Cognitive Control (Executive Functions) in Young Children: Relevance of what we know to what can be done to help children

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The “Executive Functions” (EF) that depend on prefrontal cortex include 3 core abilities:

(a)Inhibitory Control

(b) Working Memory

(c) Cognitive Flexibility

(a) INHIBITORY CONTROL…

is the ability to resist a strong inclination to do one thing

and

instead do what is most appropriate or needed

Being able to…

1) resist first impulse (perhaps a socially inappropriate remark or grabbing another's toy) and give a more considered (polite) response instead

2) stay on task despite boredom or the temptation to go out and play

Being able to…

3) control your attention despite distraction (selective or sustained attention)

e.g., suppressing attention to what your neighbors are saying so that you can concentrate on what the teacher is saying

or screening out all but one voice at a cocktail party

Why is INHIBITION important?

The ability to inhibit a strong behavioral inclination helps make

discipline

and change possible,

as well as social politeness & focused atten.

Inhibition allows us a measure of control over our attention and our actions, rather than simply being controlled by external stimuli, our emotions, or engrained behavioral tendencies.

(b) WORKING MEMORY:

Holding information in mind while mentally working with or updating it

such as

- relating one idea to another
- relating what you read earlier to what you are reading now
- doing mental arithmetic (e.g., adding or subtracting)
- remembering the order in which things need to be done

Why is WORKING MEMORY important?

WM makes it possible to

- consider things from different perspectives,
- understand a story – relating the beginning, middle, & end
- translate instructions into action plans.

It is critical to our ability to see connections between seemingly unconnected things, and hence for creativity, for the essence of creativity is to be able to disassemble and re-combine elements in new ways.

(c) COGNITIVE FLEXIBILITY

being able to flexibly switch perspectives or the focus of attention,

flexibly adjusting to changed demands or priorities.

Note that shifting mental sets involves both:
activating the new set
& de-activating the old one

Why is COGNITIVE FLEXIBILITY important?

This is critical for creative problem-solving…

for considering something from a fresh or different perspective, and for ‘thinking outside the box.’

There is much overlap between EF, especially its inhibitory component, and self-regulation. But:

Historically, EF researchers have focused most on:

cognition,
in non-emotionally-charged situations,
using objective, behavioral measures.
Emotion seen as something to be controlled.

Historically, SR researchers have focused more on:

on social situations,
often with strong motivational components,
often relying on parent or teacher report.
Emotions need expression as well as controlled.

There's little overlap between EF and what most traditional IQ tests assess

most IQ tests assess "crystallized" intelligence

e.g., memory of previously learned facts

Patients in whom the frontal lobe has been removed usually score within the normal range on such IQ tests.

BUT, there is much overlap between EF and "fluid intelligence" (i.e., reasoning and problem-solving) which tests like Raven's Progressive Matrices assess.

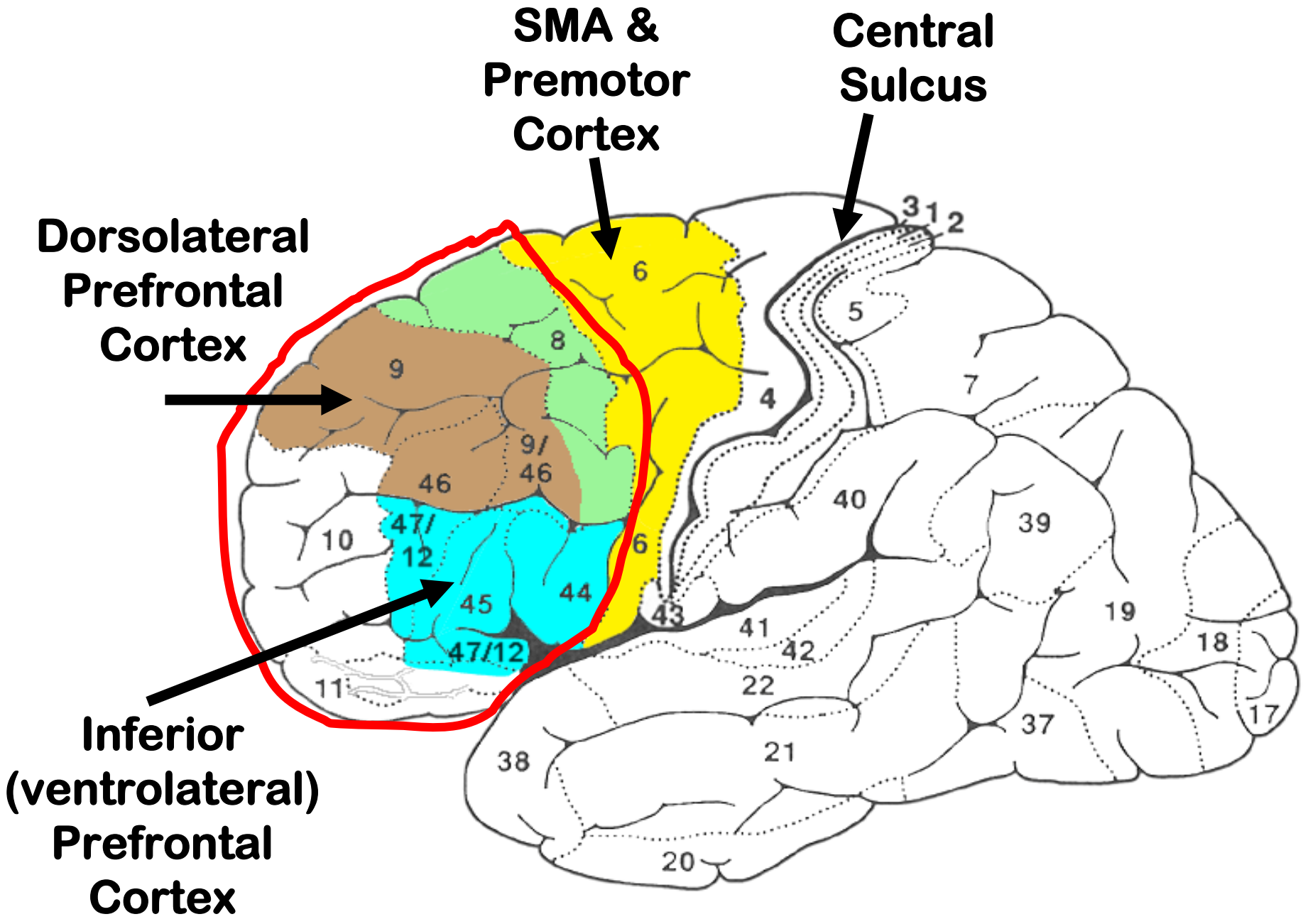
So, Executive Functions are required whenever going “on automatic” would not suffice or would be detrimental.

such as when…

learning new or challenging material,

in a noisy or distracting environment,

or there are strong temptations to be undisciplined.


