Understanding Executive Functions

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‘Executive Functions’ refers to a family of mental functions that are **needed** whenever going ‘on automatic’ would be insufficient or detrimental.

The 3 core Executive Functions are:

- Inhibitory Control (self-control)
- Working Memory
- Cognitive Flexibility

Higher-order Executive Functions are:

- Problem-solving
- Reasoning
- Planning

Inhibitory control is by far the greatest challenge for young children, so I'll spend the most time on that.

(1) Inhibitory control of attention

enables us to inhibit distraction & selectively attend, focusing on what we choose and suppressing attention to other stimuli

SELECTIVE or FOCUSED ATTENTION

such as screening out all but one voice at a cocktail party

(2) Self-control: resist temptations, think before you act, inhibit acting impulsively:

- resist grabbing another child's toy
- resist blurting out what first comes to mind
- resist 'tit for tat' (hurting someone because that person hurt you)
- resist jumping to an interpretation of what something must have meant or why it was done
- resist indulging too much

(3) resisting the many temptations not to do your assignments or finish what you started

stay on task despite boredom, initial failure, interesting tangents, or tempting distractions

DISCIPLINE

Discipline accounts for over twice as much variation in final grades as does IQ.

(Duckworth & Seligman, 2005)

Children with less inhibitory control (i.e., children who were less persistent, more impulsive, and had poorer attention regulation)

as adults 30 years later have…

- worse health
- earn less
- and commit more crimes

than those with better inhibitory control as young children,

controlling for IQ, gender, social class, & home lives & family circumstances growing up

across diverse measures of inhibitory control.

That's based on a study of 1,000 children born in the same city in the same year followed for 32 years with a 96% retention rate.

by Terrie Moffitt et al. (2011)
Proceedings of the Nat'l Academy of Sci.

They conclude that "interventions that achieve even small improvements in [inhibitory control] for individuals could shift the entire distribution of outcomes in a beneficial direction and yield large improvements in health, wealth, and crime rate for a nation."

(b) Working Memory:

Holding information in mind and mentally working with it

Working memory is critical for making sense of anything that unfolds over time, for that always requires holding in mind what happened earlier & relating that to what is happening now.

- relating one idea to another
- relating what you read (or learned / heard) earlier to what you are reading (learning / hearing) now
- mental math calculations
- understanding cause and effect
- remembering multi-step instructions & executing them in the correct order

(c) COGNITIVE FLEXIBILITY

being able to easily & quickly switch perspectives or the focus of attention,

flexibly adjusting to changed demands or priorities,

being able to think outside the box.

For example, try to think of as many uses for a TABLE as you can.

What are all the things you might use a table for?

A table might be used to write on or to eat food on.

It might be turned on its side and used to keep a door closed or used as a shield against snowballs.

You could get under it to hide or to keep dry.

You could dance on it.

You could cut it up for firewood.

c.1) Creativity

- Coming up with new ideas, hypotheses and Inventions.
- If one way of solving a problem isn't working, how else might we succeed? Can we think outside the box to come up with a entirely new way of attacking this that no one has ever considered before?

c.2) Flexibility

- Seeing opportunities and seizing them: I was planning to do X, but an amazing opportunity has come up to do Y, do I have the flexibility to take advantage of serendipity?
- My opinion was X, but now that I see this new information, I'm able to change my opinion.
- Being able & willing to change course when it seems you were wrong

An example of poor cognitive flexibility:

When one door closes, another door opens;
but we often look so long and so regretfully upon the closed door, that we do not see the ones which open for us.

- Alexander Graham Bell

When a student isn't grasping a concept, educators often blame the student: "If only the student were brighter, she would have grasped what I'm trying to teach."

But we need to be flexible enough to try different perspectives….

… to realize our own role in the learning process and that different people learn in different ways. If a child isn't getting something:

What might I, the teacher, do differently? How can I present the material differently, or word the question differently, so that this child can succeed?

