Executive Function and the Developing Brain: Implications for Education

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Executive Function

- One of a number of overlapping constructs:

Self regulation

Effortful control

Self control

Executive attention

Cognitive control

Fluid reasoning

Executive Function

- The brain processes involved in the top-down, goal-directed modulation of attention, thought, emotion, motivation, and action

- Processes related to, but different from, “intelligence”
  - Using knowledge in service of goals

- Often discussed in terms of 3 facets:
  - *Cognitive flexibility*
  - *Working memory*
    - Holding info in mind and working with it
  - *Inhibitory control*

Miyake et al. (2000)

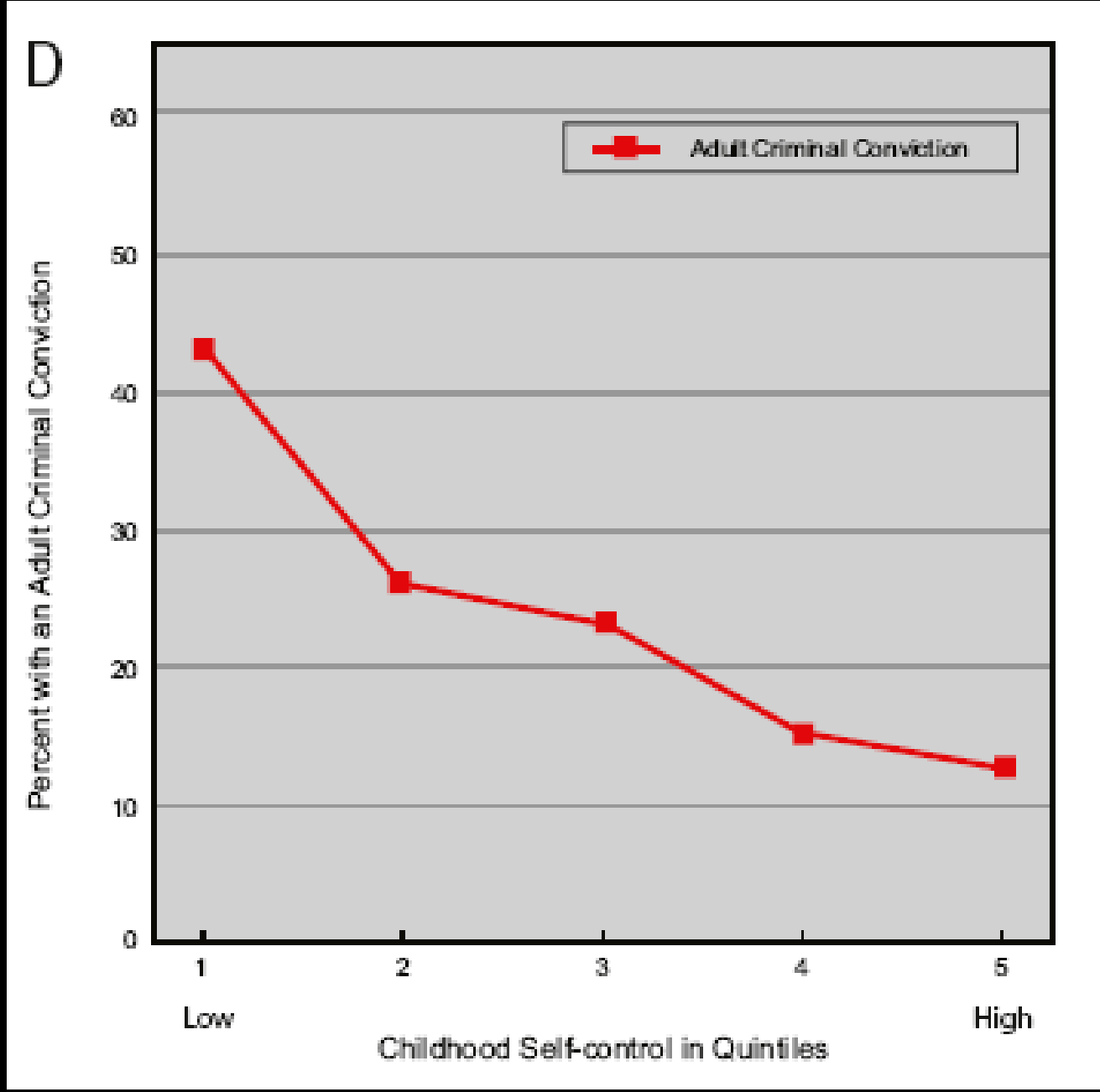
Interest in Development of EF

- Problems with EF are associated with psychiatric disorders w/ child onset
  - Conduct Disorder, autism, ADHD
- Specific problem beh's such as aggression

Interest in Development of EF

- EF in childhood predicts key dev'l outcomes:
- Self and social understanding
  - *e.g., Carlson et al., 2004*
- School readiness (early math and reading ability)
  - *e.g., Blair & Razza, 2007; Bull & Scerif, 2001*
  - Better than IQ
  - Teachers say more important to sit still, pay attention, follow rules
    - *Rimm-Kaufmann, Pianta, Cox, 2000*
- Predicts SAT scores (*Shoda et al., 1990*)
- Even predicts from preschool to middle age
  - *e.g., Casey et al., 2011*

- EF in childhood predicts outcomes at age 32 y:
  - Physical health
  - Drug dependence
  - SES
  - Criminal convictions
  - *Controlling for SES, IQ when a child*



Moffitt et al. (2011)

EF is Modifiable thru Experience

- While stable individual differences (in part because contexts remain stable), EF is clearly malleable

- Develops (into adulthood) as the underlying brain processes adapt to the environment

Executive Function in Everyday Life

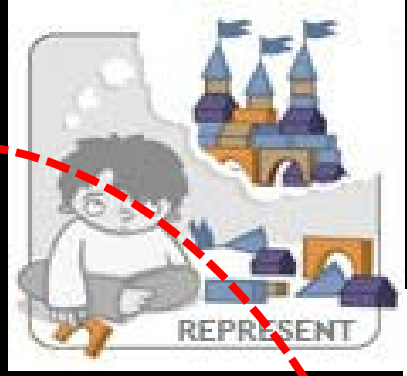
- Although much of what we do is habitual, the need for EF is pervasive
  - We need EF to control attention/ behavior in social contexts, avoid distractions, resist impulses
  - To change our behavior (break habits)
    - Dieting, exercise, etc.
  - Essential for problem solving