SMA &
Premotor
Cortex
Central
Sulcus
Dorsolateral
Prefrontal
Cortex
Inferior
(ventrolateral)
Prefrontal
Cortex
3
1
2
6
5
8
9
7
4
9/
46
46
40
39
10
47/
12
6
45
44
43
41
42
19
18
47/12
11
22
17
37
38
21
20

EF skills are important for school readiness.

They are more strongly associated with school readiness than IQ or entry-level reading or math.

Prediction of Math in Kindergarten

	β	β
Vocabulary in Pre-K	**.22	.12
Raven in K	**.25	.13
Teacher Rating in Pre-K	**.27	*.18
EF in Pre-K	---	**.30
EF in K	---	**.21

From Blair & Razza (2007)
Child Development.

*$p < .05$, **$p < .01$

EF is important for school success.

Working memory and inhibitory control each independently predict both math & reading competence throughout the school years.

Discipline accounts for over twice as much variance in final grades as does IQ, even in college (Duckworth & Seligman, 2005).

	WORKING MEMORY	INHIBITION
VERY EARLY GRADES		
Language Skills	Adams & Gathercole, 1995; Blair & Razza, 2007	Blair & Razza, 2007; McClelland et al., 2007
Math Skills	Blair & Razza, 2007; Espy et al., 2004; Passolunghi et al., 2007	Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007
LATER GRADES		
Language Skills	De Beni et al., 1998; Gathercole et al., 2004, 2005; Savage et al., 2006	De Beni et al., 1998; Fiebach et al., 2007; Savage et al., 2006
Math Skills	Barrouillet et al., 2005; Bull & Scerif, 2001; Gathercole et al., 2004; Swanson & Kim, 2007	Bull & Scerif, 2001; Shallice et al., 2002; Passolunghi & Siegel, 2001

Many children begin school lacking needed executive function skills.

Kindergarten children at risk because of economic disadvantage are disproportionately behind in EF

relative to other cognitive skills

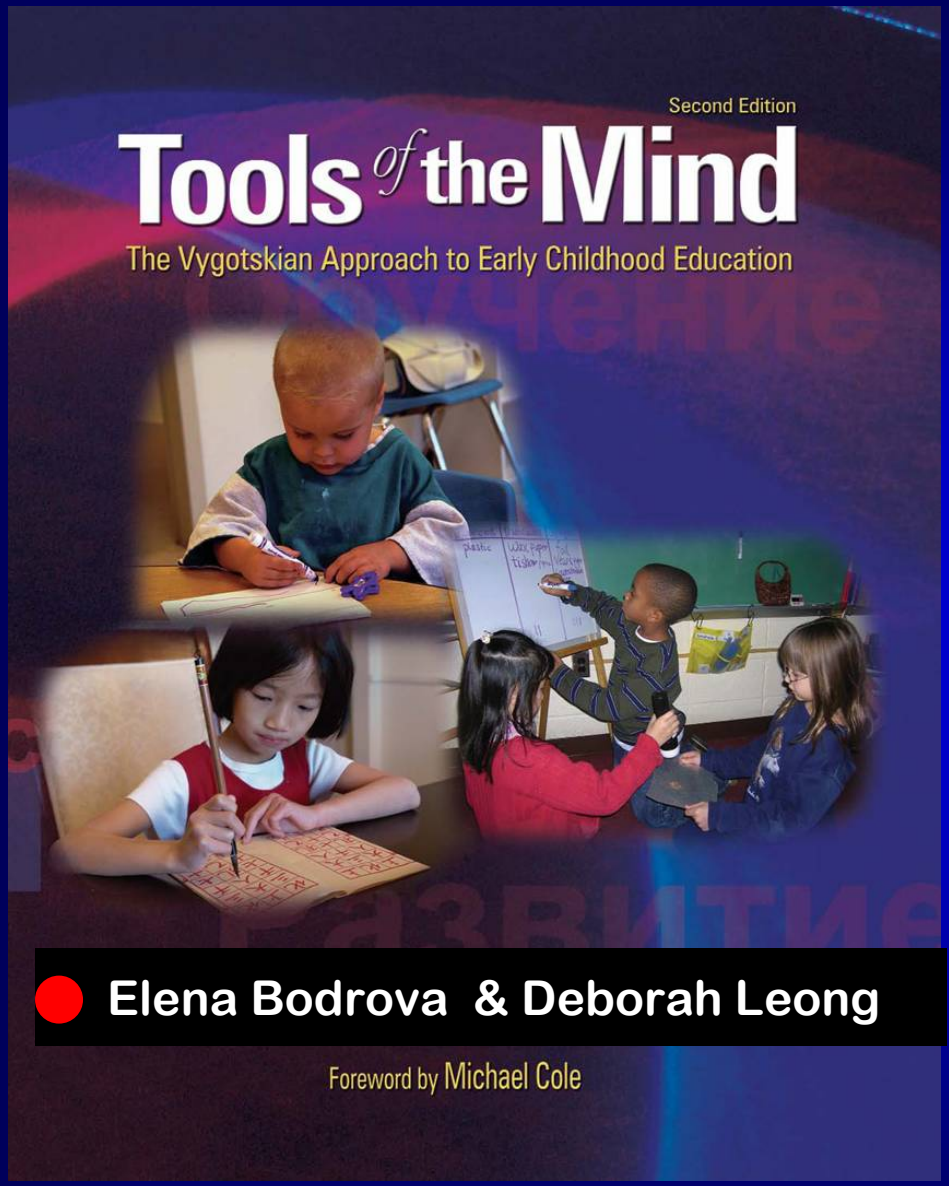
and

relative to children from middle-income homes.

(Farah et al., 2006; Noble et al., 2005, 2007; D'Angiulli et al., 2008; Neville & colleagues)

I predict that improving young children's EF skills will improve their longterm acquisition of academic skills, their school success and retention, and can reduce the disparity in achievement between rich and poor.