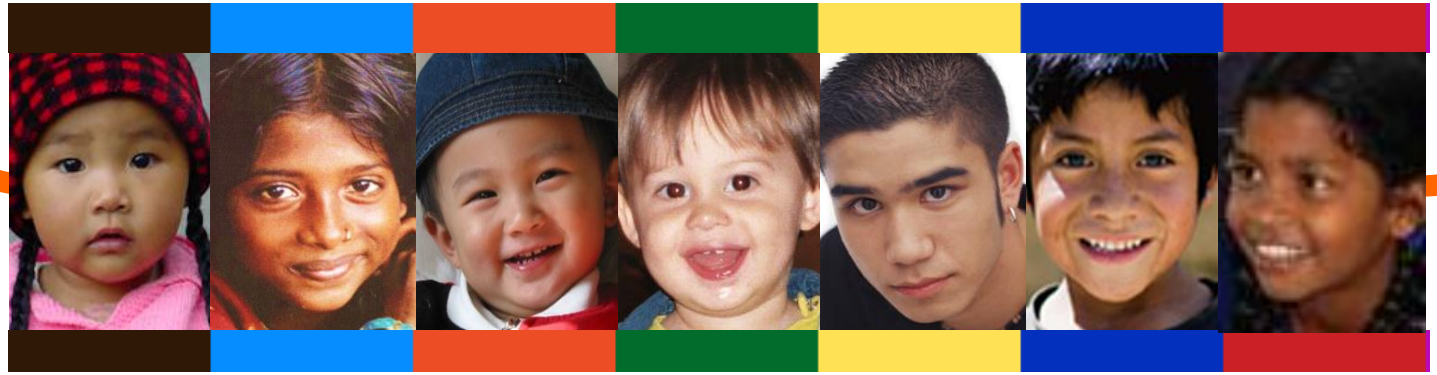
We can also change the focus of our attention by changing whether we are focusing on what others are doing wrong to focusing on what *we* might be doing wrong or how we might respond to the problem differently.

What do we want for your children?

What I want for my children is that….

- …they should be good people, caring and compassionate.
- …they should be happy; leading fulfilling & meaningful lives.
- …they should be successful in the careers of tomorrow.

What will it likely take to be successful in the 21st century?



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- My opinion was X, but now that I see this new information, I'm able to change my opinion.
- Being able & willing to change course when it seems you were wrong

3) Self-control

Having the self-control to…

- think before you speak or act
- not put your foot in your mouth
- not do something you might regret
- resist temptations
- give a considered response instead of an impulsive one

4) Discipline

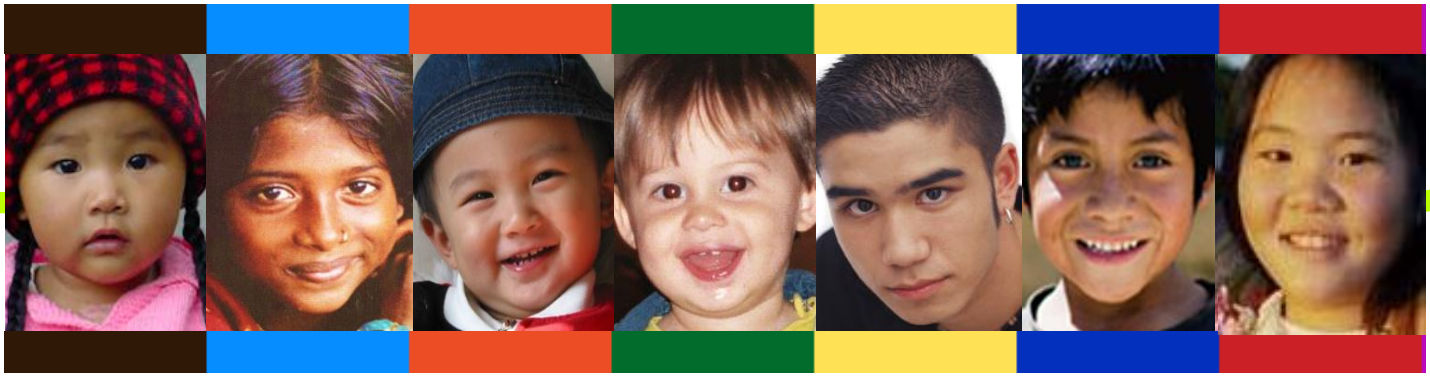
Having the discipline to stay on task…

- seeing it through to completion despite some aspects being tedious or difficult
- being able to stay focused despite distractions
- continuing to work at something though the reward may be a long time in coming

ALL of the above are

"Executive Functions"

or rely on them



The 3 core Executive Functions are:

- **Cognitive Flexibility**

  (including being able to switch perspectives & see things in a new light)

- **Inhibitory Control**

  (which includes self-control & discipline)

- **Working Memory**

Higher-order Executive Functions are:

- Problem-solving
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The 3 core Executive Functions are:

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- Working Memory
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Higher-order Executive Functions are:

- Problem-solving
- Reasoning

} = Fluid Intelligence

- Planning

Why should we care about Executive Functions?