Represent

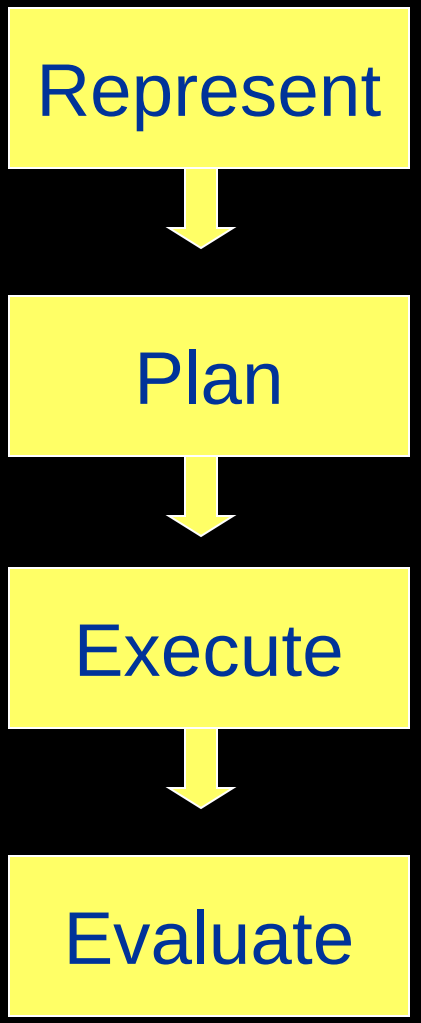
Plan

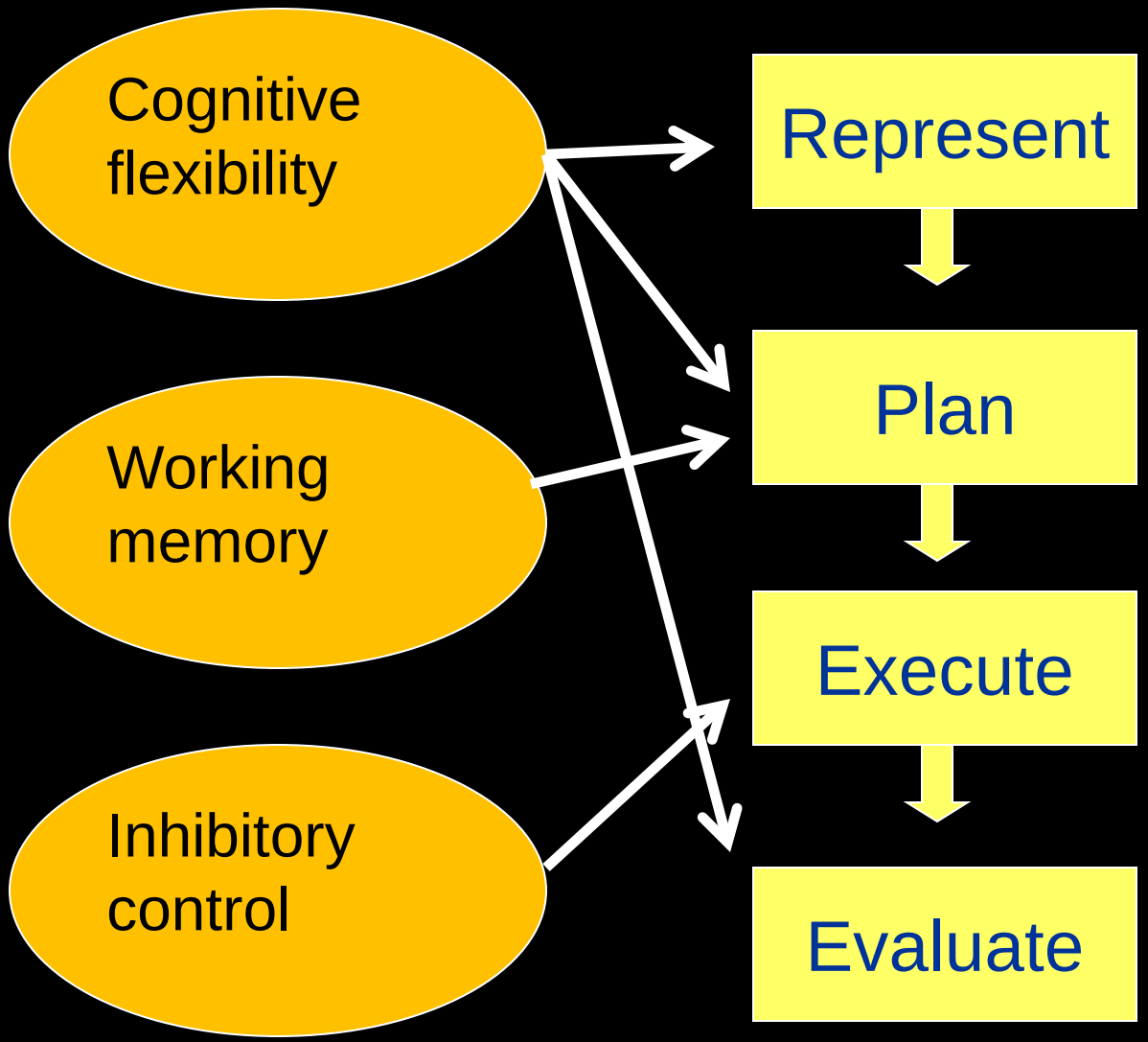
Execute
intend/use

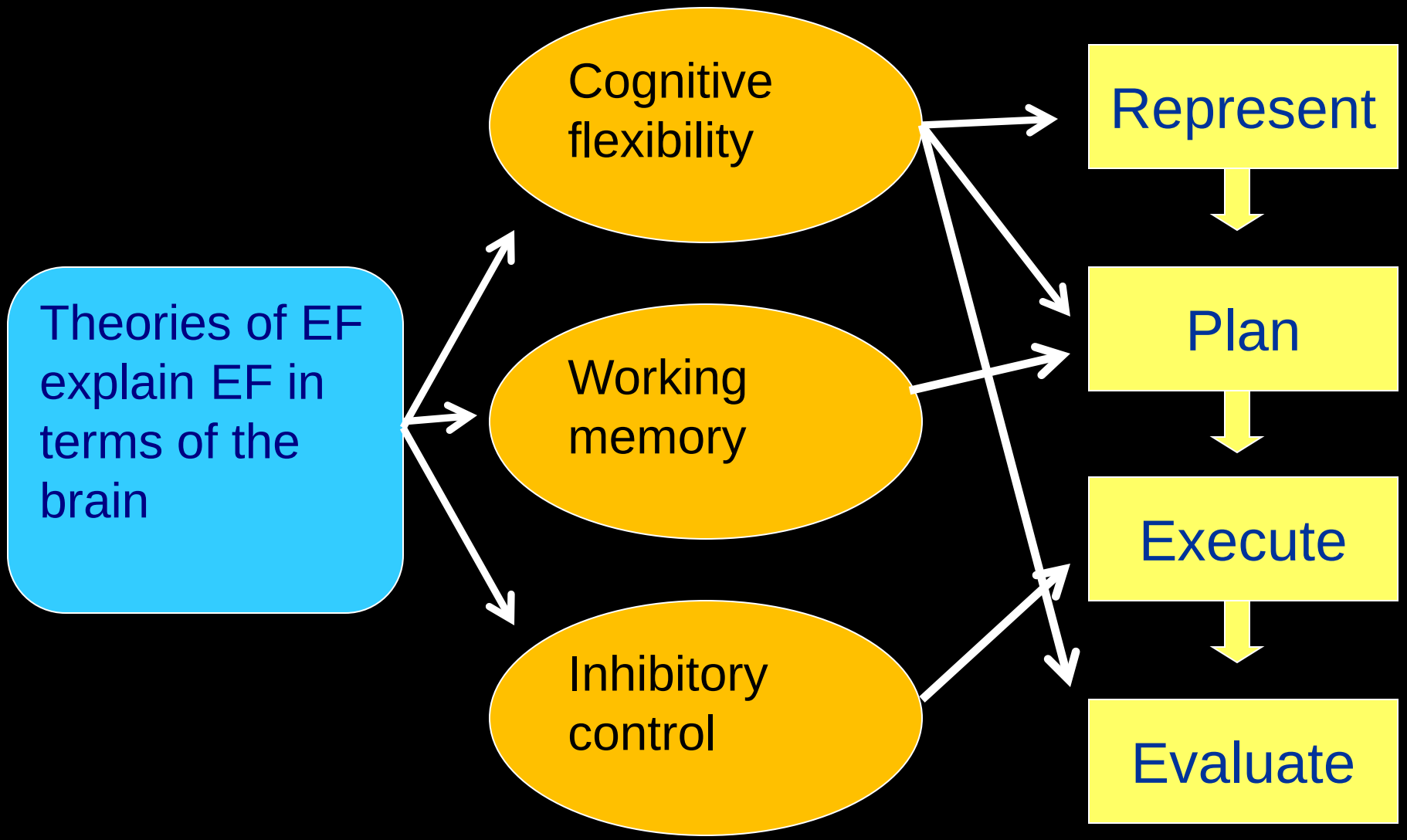
Evaluate
detect/correct



- EF failures can occur in any phase— resulting in inflexibility, rigidity
- EF refers to the processes that make problem solving possible



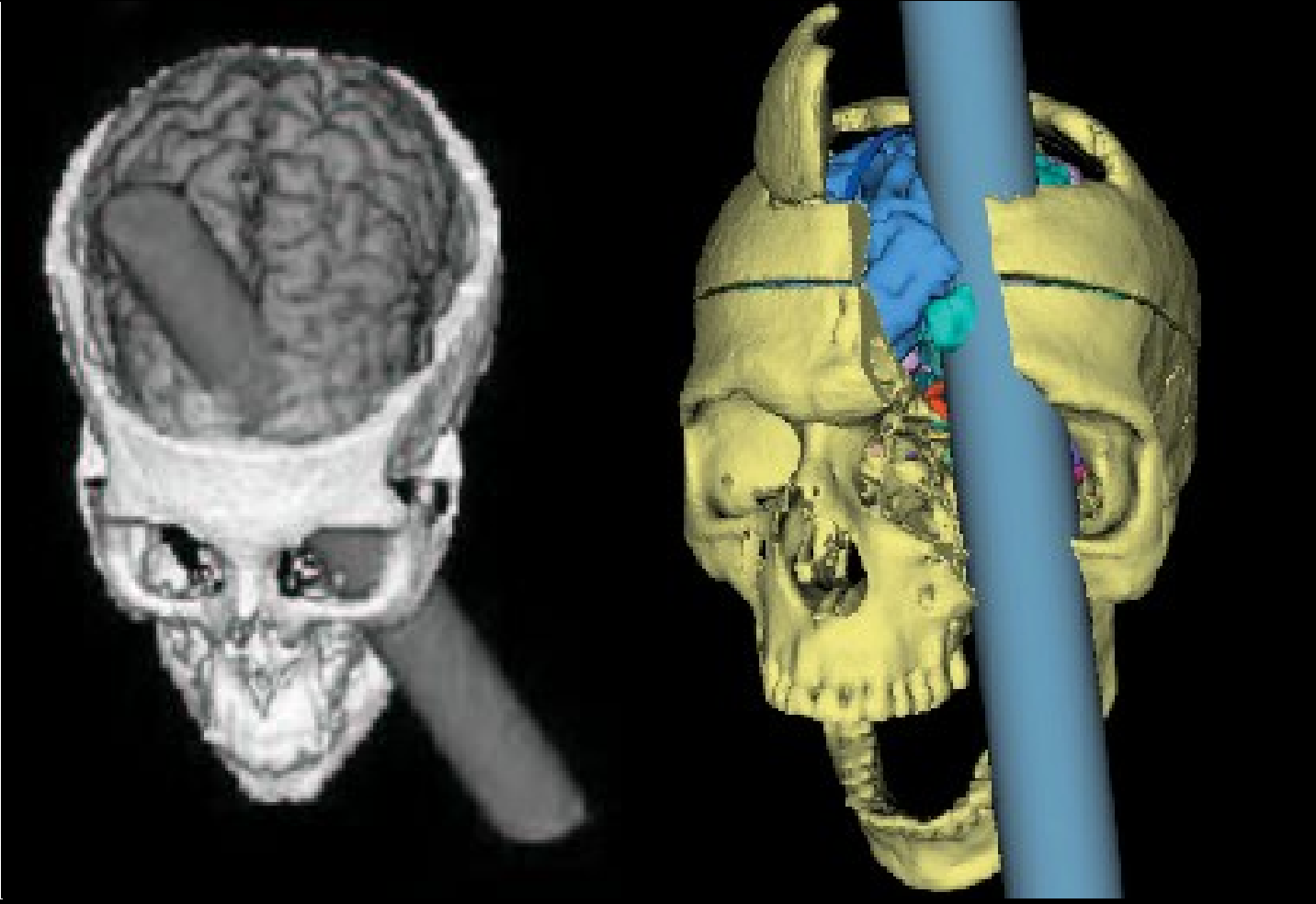

Cognitive flexibility
Working memory
Inhibitory control
Represent
Plan
Execute
Evaluate


Theories of EF explain EF in terms of the brain
Cognitive flexibility
Working memory
Inhibitory control
Represent
Plan
Execute
Evaluate

EF and the Brain

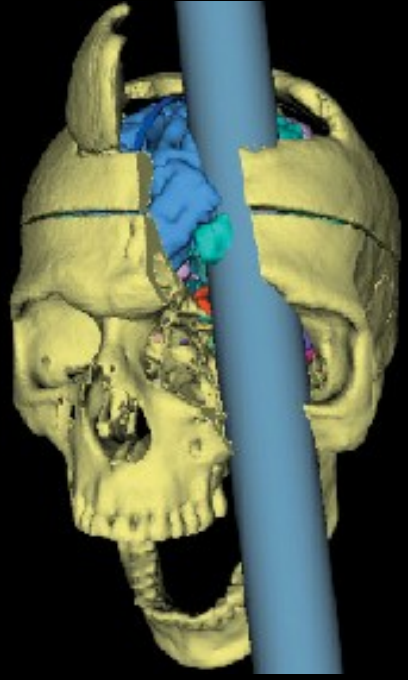
- Long known that EF depends importantly on *prefrontal cortex*
  - Front 1/3 brain

- Consequences of damage have informed our characterization of EF since the 19th century



Phineas P. Gage, foreman working on the construction of railroad track in VT. Accident on 13 Sept., 1848, during which a 3 ft tamping iron was blown through his skull

Survived, but despite recovery of general cognitive functions…



Impairments in executive function

He was “*…fitful, irreverent… devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible….” (Harlow, 1868)*

“Dysexecutive” Syndrome

- Distractible hyperactivity
- Cognitive inflexibility
- Lack of self awareness
- Impulsivity
- “Environmental dependency”

- Lhermitte noted that PFC patients exhibit stimulus-driven behavior (use objects reflexively)
  - E.g., He had one patient who had been a nurse … he casually arranged props in his office such as a sphygmomanometer and tongue depressor. . .