How can we help young children develop these critical executive function / self-regulation abilities?



The Tools of the Mind early childhood program, based on theories of Vygotsky and Luria

Tools of the Mind is grounded in the idea that social, emotional, and cognitive self-regulation is learned best by embedding training in this in all aspects of the school day.

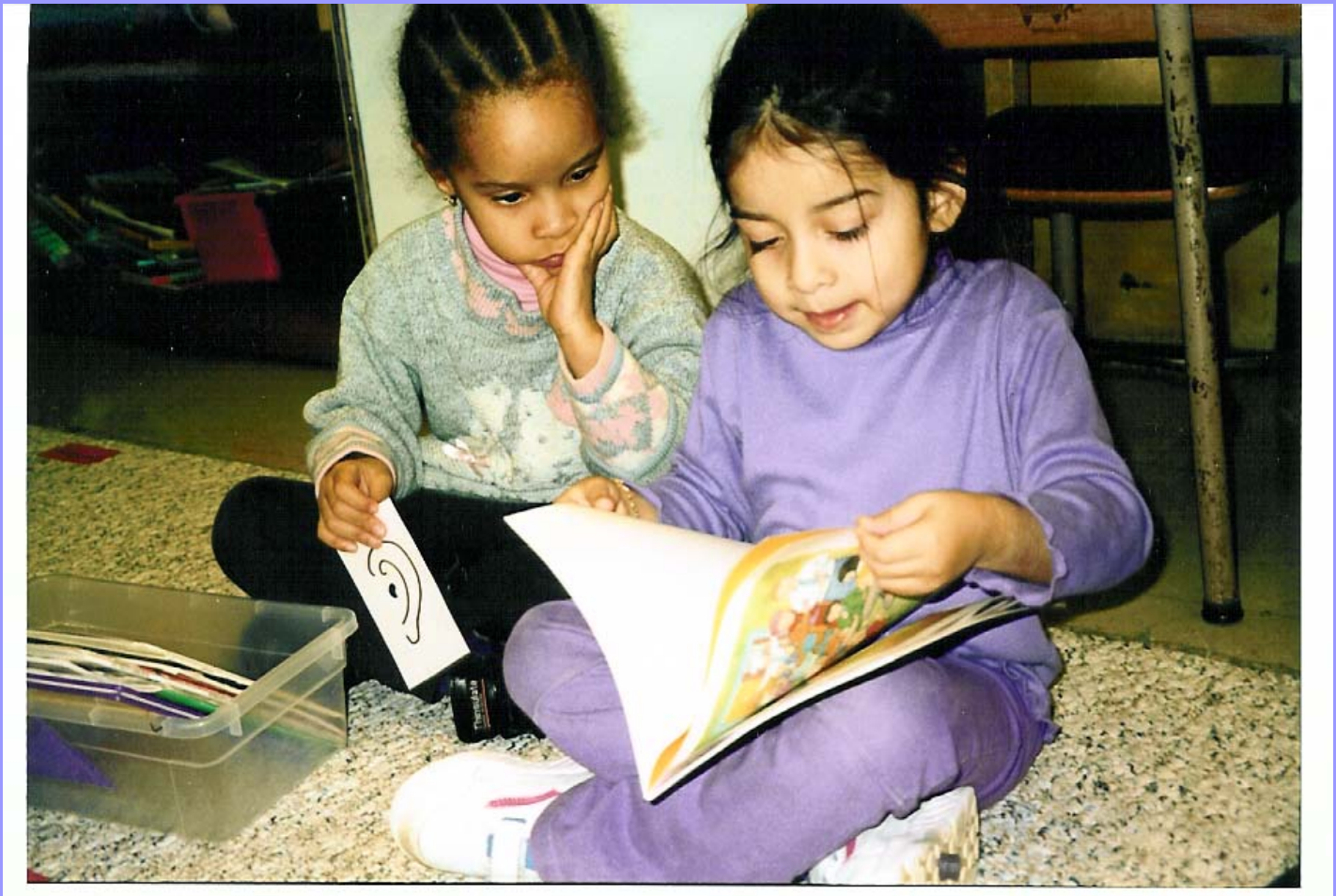
Deb and Elena tried EF activities as a module, added onto a curriculum. They found that children improved on what they practiced in the module, but the benefits did not transfer to other contexts or other EF skills.

Vygotsky: Engagement in mature make-believe play is the major mechanism for developing self-regulation in preschoolers. It is emphasized in Tools.

- During social pretend play, children must hold their own role and those of others in mind (working memory)
- inhibit acting out of character (employ inhibitory control), and
- flexibly adjust to twists and turns in the evolving plot (cognitive flexibility)

-- all three of the core executive functions thus get exercise.

Buddy Reading



Both conditions involved…

- new programs, instituted at the same time.
- the same books, classroom set-up, toys, & materials.
- the same amount of in-classroom coaching support, same # of professional development hours, and same teacher stipends for attending workshops.
- the same curricular content and covered the same topics.

Teachers & assistants were randomly assigned to condition by level of education (half of those w/ AA degrees & half w/ BAs were randomly assigned to each condition).

The conditions differed in some approaches to instruction but primarily in that the Tools condition included EF-promoting activities interwoven in all school activities throughout the day.

All children came from the same neighborhood and were randomly assigned to Tools or district-curriculum classrooms.

	1 or 2 Yrs of District Curr.	1 Yr of Tools	2 Yrs of Tools
Mean age in years	5.14	5.15	5.12
Percent Hispanic	93	91	91
Percent Male	55	41	51
% w/ family income <$25,000/year	76	71	86
Avg yrs of mother's ed	12	12	12
Ns per group	62	32	63

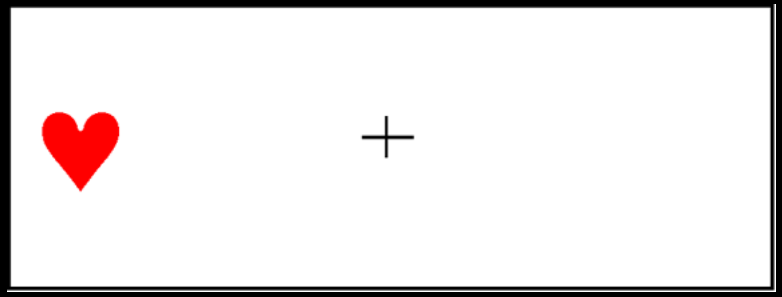
all were poor & at risk. all tested in their 2nd yr of presch.