Executive Function skills are more important for school readiness than are IQ or entry-level reading or math.

(e.g., Blair, 2002; 2003; Blair & Razza, 2007; Normandeau & Guay, 1998)

Executive Functions are also important for school success throughout the school years.

Improving EFs improves academic outcomes.

(e.g., Blair & Razza, 2007; Espy et al., 2004; Gathercole et al., 2004, 2005; McClelland et al., 2007; Passolunghi et al., 2007; Raver et al. 2011; Savage et al., 2006)

Executive Functions are also critical for job success.

Poor EFs lead to poor productivity and difficulty finding and keeping a job (Prince et al. 2007).

Executive Functions are also important for marital harmony.

People with poor EFs are more difficult to get along with, less dependable, and more likely to act on impulse (Eakin et al. 2004).

Poor EFs can lead to social problems

such as aggression, emotional outbursts, & crime (Bailey 2007; Broidy et al. 2003; Moffitt et al. 2011; Prince et al. 2007; Saarni 1999).

Early EF gains can reduce the later incidence of aggression & anti-social behavior (Nagin & Tremblay 1999).

EFs are core skills critical for cognitive, social, and psychological development,

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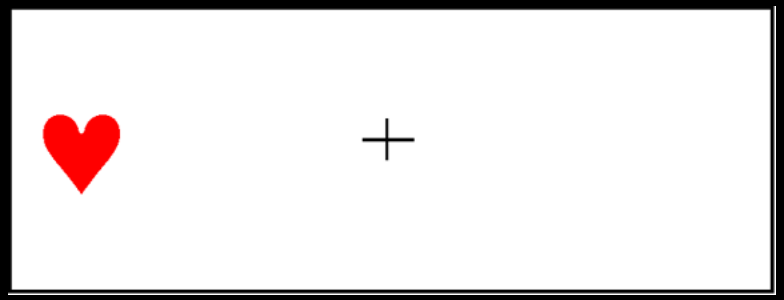
EFs are core skills critical for cognitive, social, and psychological development, mental and physical health, and success in school and in life.

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

HEARTS & FLOWERS

Congruent



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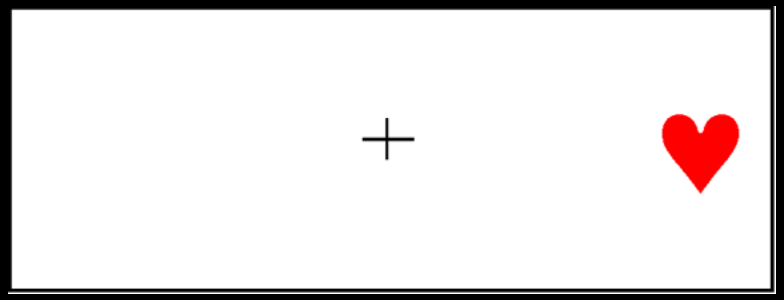
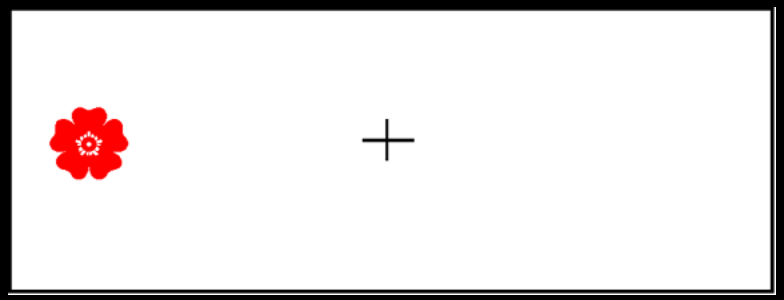


Push Right

Incongruent



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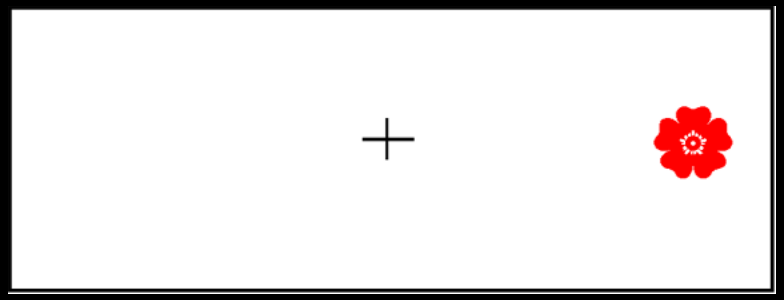