From: Lhermitte (1986)

Development of Self Control During Childhood

- As any parent knows, childhood involves a transformation
  - From a relatively stimulus-bound, present-oriented infant
    - Distraction
  - To a willful toddler
    - Temper tantrum in check-out aisle
  - To a preschooler able to think about other people's perspectives and plan for the future
    - Plan their birthday party

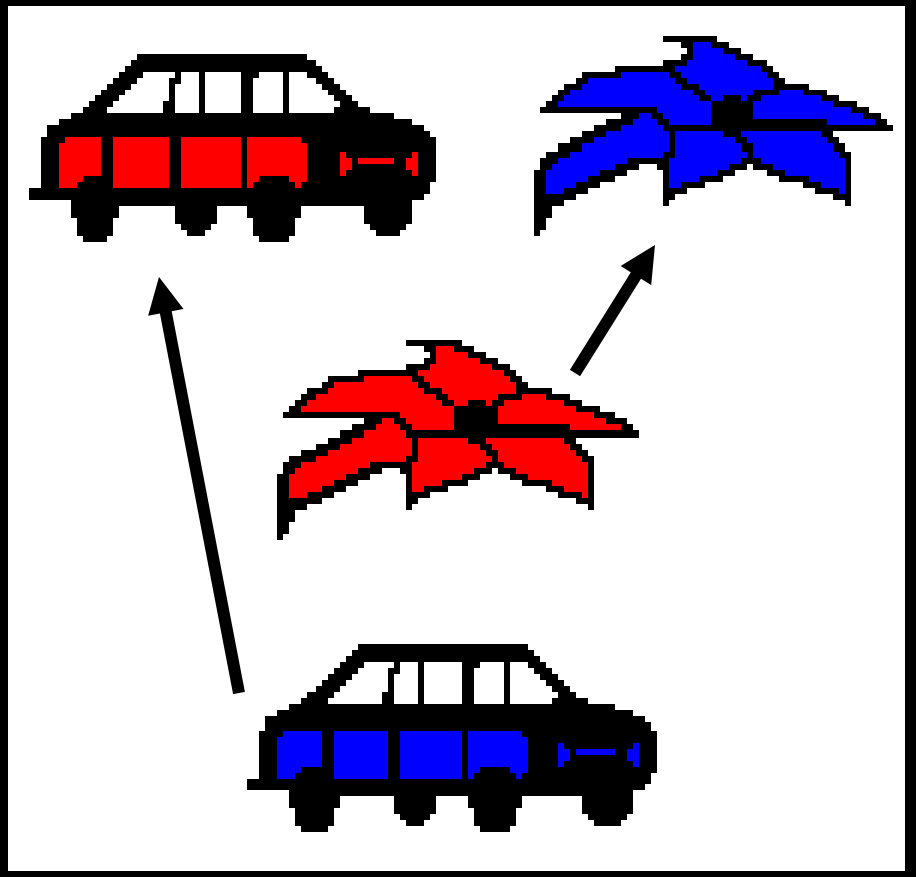
But… the development of planning, inhibitory control, and adaptive decision-making is a slow process, extending into adolescence

Example of EF Measure

Dimensional Change Card Sort (DCCS)

Target Cards

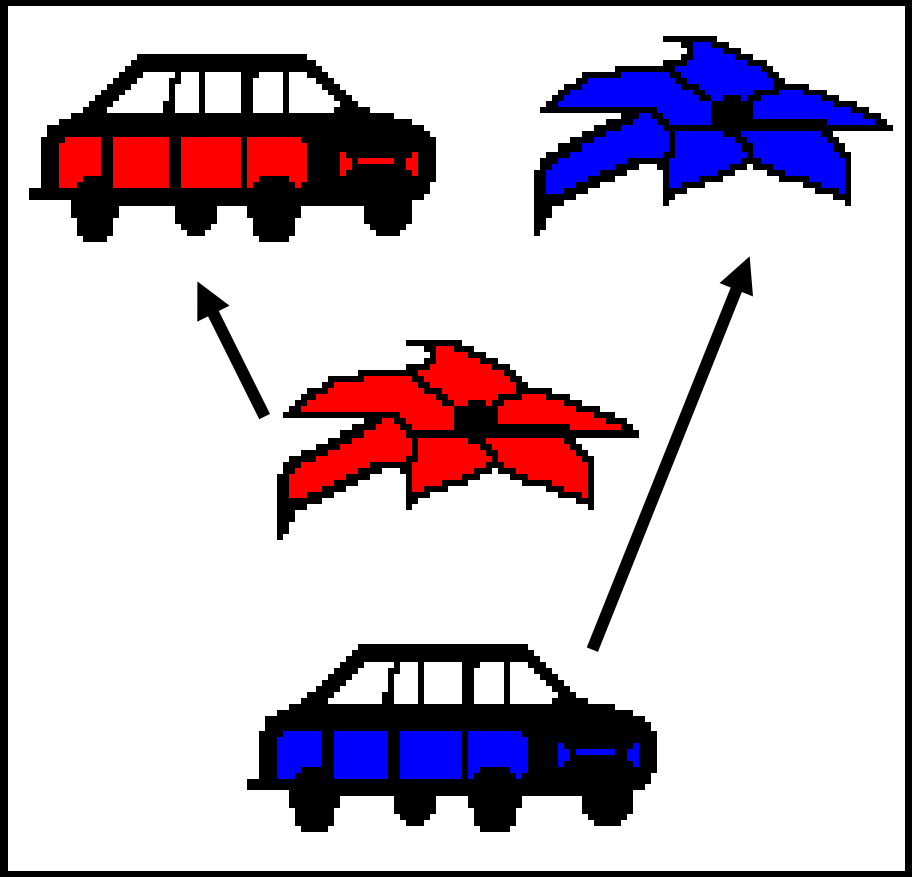
Test Cards



Told to sort by shape

Target Cards

Test Cards



Told to switch and sort by color
Told rules on every trial

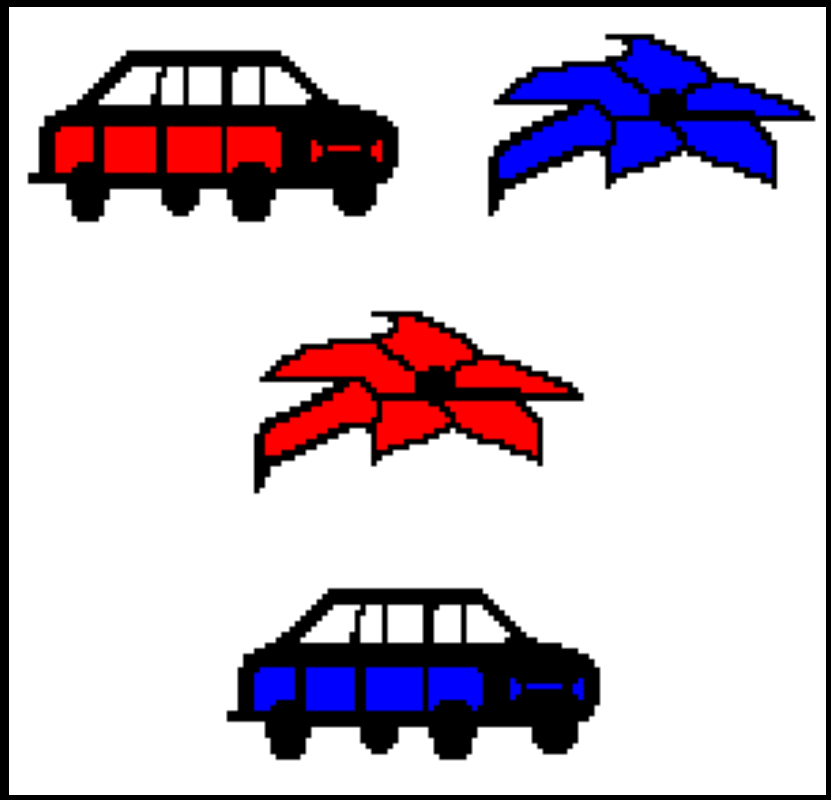
Basic Results

- Regardless of dimension order, 3-year-olds:
  - Continue to sort by the first dimension (e.g., shape)

- Despite:
  - Demonstrating knowledge of the new rules
  - When asked, “Where do the red ones go?” they’re correct
  - “Where does this red one go?” they *perseverate*, and sort by shape….

- By 4 years, most children switch flexibly

- Like adults, seem to know immediately that they know 2 ways of approaching the task (i.e., they step back and reflect on their rules)



Reflection changes one's perspective, providing "psychological distance" from a situation

Just as physical distance provides a panorama, psychological distance

- shows us the range of possible responses
- allows us to select among them

Reflection is effortful, develops into adulthood

NIH Toolbox

Assessment of Neurological and Behavioral Function

Opportunity to look at EF across the lifespan as part of the NIH Toolbox project

NIH Blueprint for Neuroscience Research

Tools, Resources and Training

For more information, please visit www.nihtoolbox.org
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Toolbox Objective

Develop standardized measures of *cognitive, emotional, sensory, & motor* health and function that are:

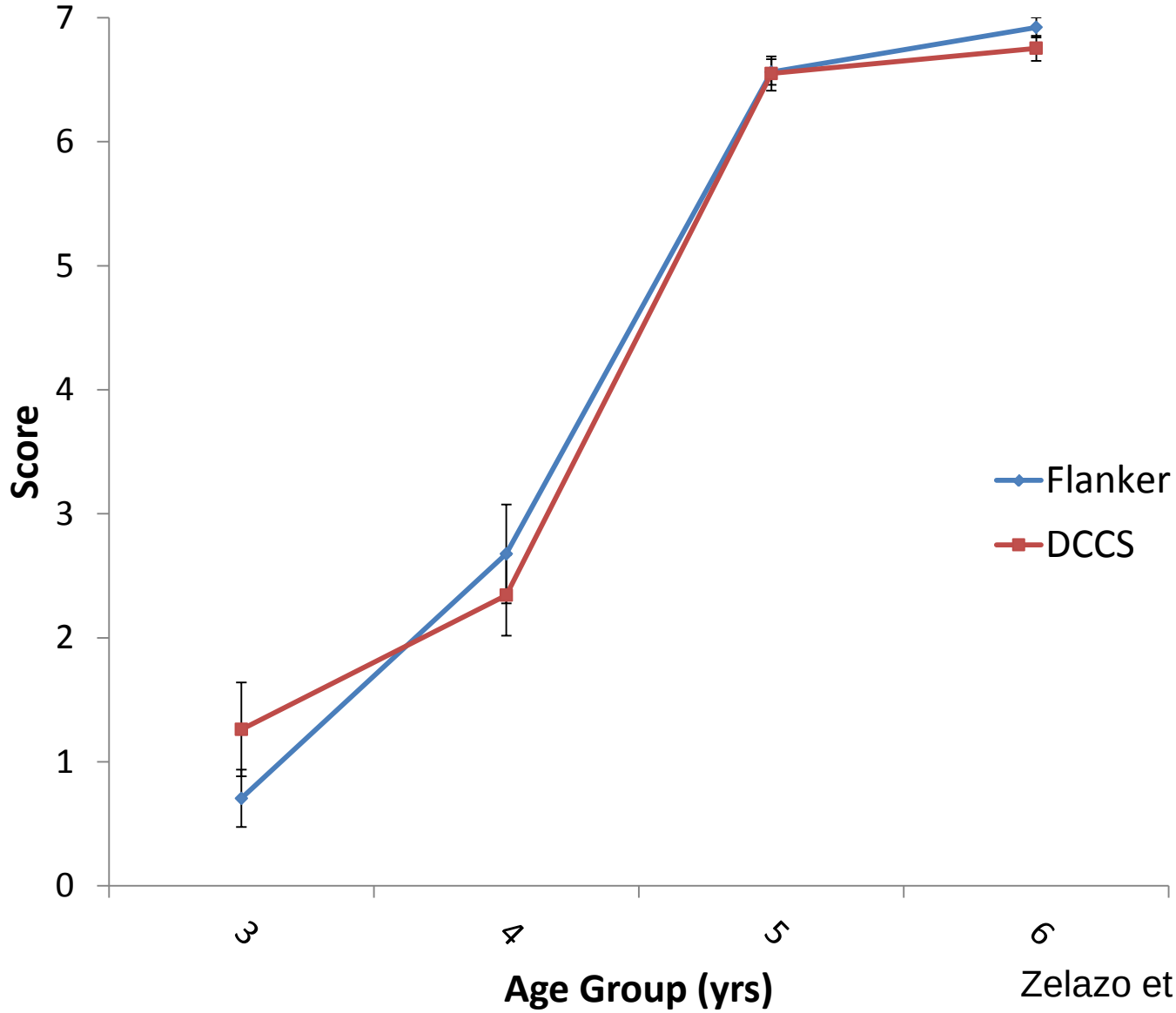
- **Brief yet comprehensive**
- **Reliable, and validated**
- **Freely available and inexpensive to use**
- **English & Spanish**
- **Appropriate for longitudinal or intervention research**