For our two EF outcome measures we specifically chose activities completely different from anything any of the children had ever done before.

To see a difference by condition, the children would have to TRANSFER their training in EF to utterly new situations.

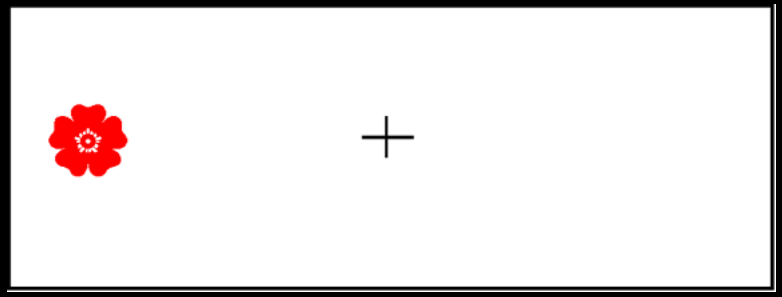
HEARTS & FLOWERS version of the DOTS task from the DIRECTIONAL STROOP BATTERY

Congruent

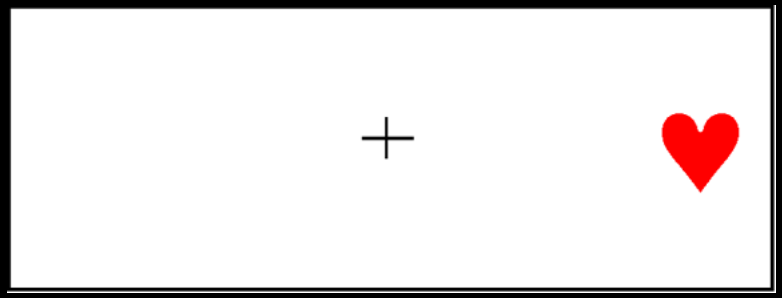


Push Left

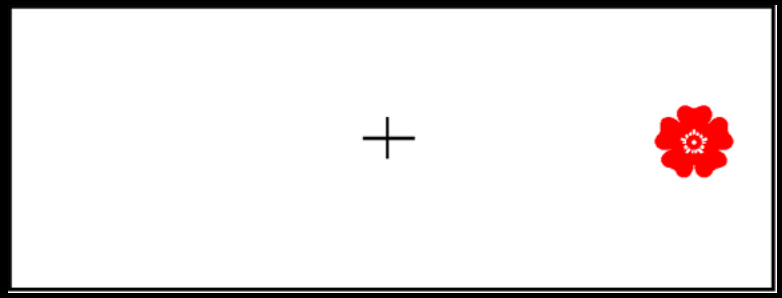
Incongruent



Push Right



Push Right



Push Left

HEARTS - CONGRUENT

Each time you see a HEART, press with the thumb or forefinger on the SAME side as the stimulus.

For example, if the heart appears on the left, press with your left hand.

Remember:

PRESS ON THE SAME SIDE AS THE HEART

FLOWERS - INCONGRUENT

Now you'll see a flower. Press on the side OPPOSITE the flower.

For example, if a flower appears on the left, press with your right hand.

(Here, you'll need to inhibit on every trial the natural tendency to respond on the same side as the stimulus)

Remember:

PRESS ON THE SIDE <u>OPPOSITE</u> THE FLOWER

HEARTS & FLOWERS-MIXED: Now you will sometimes see a heart and sometimes a flower.

On only half the trials will you have to inhibit the tendency to press on the same side as the stimulus, BUT you'll have to switch between the same-side and opposite-side rules.

The rules stay the same:

For HEARTS, press on the SAME side.

For FLOWERS, press on the OPPOSITE side.