Push Left

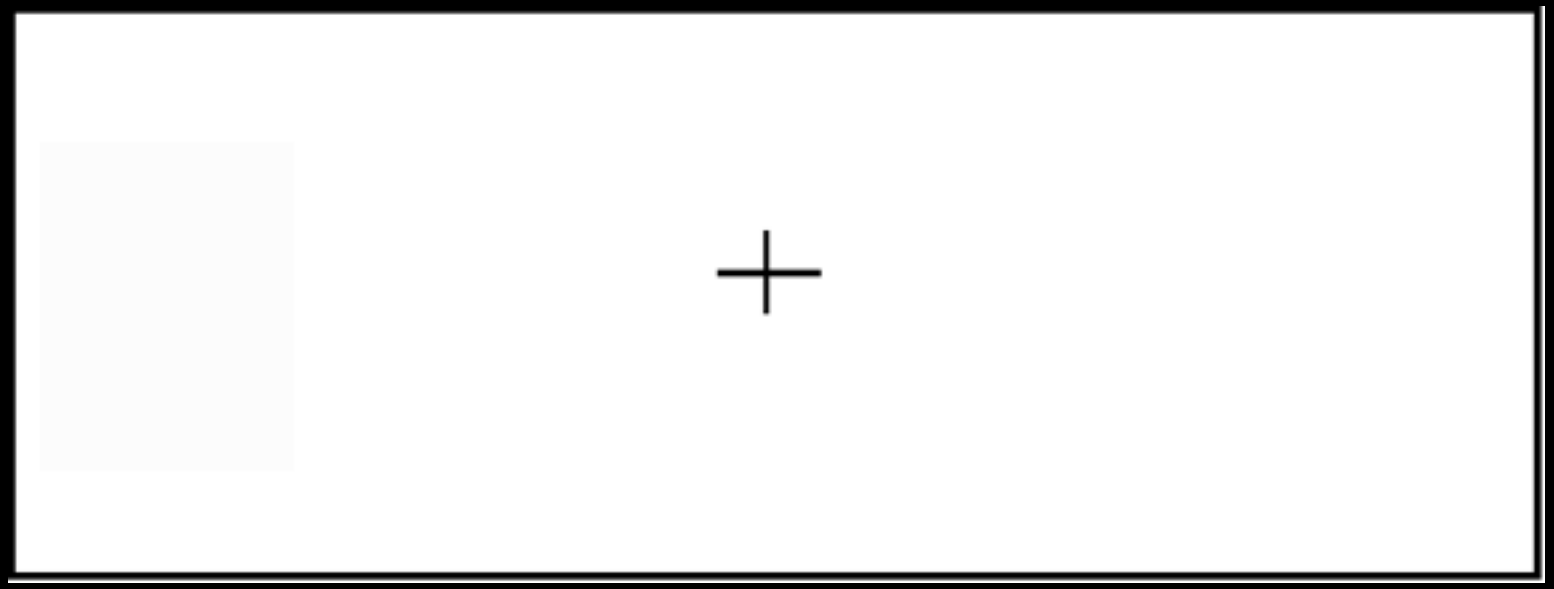
HEARTS – CONGRUENT

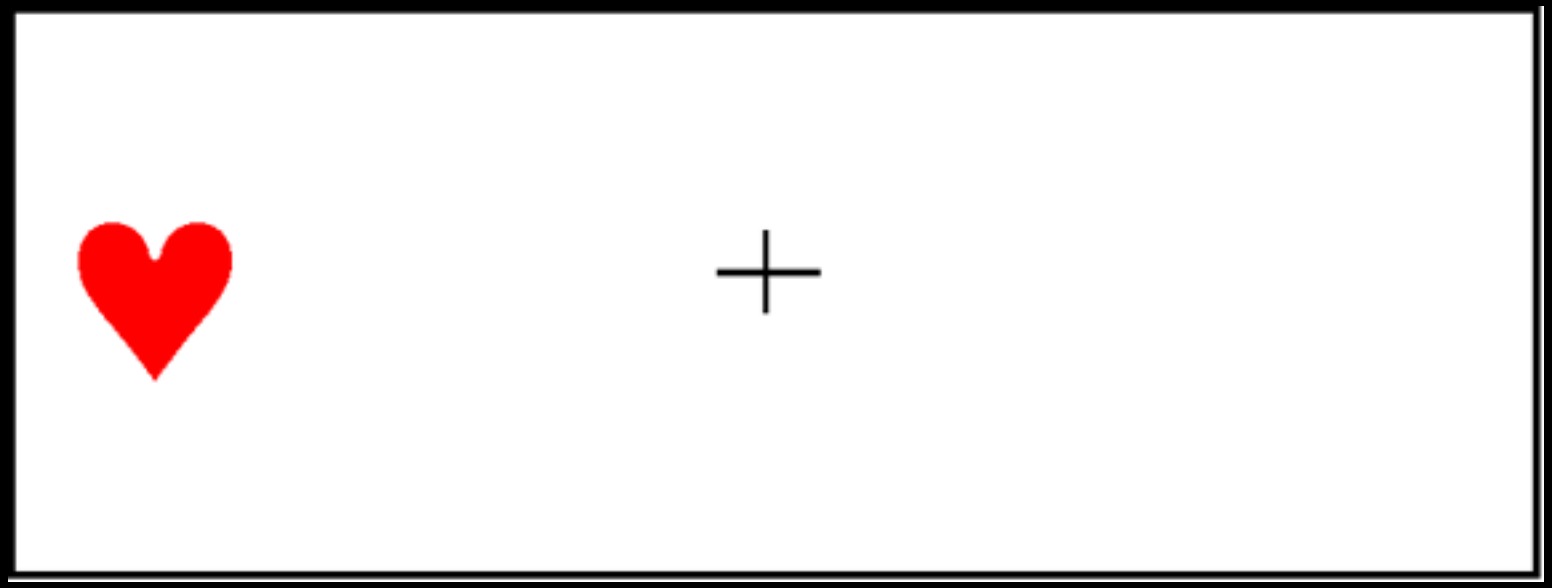
Each time you see a HEART, press with the thumb or