Suitable for participants ages 3-85 years

Flanker Test of Inhibitory Control and Attention

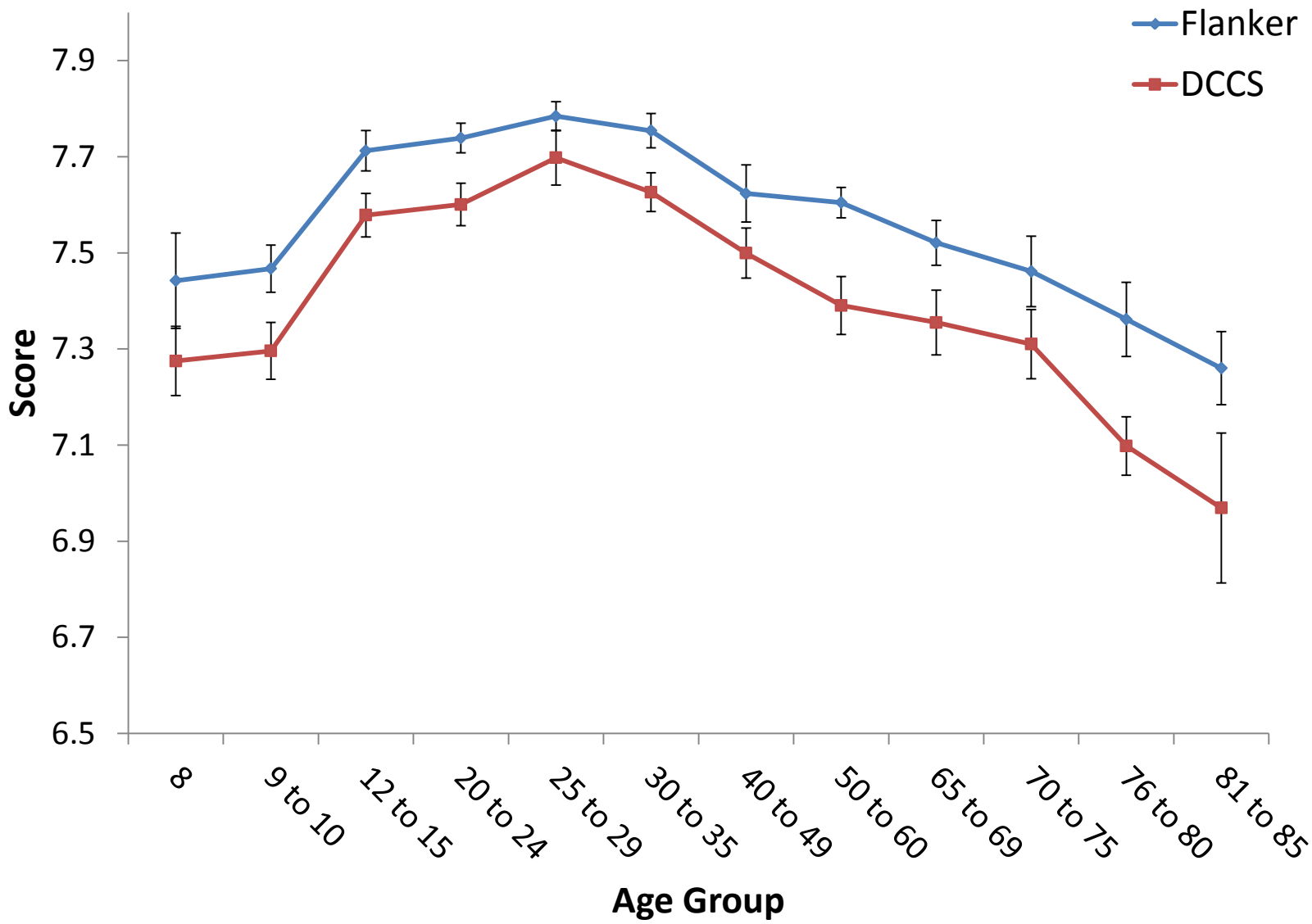
- Feed the fish
- Indicate direction of middle fish/arrow

EF: 3 to 6 Years

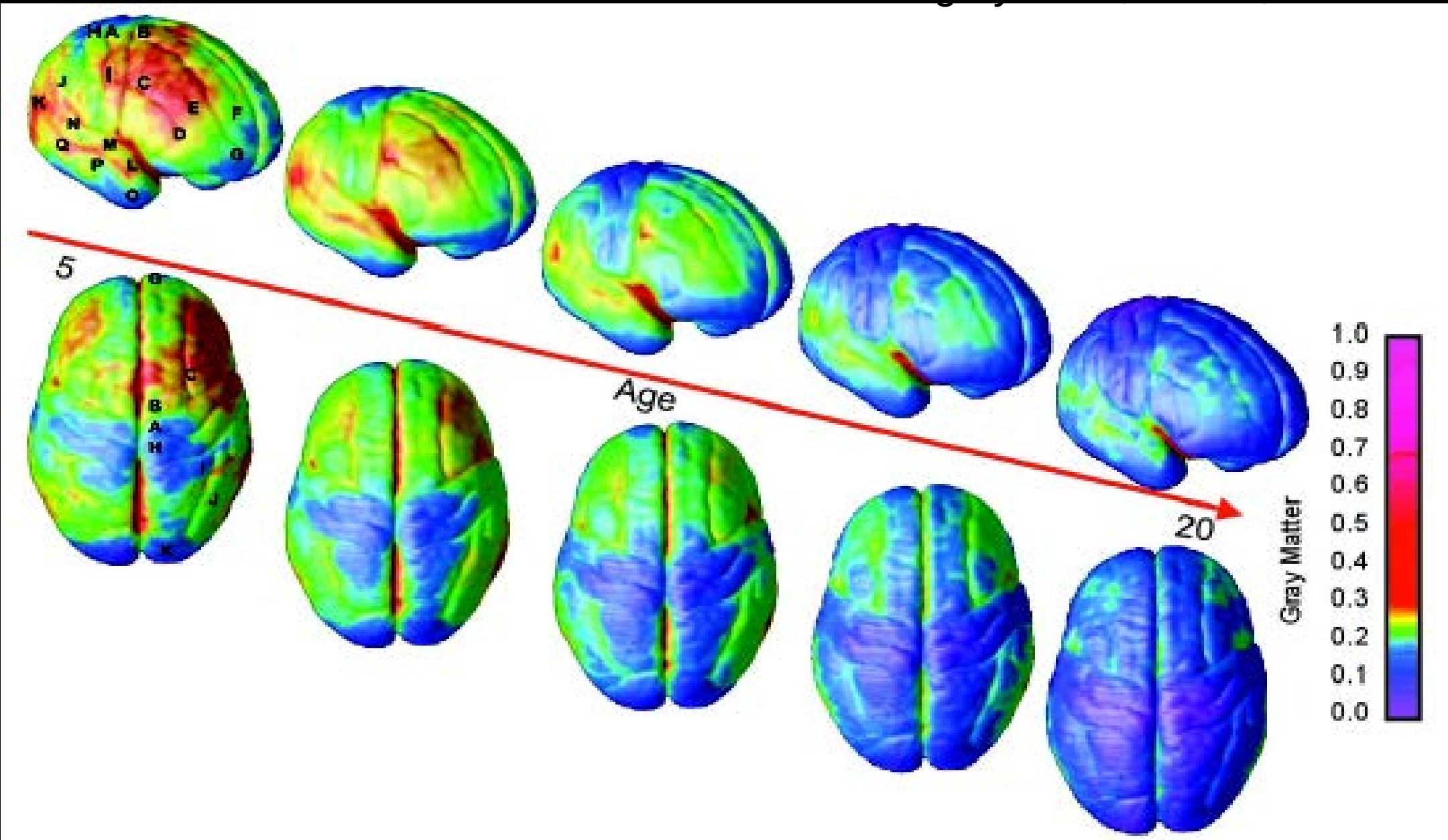


Zelazo et al., *SRCD Mono*

EF: 8 to 85 Years



Fits with what we know about the development of PFC



Developmental Cognitive Neuroscience

- The brain is an inherently adaptive organ, which develops as it is used, in a continual interaction with the environment

- Cognitive, emotional, behavioral tendencies as skills that depend on the activation of specific neural circuits

Neuroplasticity

- We grow our brains by using them
  - We grow our brain in particular ways by using them in particular ways

– Periods of relative plasticity

Plasticity during Preschool Period

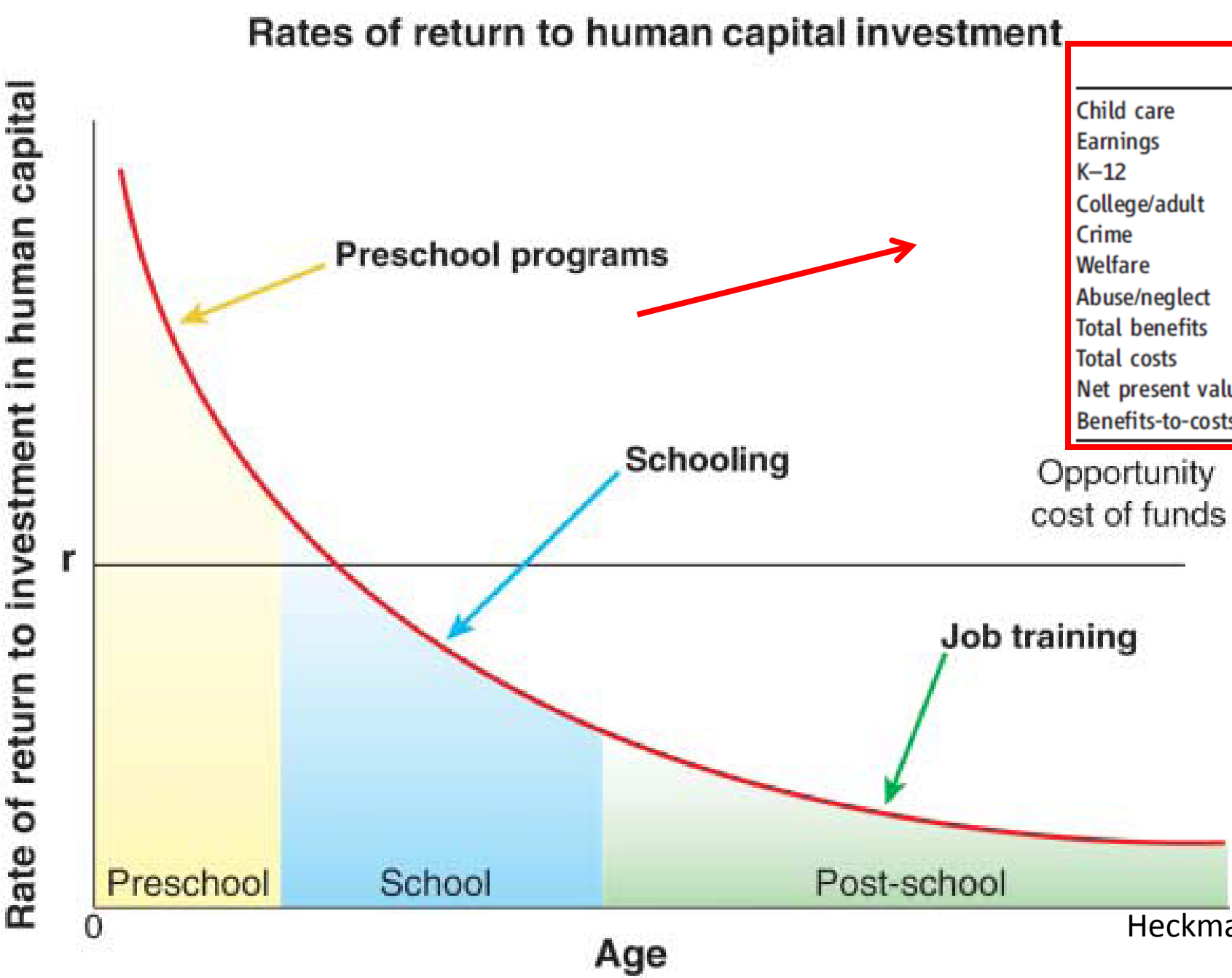
- Period of rapid growth (adaptation to environment) suggests window of opportunity (malleability) for top-down skills