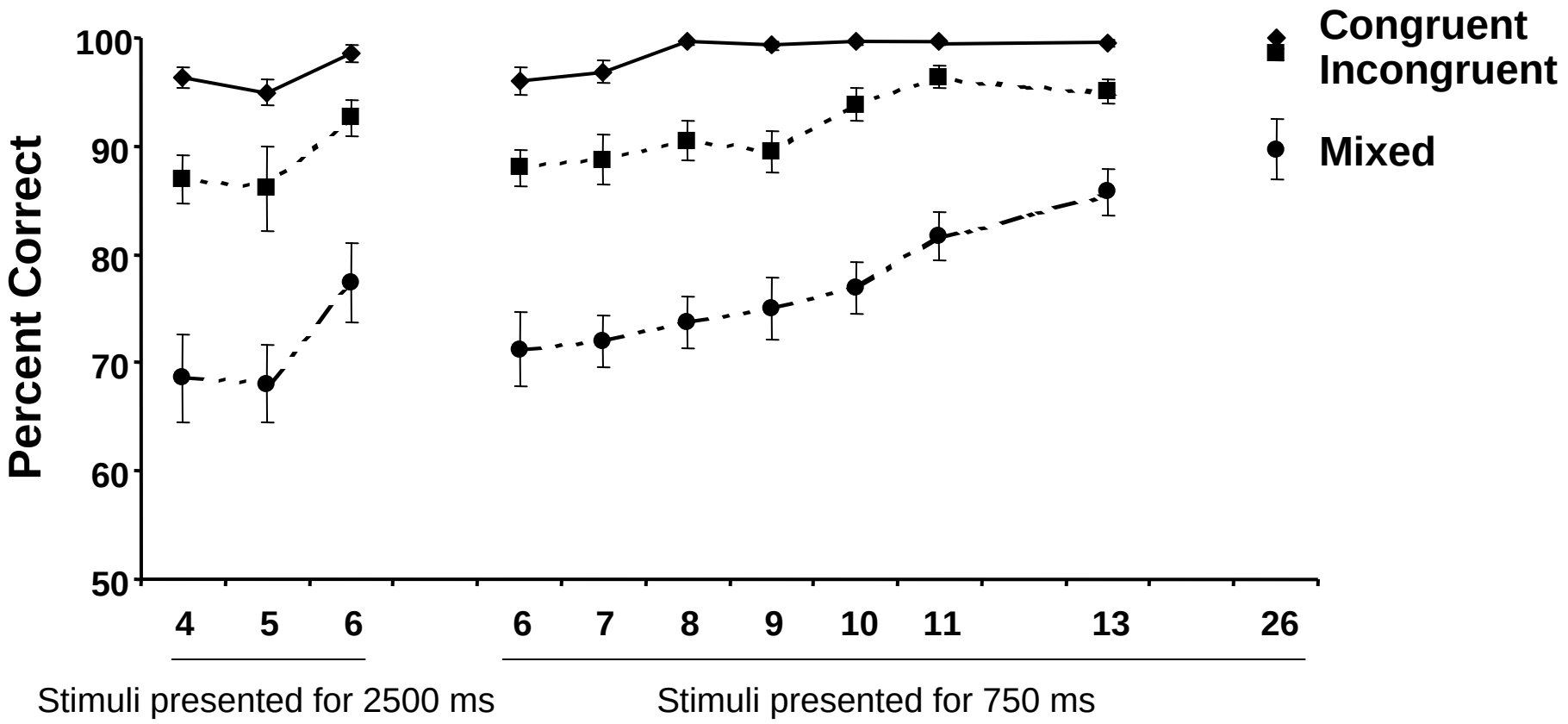
HEARTS – SAME SIDE

FLOWERS – OPPOSITE SIDE

In all conditions, mental manipulation of the same/opposite rules is needed to instantiate them as L or R keypresses.

Children who err typically remember which rule they should use (same or opposite) but impulsively respond before allowing themselves enough time to compute that means a R or L keypress.

Dots Conditions: Accuracy



Davidson et al., 2006

Adults have little difficulty exercising inhibition in steady-state in single-task blocks,

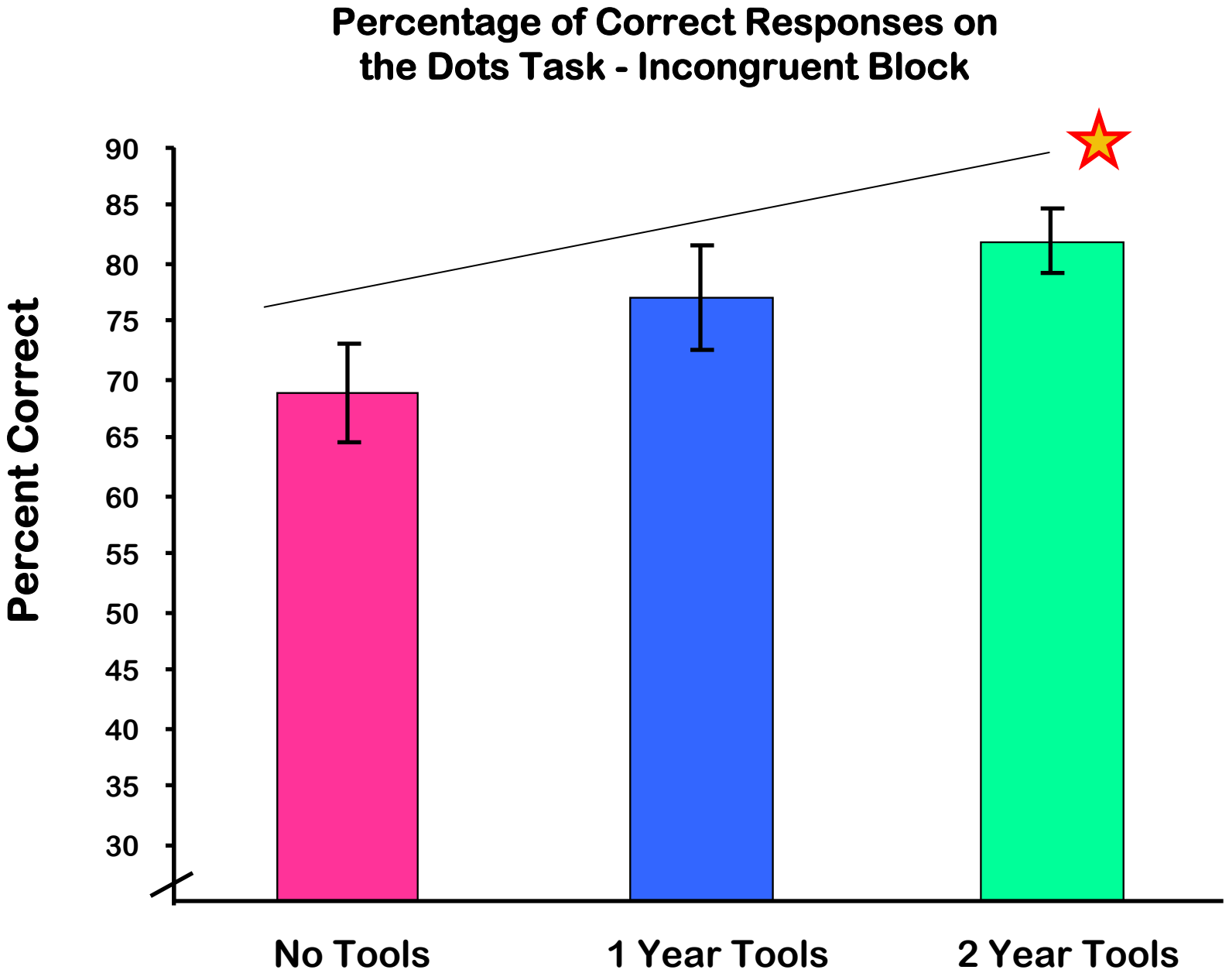
but children of all ages demonstrated a cost in doing so, albeit a much lesser cost than in the mixed condition.

Increasing demands on inhibition are more difficult for children than increasing demands on how much information they must hold in mind (2 to 6 items).