forefinger on the SAME side as the stimulus.

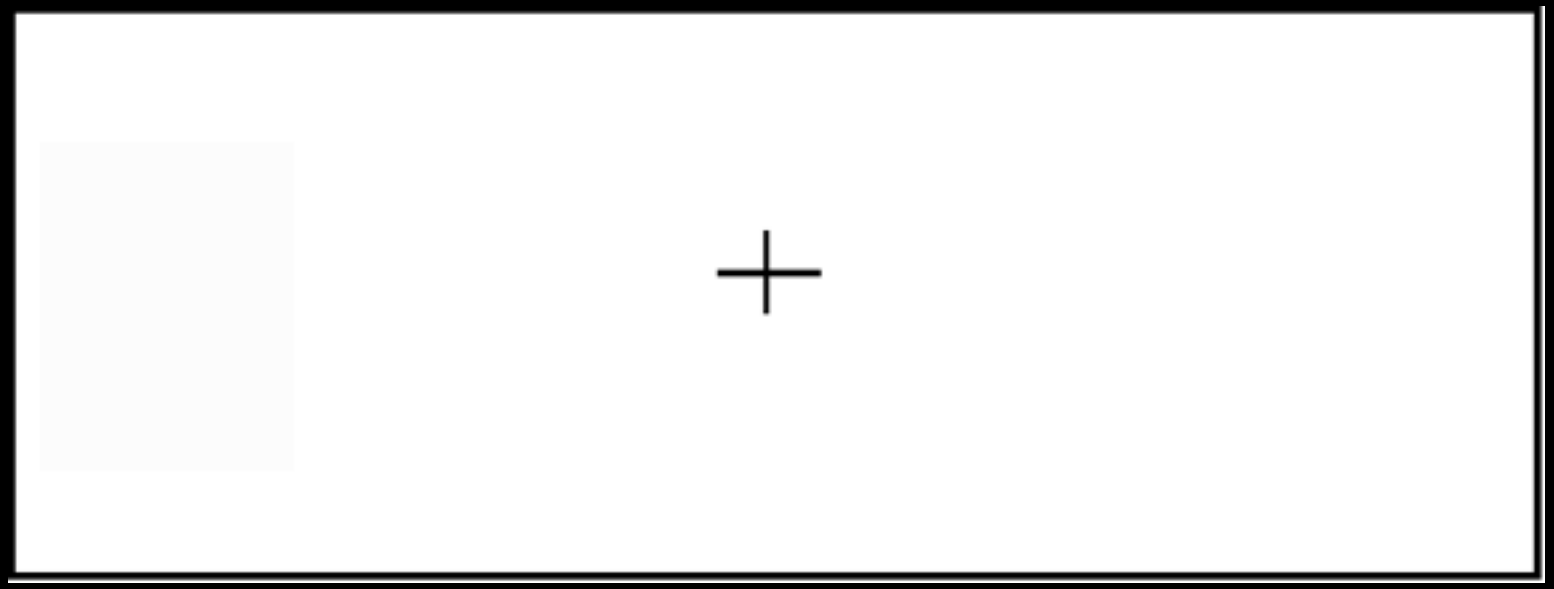
For example, if the heart appears on the left, press with your left hand.