- *Also*:
- Easier to build good habits when do not first need to break bad habits

- Boost in EF prior to a sharp increase in demands placed on children's EF (i.e., kindergarten)

- Initiate a cascade of events: establish positive association to school, > motivation to learn, good relationships w/ teachers, reduce problem behaviors

Rates of return to human capital investment



	Perry Preschool
Child care	$986
Earnings	$40,537
K–12	$9184
College/adult	$–782
Crime	$94,065
Welfare	$355
Abuse/neglect	$0
Total benefits	$144,345
Total costs	$16,514
Net present value	$127,831
Benefits-to-costs ratio	8.74

Heckman, 2006; Barnett, 2004

Preschool Programs & Focal Training

- Programs address EF, or effects mediated by changes in EF
  - Tools of the Mind (Leong, Bodrova)
  - PATHs (Greenberg et al.)
  - Chicago School Readiness Project (Raver et al.)
- Focal Training of EF
  - Attention Network Task (Rueda, Posner, Rothbart et al.)
  - CogMed (Klingberg et al.)
  - Redescription training on DCCS (Kloo & Perner)

Effective EF Interventions

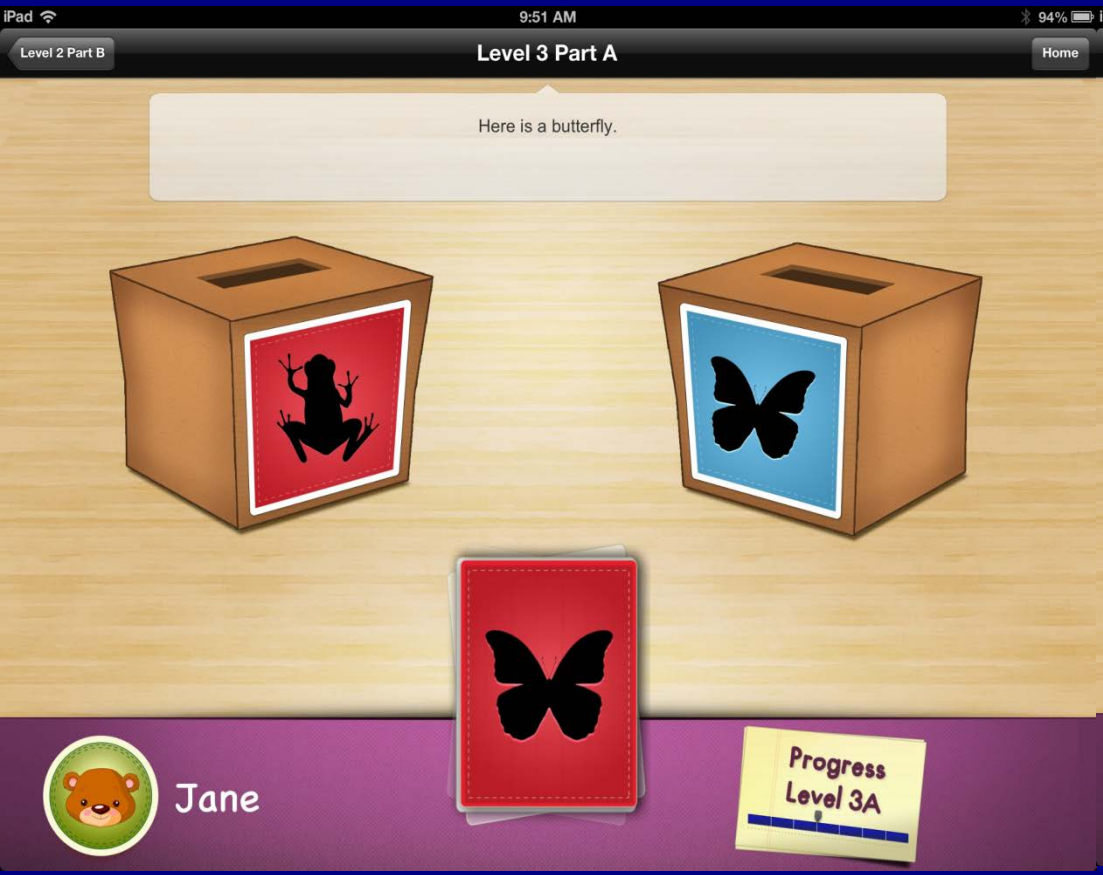
- Engage children in motivated, goal-directed activity
- Require reflection (stepping back, considering)
- Continually challenge children's skills
  - Increasing levels of difficulty
- Involve lots of practice

Importance of Direct Assessment

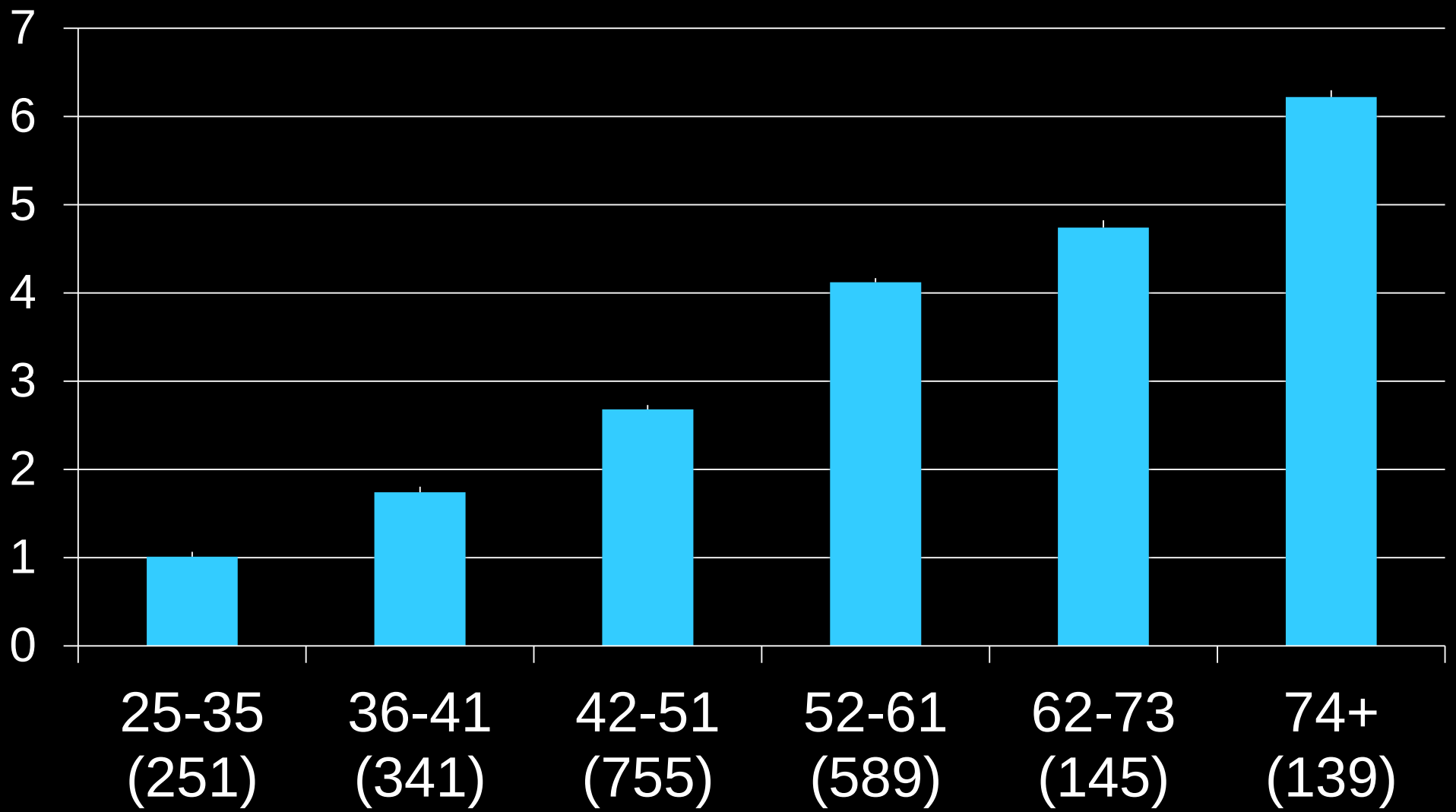
- Standardized
- Reliable
- Valid
- Brief and easy to administer
- Capture growth across wide range of ability levels
- Can be administered repeatedly to same children