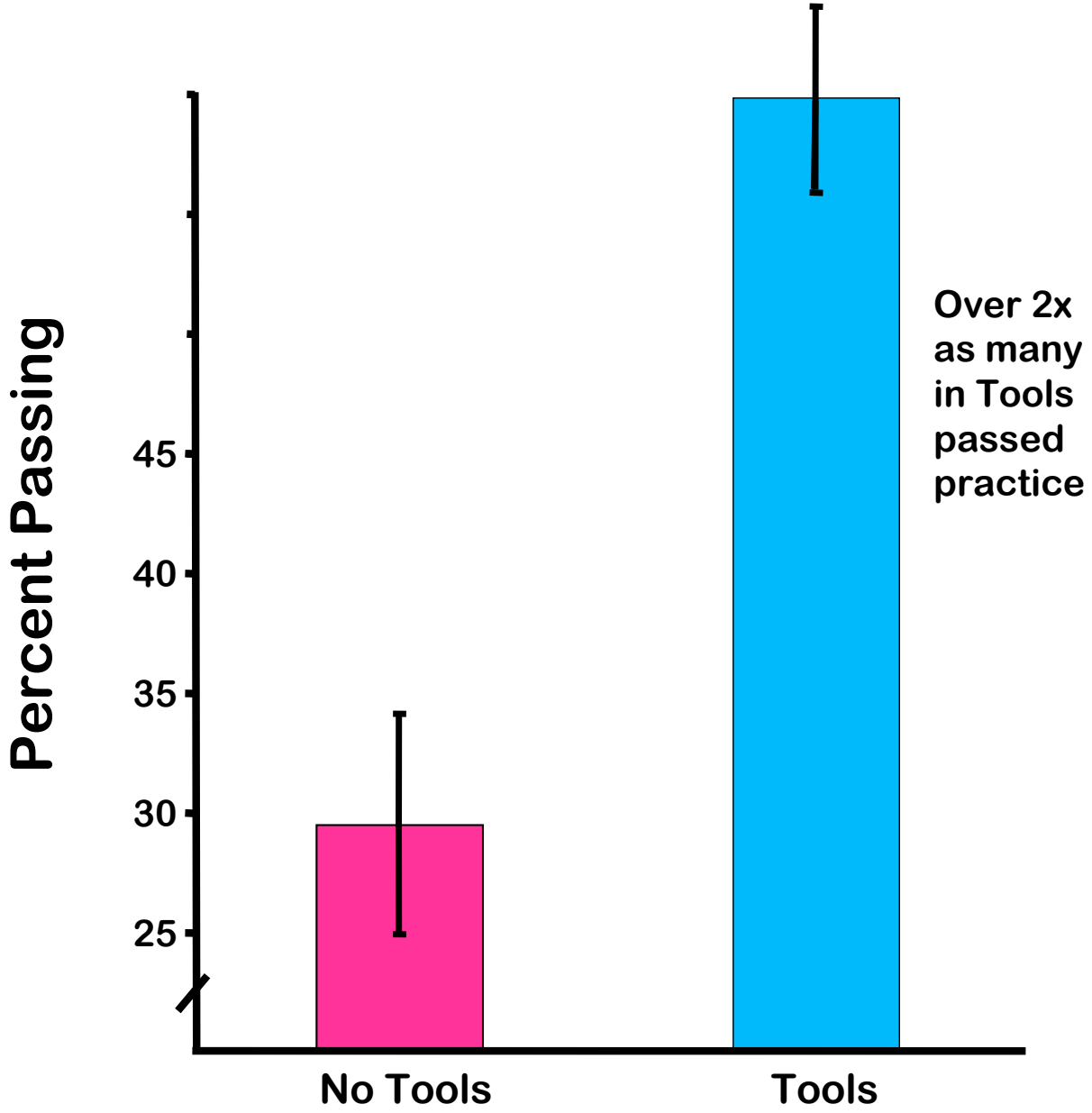
The opposite is true for young adults: increasing memory load is disproportionately more difficult for adults than increasing inhibitory demands.

Adults may not appreciate how inordinately difficult inhibition is for young children because it is less taxing for us.


MicroTouch


Percentage of Correct Responses on the Dots Task - Incongruent Block
Percent Correct
90
85
80
75
70
65
60
55
50
45
40
35
30
No Tools
1 Year Tools
2 Year Tools

Dots Task – Mixed Block
Percent of Children who Passed Criterion for Testing



Diamond et al., (2007). *Science, 318*, 1387-1388.

PRESCHOOL PROGRAM IMPROVES COGNITIVE CONTROL

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Steven Barnett
Jessica Thomas &
Sarah Munro