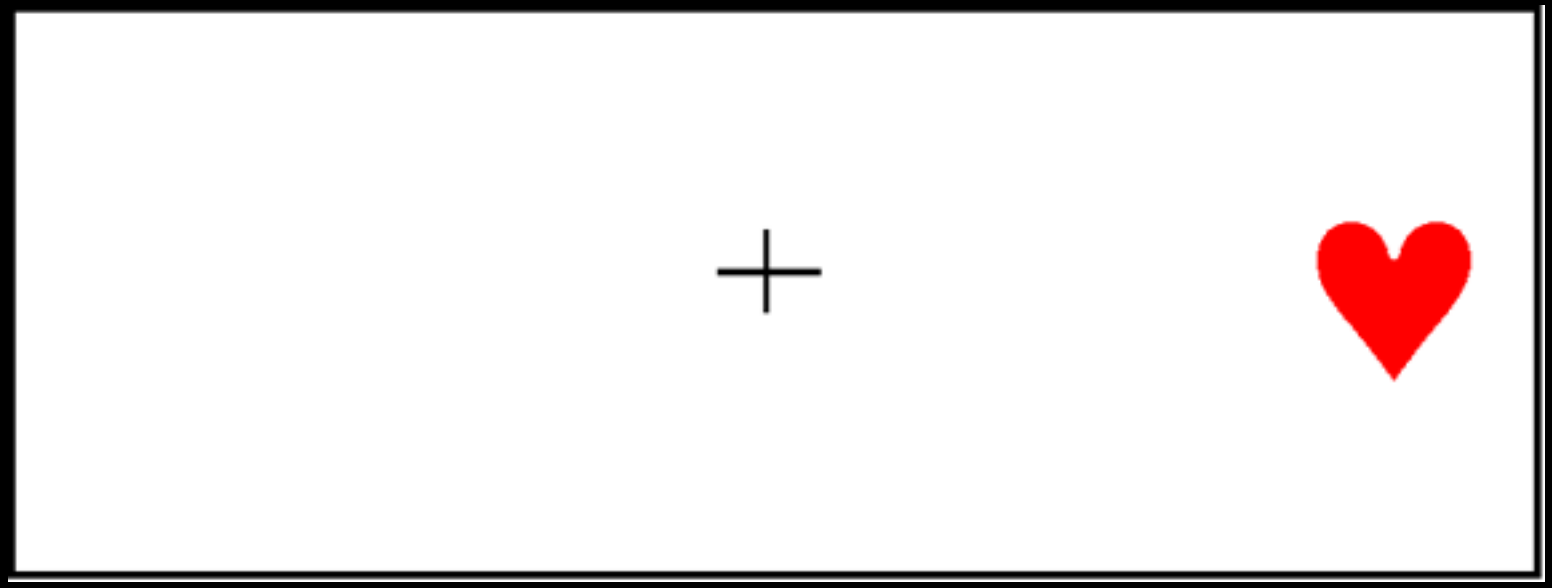
Remember:

PRESS ON THE SAME SIDE AS THE HEART









FLOWERS - INCONGRUENT

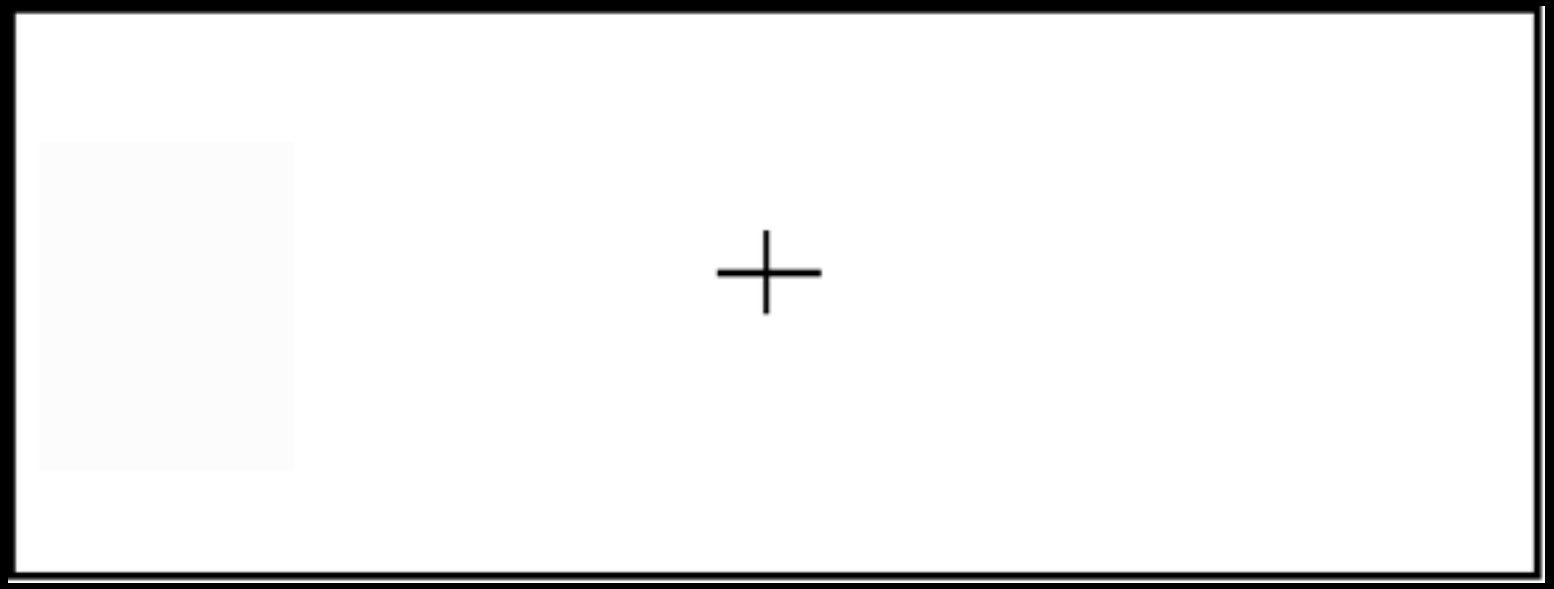
Now you'll see a flower. Press on the side OPPOSITE the flower.

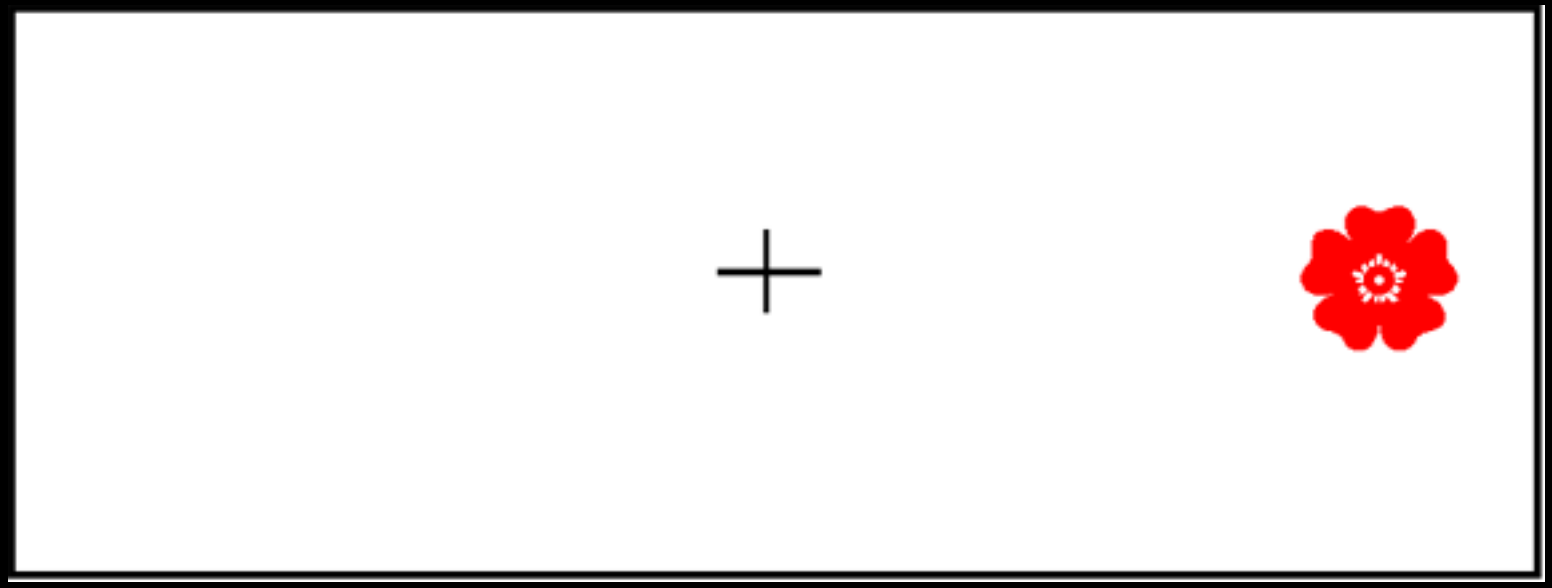
For example, if a flower appears on the left, press with your right hand.