Executive Function Scale for Early Childhood

- Direct, behavioral measure
- Measures 7 levels of EF from 2-6 years



Highest Level Passed on EF Scale



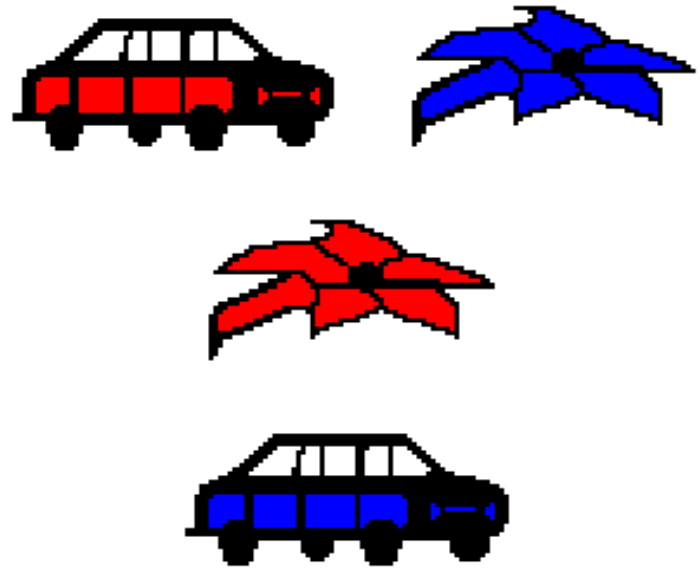
N = 2220

Carlson, 2013

Reflection Training

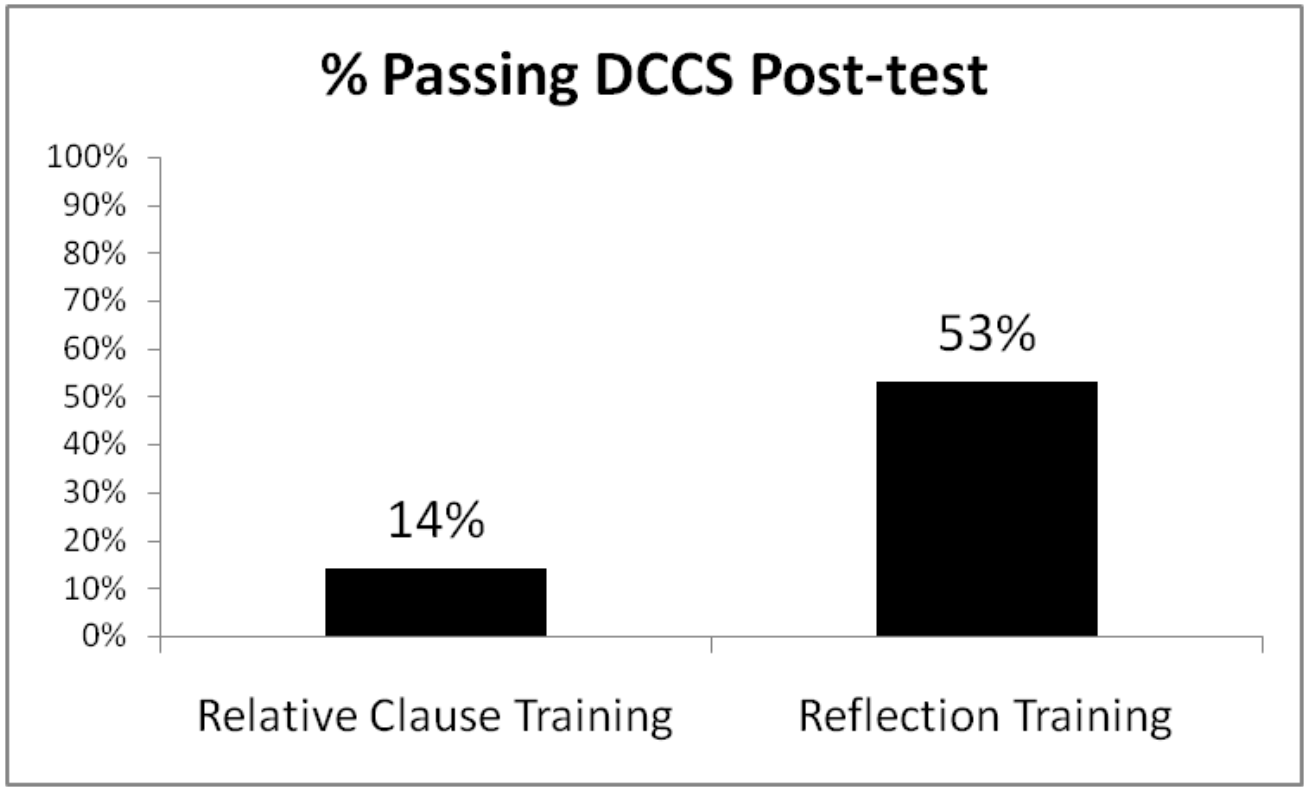
– Practice stepping back, reflecting, formulating a higher-order rule

– "Oops. When you saw the red one, you pressed the button with red on it, that means you looked at the color… Now, we are playing the *shape* game - the game with boat and rabbit."



DCCS: 3-year-olds tend to perseverate

- 3 experiments, kids who failed DCCS: training improved performance, generalized (e.g., theory of mind)



Espinet, Anderson, Zelazo, 2013, *DCN*

- Reflection training → changes in brain activity during the task
- Trained children not only did better, but their neural responses now looked like those of older children

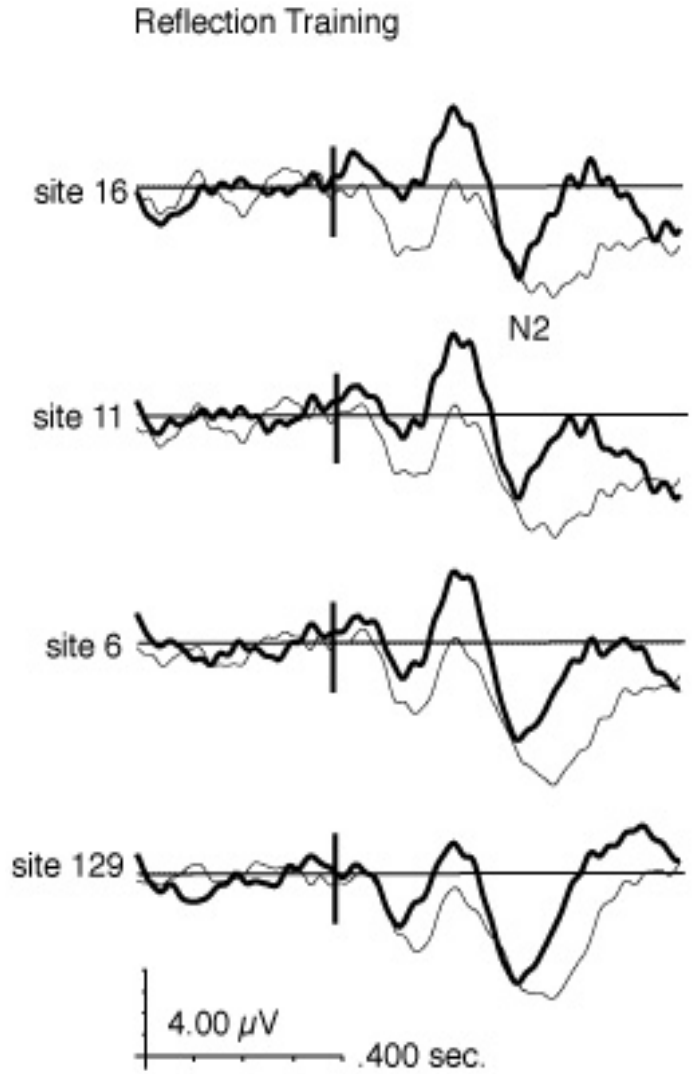


Photo: Electrical Geodesics Inc.

Summary

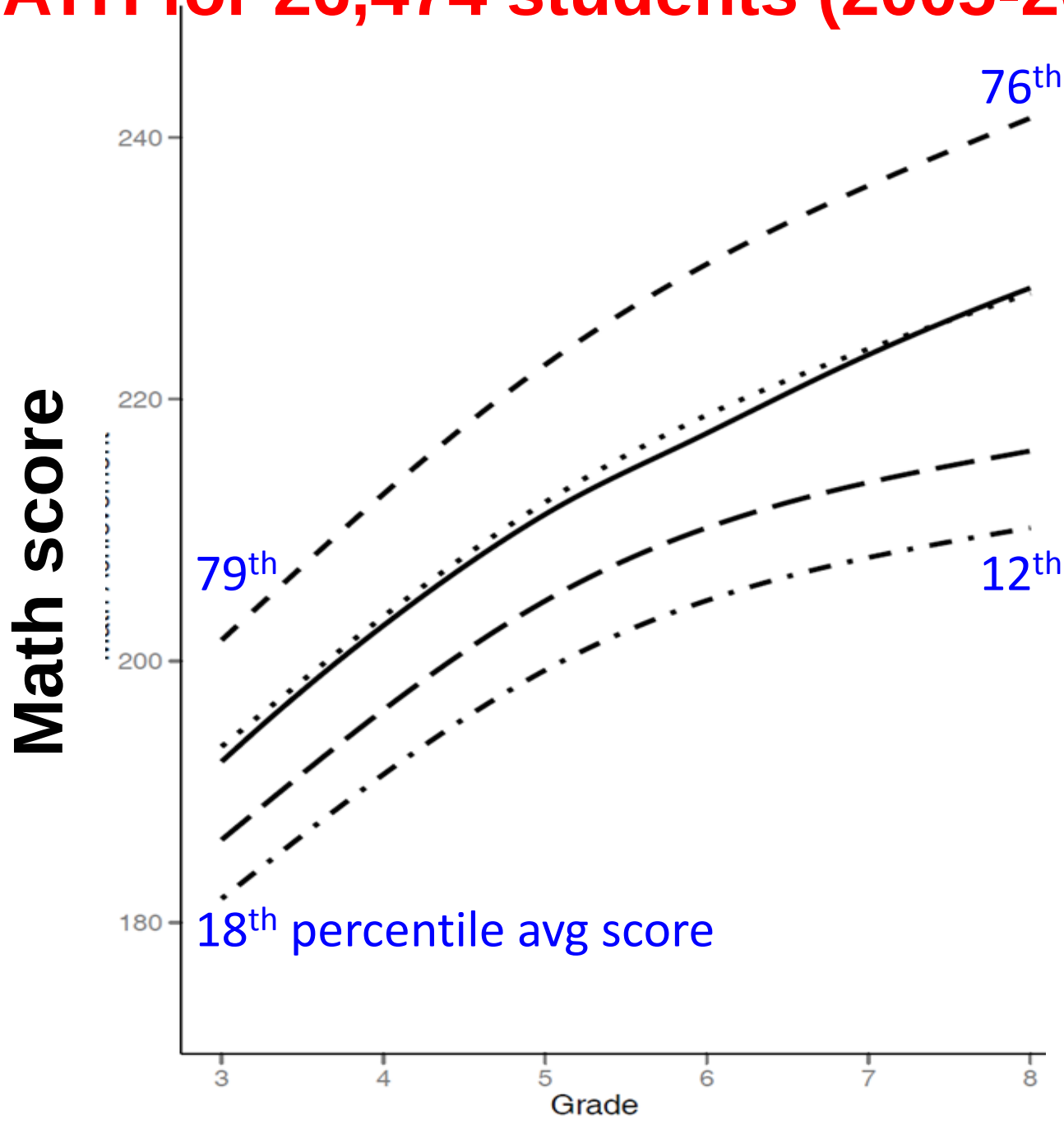
- Even a brief intervention aimed at teaching children to reflect on the task and formulate higher-order rules leads to improvement on DCCS

- Improvement also seen in flexible perspective taking, and in neural activity

Who Can Benefit?