SCIENCE
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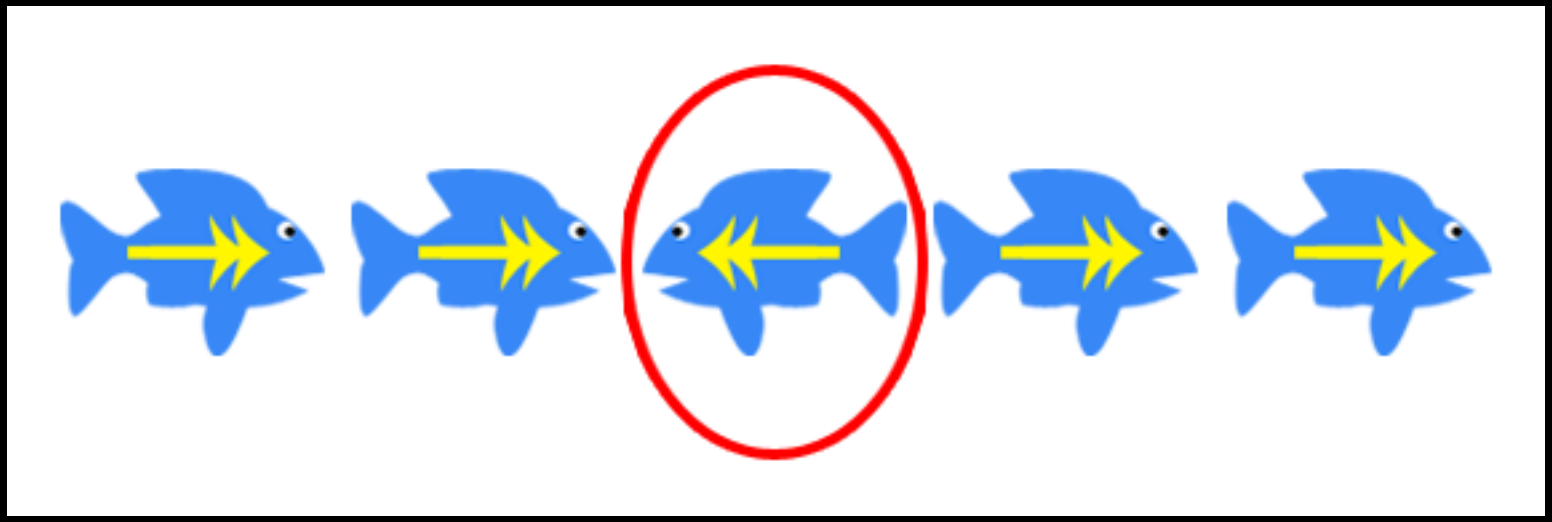
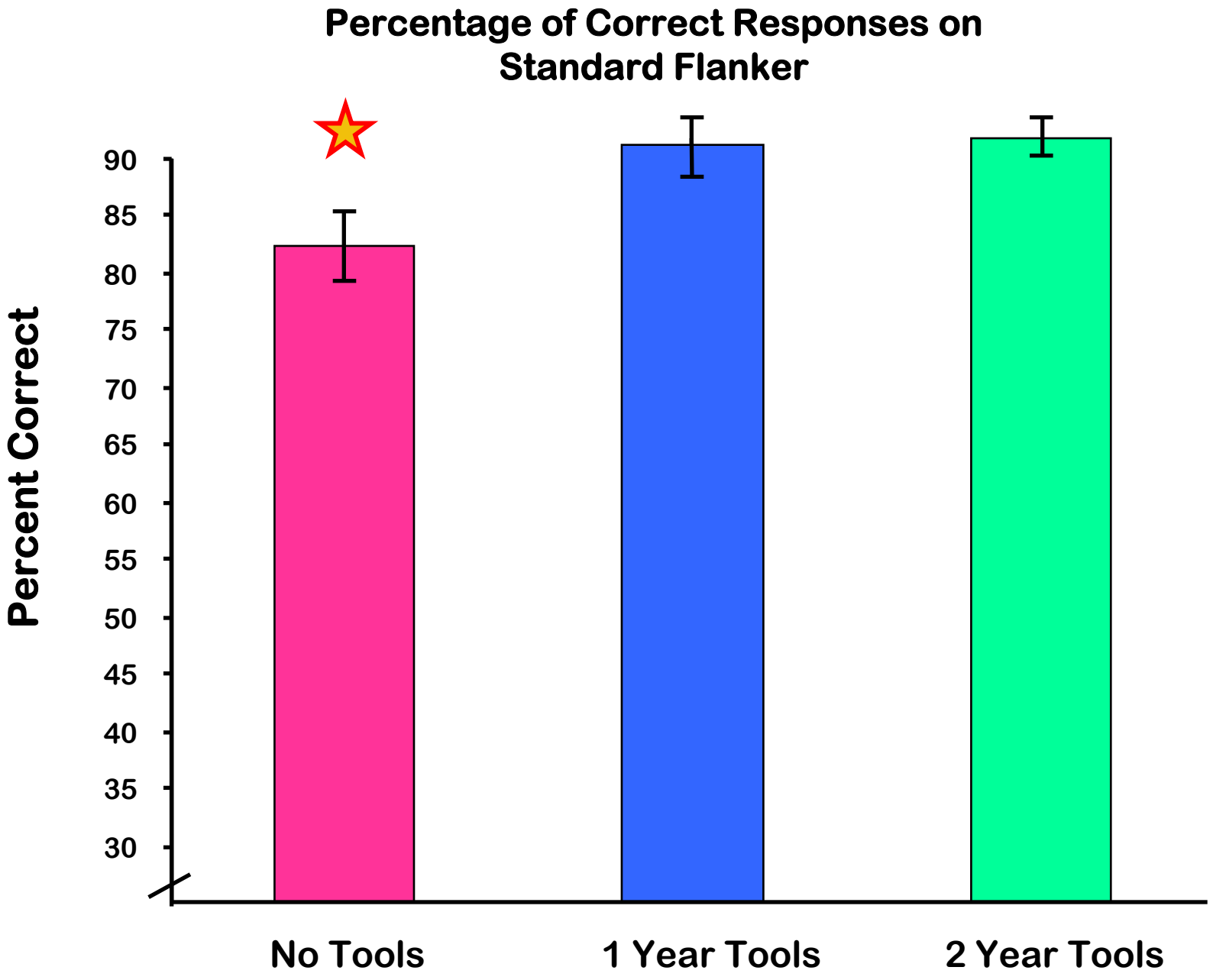
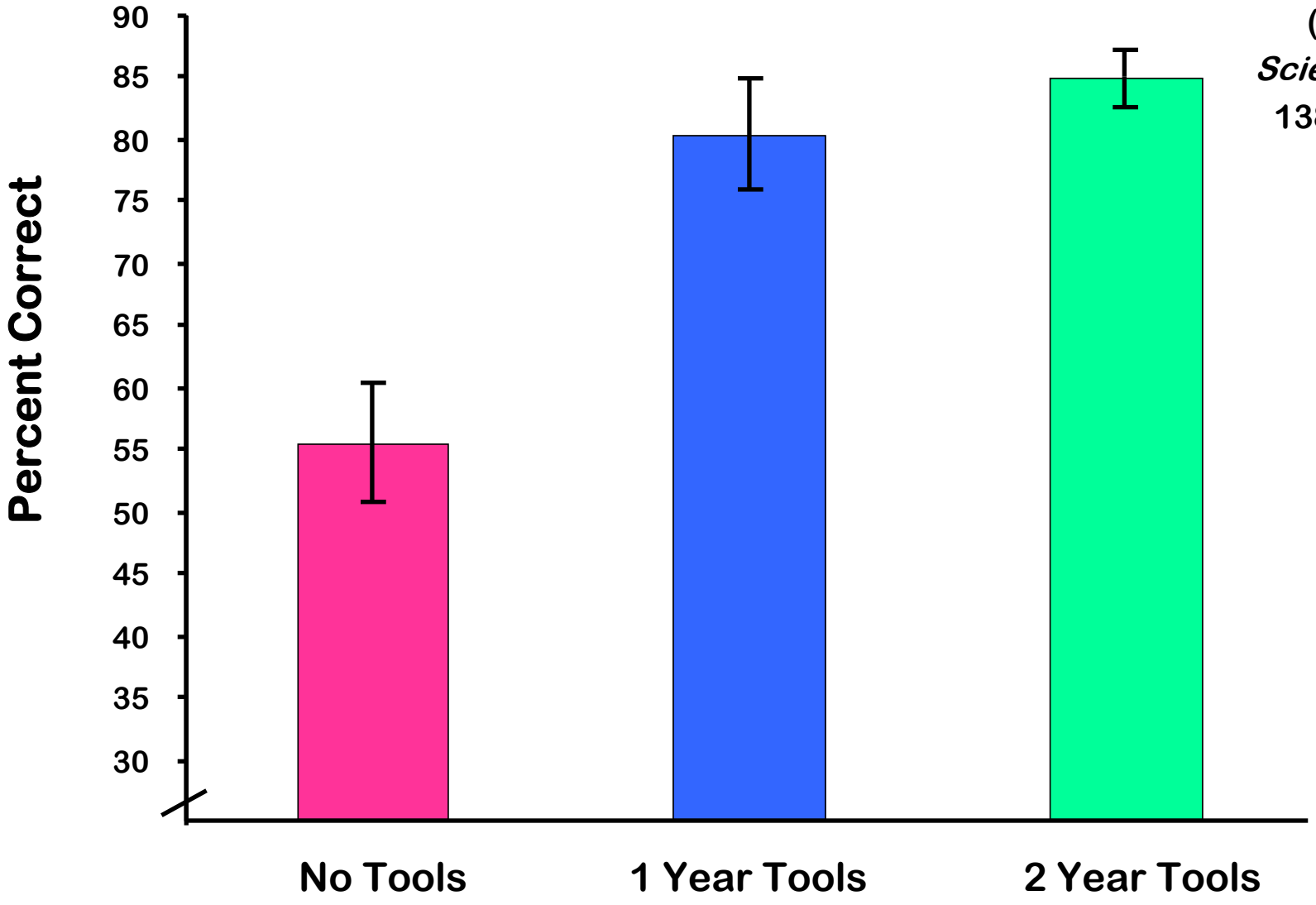
Flanker Task




