved statistical tests. *J Econ Perspect* 15: 129–141.
61. Cameron AC, Gelbach JB, Miller DL (2008) Bootstrap-based improvements for inference with clustered errors. *Rev Econ Stat* 90: 414–427.
62. Davis EP, Bruce J, Gunnar MR (2002) The anterior attention network: Associations with temperament and neuroendocrine activity in 6-year-old children. *Dev Psychobiol* 40: 43–56.
63. Blair C, Granger D, Peters Razza R (2005) Cortisol reactivity is positively related to executive function in preschool children attending Head Start. *Child Dev* 76: 554–567.

64. Sapolsky R, Romero M, Munck A (2000) How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. *Endocr Rev* 21: 55–89.
65. de Kloet RE, Karst H, Joëls M (2008) Corticosteroid hormones in the central stress response: Quick-and-slow. *Front Neuroendocrin* 29: 268–272.
66. Watamura SE, Coe CL, Laudenslager ML, Robertson SS (2010) Child care setting affects salivary cortisol and antibody secretion in young children. *Psychoneuroendocrinology* 35: 1156–1166.
67. Watamura SE, Kryzer EM, Robertson SS (2009) Cortisol patterns at home and child care: Afternoon differences and evening recovery in children attending very high quality full-day center-based child care. *J Appl Dev Psychol* 30: 475–485.
68. Gunnar MR, Kryzer E, Van Ryzin MJ, Phillips DA (2010) The rise in cortisol in family day care: Associations with aspects of care quality, child behavior, and child sex. *Child Dev* 81: 851–869.
69. Lisonbee JA, Pendry P, Mize J, Gwynn EP (2010) Hypothalamic–pituitary–adrenal and sympathetic nervous system activity and children’s behavioral regulation. *Mind, Brain, and Education* 4: 171–181.
70. Magnuson KA, Meyers MK, Ruhm CJ, Waldfogel J (2004) Inequality in preschool education and school readiness. *Am Ed Res J* 41: 115–157.
71. Reynolds AJ, Temple JA (2008) Long-term effects of early childhood interventions: A critical analysis. *Annu Rev Clin Psych* 4: 109–139.
72. Moffitt TE, Arseneault L, Belsky D, Dickson N, Hancox RJ, et al. (2011) A gradient of childhood self-control predicts health, wealth, and public safety. *Proc Natl Acad Sci USA* 108: 1693–2698.
73. Nye B, Hedges LV, Konstantopoulos S (1999) The long-term effects of small classes: A five-year follow-up of the Tennessee class size experiment. *Ed Eval Pol Anal* 21: 127–142.
74. Chetty R, Friedman JN, Hilger N, Saez E, Schanzenbach DW, et al. (2011) How does your kindergarten classroom affect your earnings? Evidence from Project STAR. *QJ Econ* 126: 1593–1660.
75. Weiland C, Yoshikawa H (2013) Impacts of a prekindergarten program on children’s mathematics, language, literacy, executive function, and emotional skills. *Child Dev* 84: 2112–2130.