- Anyone, but reasons to focus on young
- Children at risk
  - Working with Masten, Carlson to promote EF in preschool children who are currently homeless
  - Embedded lab with onsite preschool
  - 3-week curriculum

MATH for 26,474 students (2005-2009)



General 25%

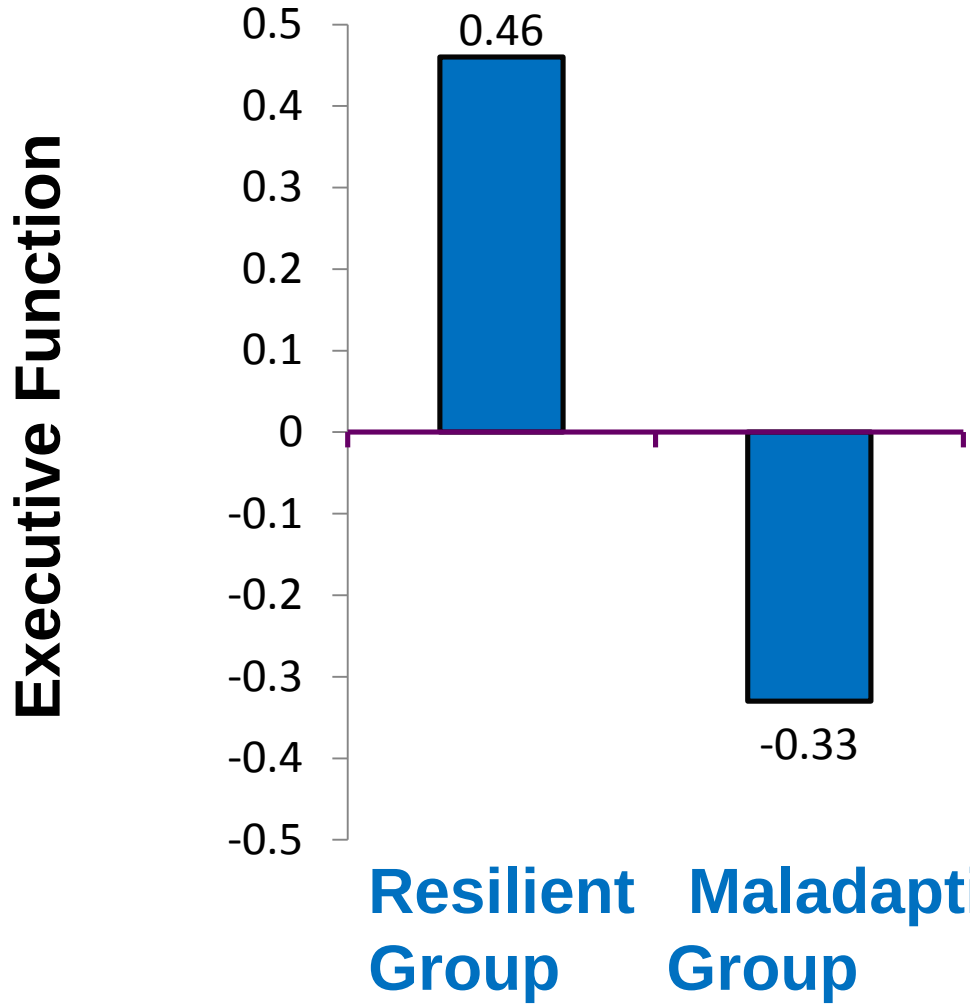
Norm & RPM 4%

Free meals 57%

HHM 14%

Cutuli et al. (2012)
Child Development

EF Skills Predict School Success



Obradovic 2010
Masten et al 2012

- May be missing the structure and teaching moments that advantaged children commonly receive
- Exposed to prolonged, “toxic” stress
  - Bottom-up influence that undermines EF
- For adequate assessment and training of EF, need to help children calm down, focus

A Related Intervention: Mindfulness

Mindfulness may be an ideal intervention for promoting EF:

Trains sustained reprocessing while *also* creating conditions conducive to reflection

- Reducing stress (< cortisol)
- Increasing openness and curiosity (> dopamine)

Mindfulness in Kids

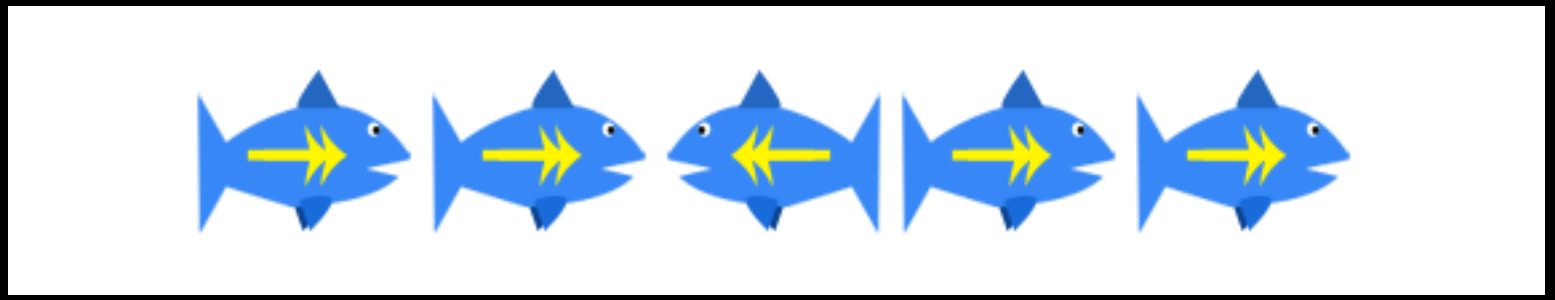
- Johnson, Forston, & Zelazo (2013)
- Children (*N* = 20, *M* = 4.5 years) randomly assigned to:
  - Mindfulness condition
  - Active control condition
    - Learning new songs, reading stories, etc.
- Ten 20-min sessions (2/week), tested pre- and post by “blind” examiner (Time 1 and Time 2)

Mindfulness Exercises (Examples)

- Calming down, reflecting on subjective experience, sustaining reflective attention, empathy
- *Breathing with stuffed animal on abdomen*
- *Listen to bell fade, raise hands when can't hear*
- *Feeling of body parts as "scanned" with hula-hoop*
- *Jumping in sync to the sound of a drum beat*