Percentage of Correct Responses on Standard Flanker
Percent Correct
90
85
80
75
70
65
60
55
50
45
40
35
30
No Tools
1 Year Tools
2 Year Tools

Percentage of Correct Responses on Reverse Flanker



Diamond et al., (2007). *Science, 318*, 1387-1388.

Whether children were in Tools or not accounted for more variance in EF than did age or gender.

Our finding of better performance on these objective, behavioral measures is consistent with findings that on questionnaire measures, parents and teachers rate children in Tools as higher on EF (Bartnett et al., 2007).

Academic outcomes were obtained independently by National Institute for Early Education Research (Steve Barnett).

The more demanding of EF was a condition of our tasks, the more highly that condition correlated with academic performance.

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

Note that the greater the degree of cognitive control (EF) required by the condition of the Dots task, the greater the size and number of significant relations with academic performance.

	Congruent: No EF required	Incongruent: An Intermediate Level of EF Needed	MIxed: Most EF required
SRSS (Social Skills Rating Scale) Externalizing subscale	0.178	0.456**	0.177
SSRS Internalizing subscale	0.161	0.149	0.023
PPVT (Peabody Picture Vocabulary) raw score	0.036	.290*	.464**
IDEA Oral Language proficiency raw score	0.165	0.183	.390*
Expressive (EOWPVT) raw score	-0.037	.272*	.383**
WIPPSI raw score	0.012	0.125	0.03
WCJ (Woodcock Johnson) letter word raw score	0.091	0.166	0.068
WCJ applied problems raw score	-0.027	.264*	.392**
Get Ready To Read raw score	0.05	.315*	.423**
PPVT standard score	0.034	.275*	.444**
Expressive (EOWPVT) standard score	-0.117	0.207	.289*
Expressive standard score new (accts for floor effect)	-0.086	0.242	.329**
WCJ (Woodcock Johnson) letter word standard score	0.08	0.167	0.12
WCJ applied problems standard score	-0.071	0.218	.359**

Superior academic performance in children who have been through Tools has been replicated

in other Tools of the Mind programs with other children and other teachers, in other schools and states, and with different comparison conditions.

Take-home Message #1:

EF skills can be improved even in preschoolers.

This can be done in regular classrooms, with regular teachers, without special equipment.

EF skills are not immutable; they can be improved.

Many educators have wrongly assumed that while they can help children improve their academic skills, EF abilities are innate and immutable.

Even those who believed that EF can be improved, have doubted whether that could be done as early as preschool since EF depends on PFC, and PFC isn't fully mature until young adulthood.

However, just because PFC isn't fully functional, doesn't mean that it isn't functional at all.

Analogy with leg length at 2 years and walking and even running at age 2.

Environmental Influence on Executive Function Development

Exercise / use / practice can improve the functioning of a neural system (cognition) just as it does muscle function (motor skills).

Take-home Message #2:

FUN

Part of why social dramatic play is important is that it exercises ALL of the 3 key executive functions

But another reason why PLAY is important is that it is FUN.

Though often thought frivolous, play may be essential.

The children in Tools, who had more time to play, performed BETTER on academic outcome measures than the children who had more time in direct academic instruction.

BUT not all Play is Equal.

Take-home Message #3:

Importance of Action (Doing) for Learning

a Chinese proverb:

I hear, and I forget.

I see, and I remember.

I do, and I understand.

If information is not relevant for action, we don't pay attention in the same way (hence the difference in route memory for the driver, versus the passenger, of a car).

Take-home Message #4:

Feedback Loops

Consider:

Poor EF leads to problems paying attention in class, completing assignments, and inhibiting impulsive behaviors.

School is less fun because…
the teacher is always getting annoyed with you & compliance w/ school demands is very hard

Teachers come to expect poor self-regulation and poor work, and the children come see themselves as poor students.

Hence, children who begin school with poorer EF, would be expected to become increasingly resistant to school and schoolwork, put less effort and self-investment in school, and it is no surprise that they drop out at much higher rates.

On the other hand, children who have better EF are likely to be praised for good behavior, enjoy school more and want to spend more time at their lessons. Their teachers enjoy them and a self-reinforcing positive feedback loop is created.

I hypothesize therefore that the benefit from early EF training may INCREASE over time, and

that helping at-risk children improve their EF skills early might be critical to closing the achievement gap and reducing societal inequalities.

The recent explosion in the diagnoses of ADHD might be due, in part, to some children never learning how to exercise self-regulation.

I predict that children who go through a preschool program that directly teaches and supports EF will be less likely to be diagnosed with disorders of EF (such as ADHD or conduct disorder) because the program will have taught them how to exercise self-control and emotion regulation.

Many issues are not simply Education issues or Health issues. They are both.

I would like to see a coalition between those in Education and those in Health.

For example, I've predicted (and am setting up to test) that preschool interventions that improve EFs will not only lead to better school outcomes but to better mental health outcomes (fewer ADHD diagnoses).