Outcome Measures

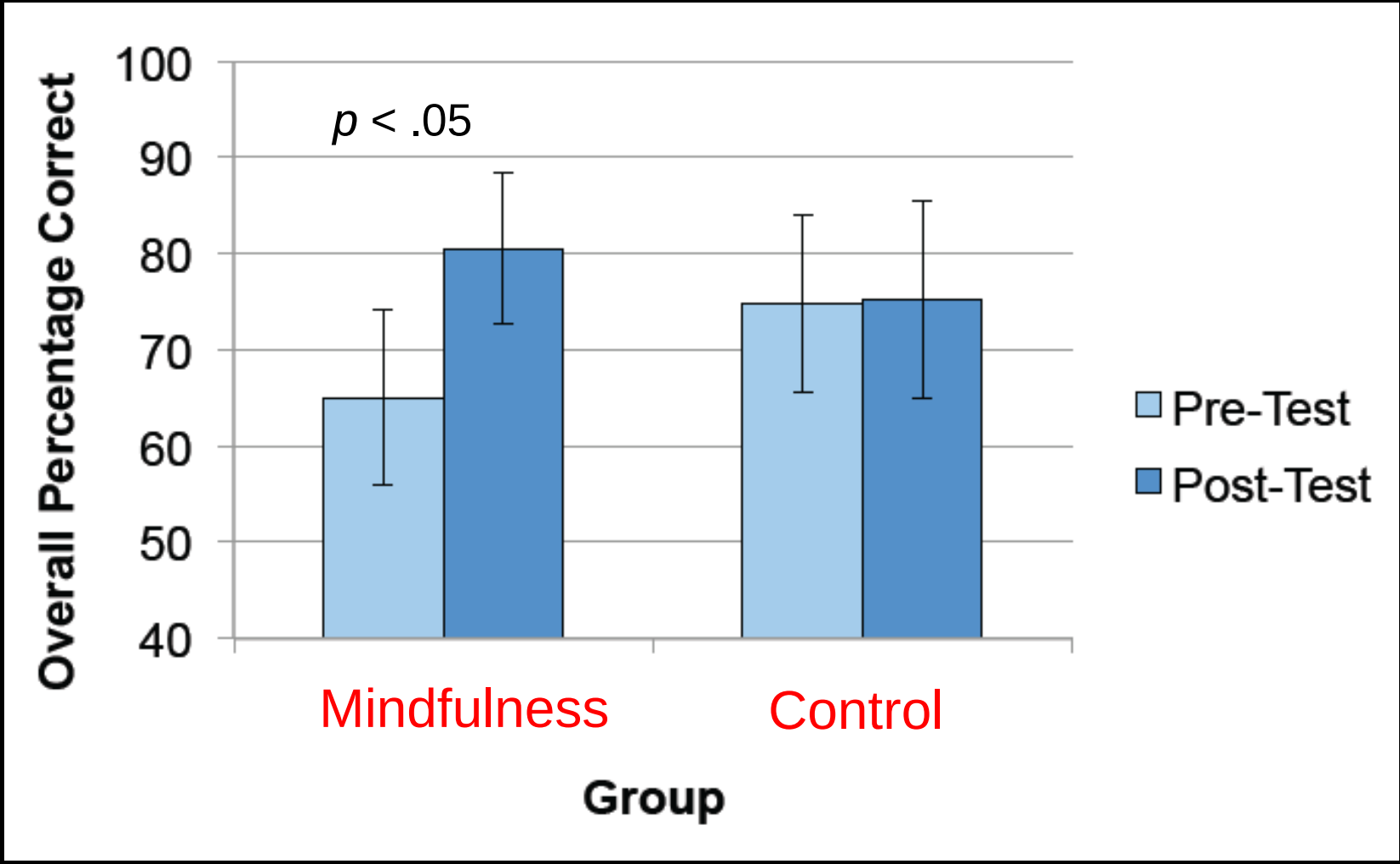
- Inhibitory Control/Attention: Flanker



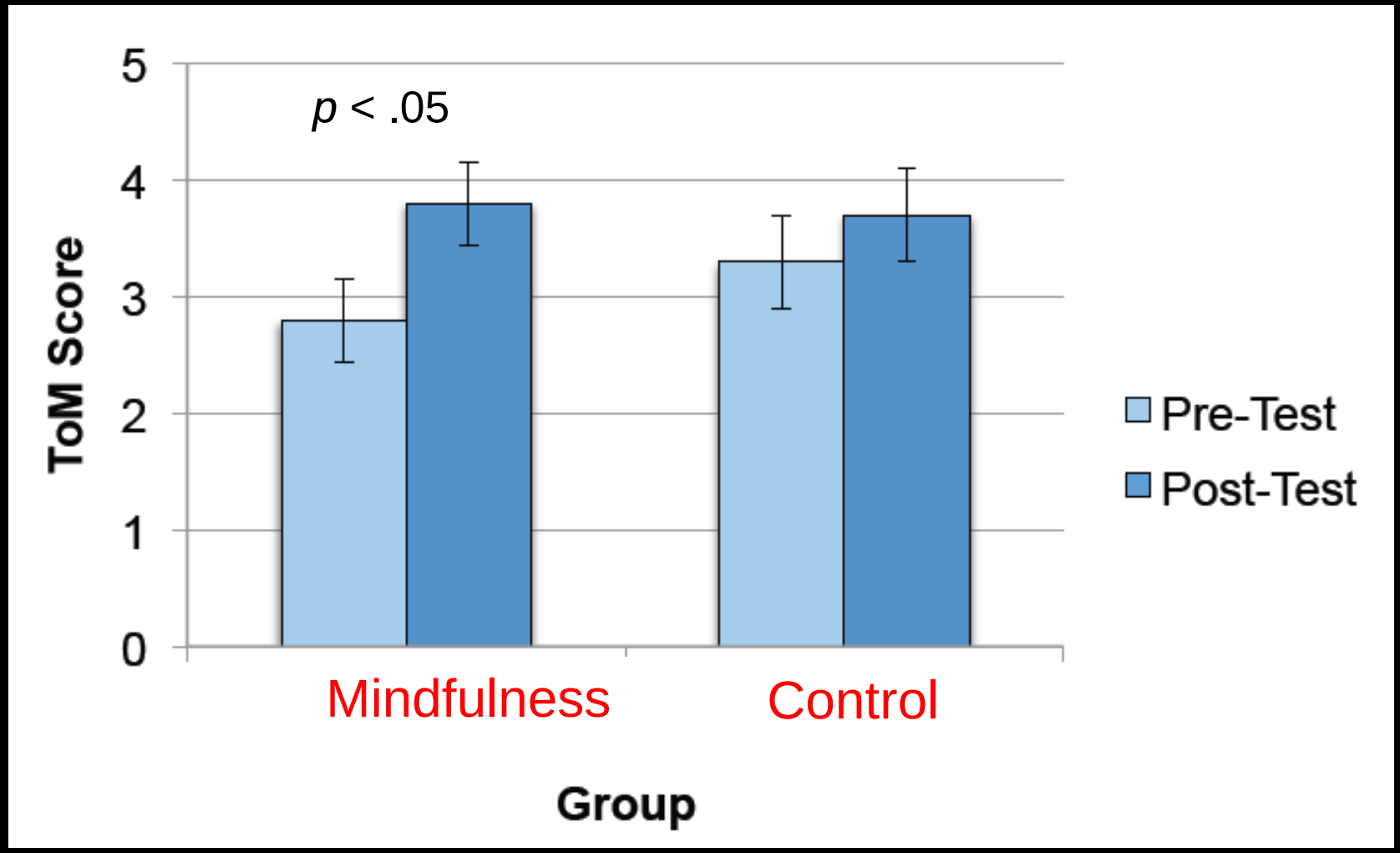
  – indicate direction of middle stim

- Self and Social Understanding (“theory of mind”)

Flanker Total Accuracy



ToM Score (0-5)


p < .05
5
4
3
2
1
0
ToM Score
Mindfulness
Control
Group
Pre-Test
Post-Test

Summary

- Brief mindfulness intervention with preschool age children was well tolerated by children and instructors
- Effects are promising, extend to perspective taking
- Larger RCT of this curriculum, funded by the Character Lab and KiPP Schools, currently being conducted

More Intensive Intervention

- Eighteen 4.5-y-olds
- 2-week “Mindfulness Camp,” yoga studio
- Eight 45-minute parent-child classes
- Daily homework activity
- No-treatment control (age, sex match)

Johnson, Lyons, Forston, & Zelazo

Before naptime or bedtime today,
take 10 deep belly breaths.

Share how it feels to breathe deeply.

Day 1

Before naptime or bedtime today,
check in with your body.

~Script on back~

Day 2

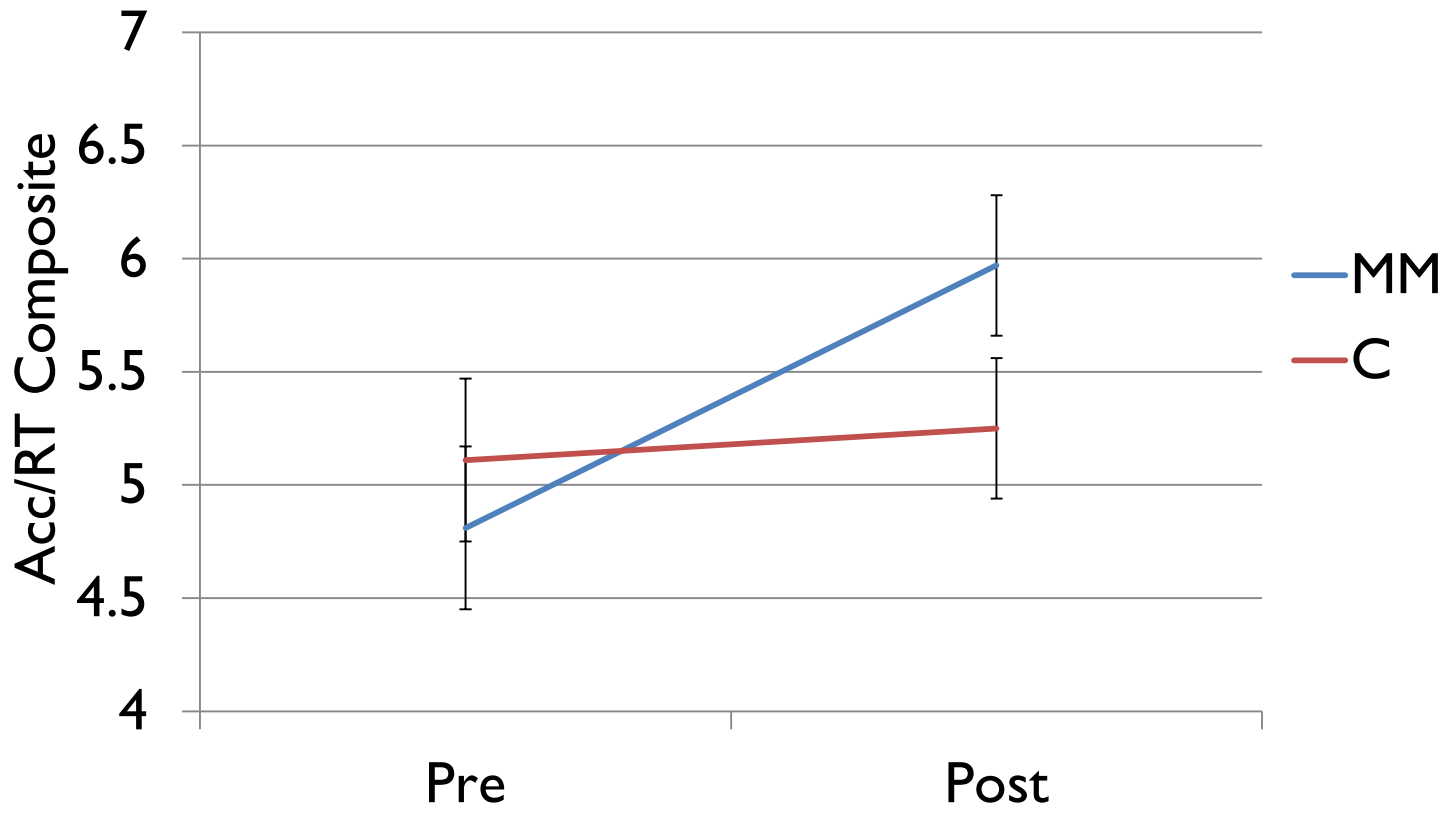
Today, practice eating one meal or snack mindfully.

Day 6

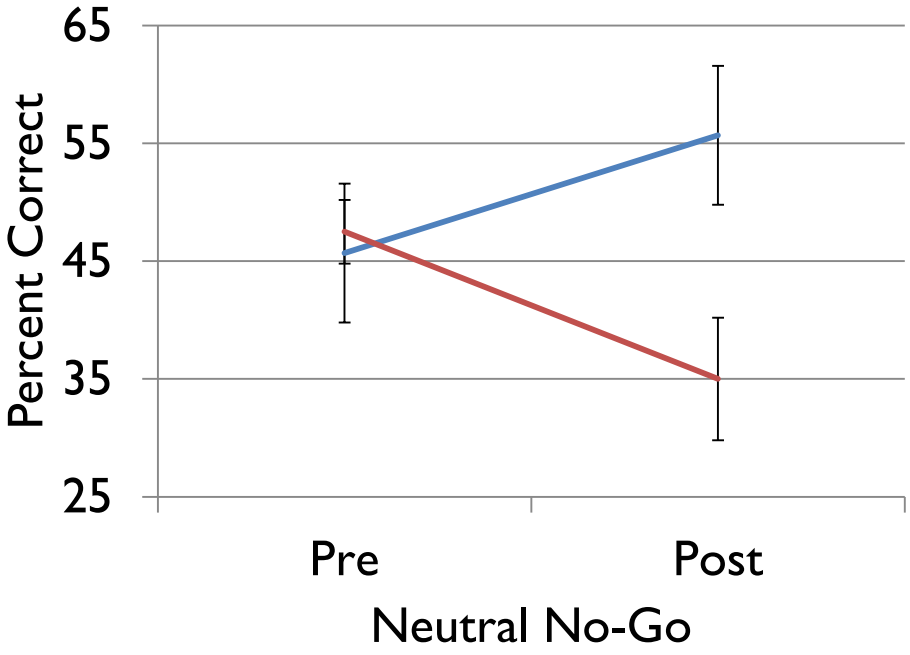
Just like flowers, people need caring for too. Today at mealtime, take care of one another by giving compliments to each member of the family.

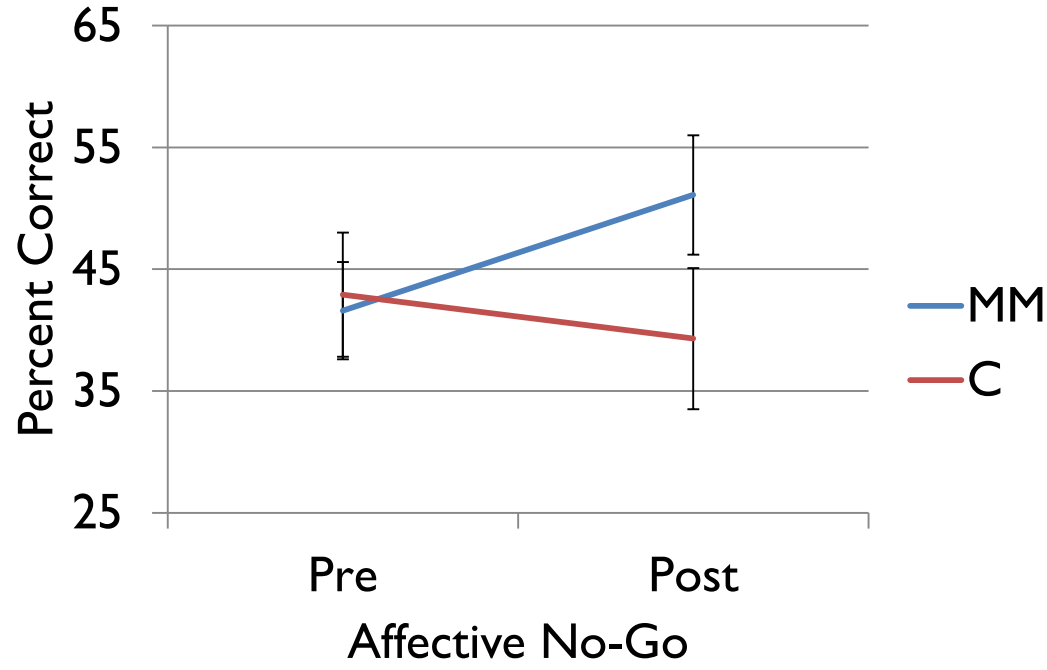
Day 8

Flanker



Emotional Go/No-Go: No-Go Trials





Summary

- EF is malleable, perhaps especially during the preschool years
- We grow our brains by using them in particular ways
- Training improves EF, changes neural activity
- Consequences are potentially far-reaching

Acknowledgements

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