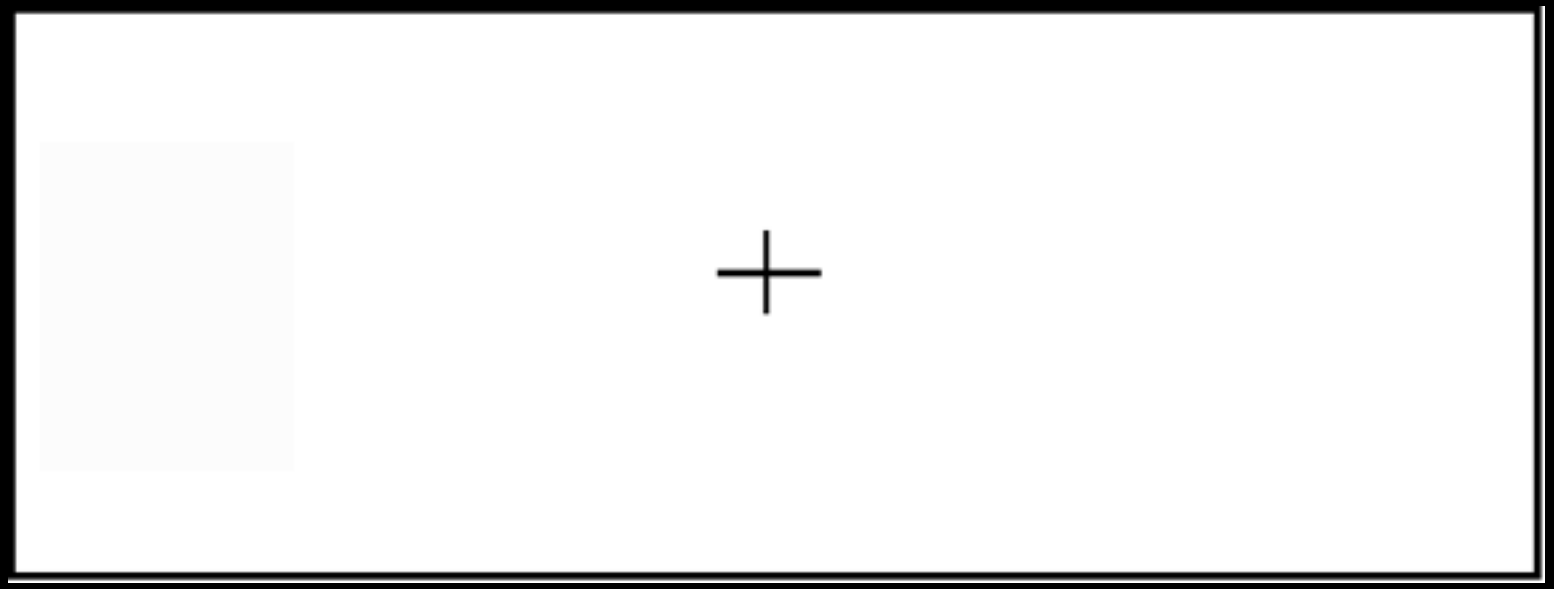
(Here, you'll need to inhibit on every trial the natural tendency to respond on the same side as the stimulus)

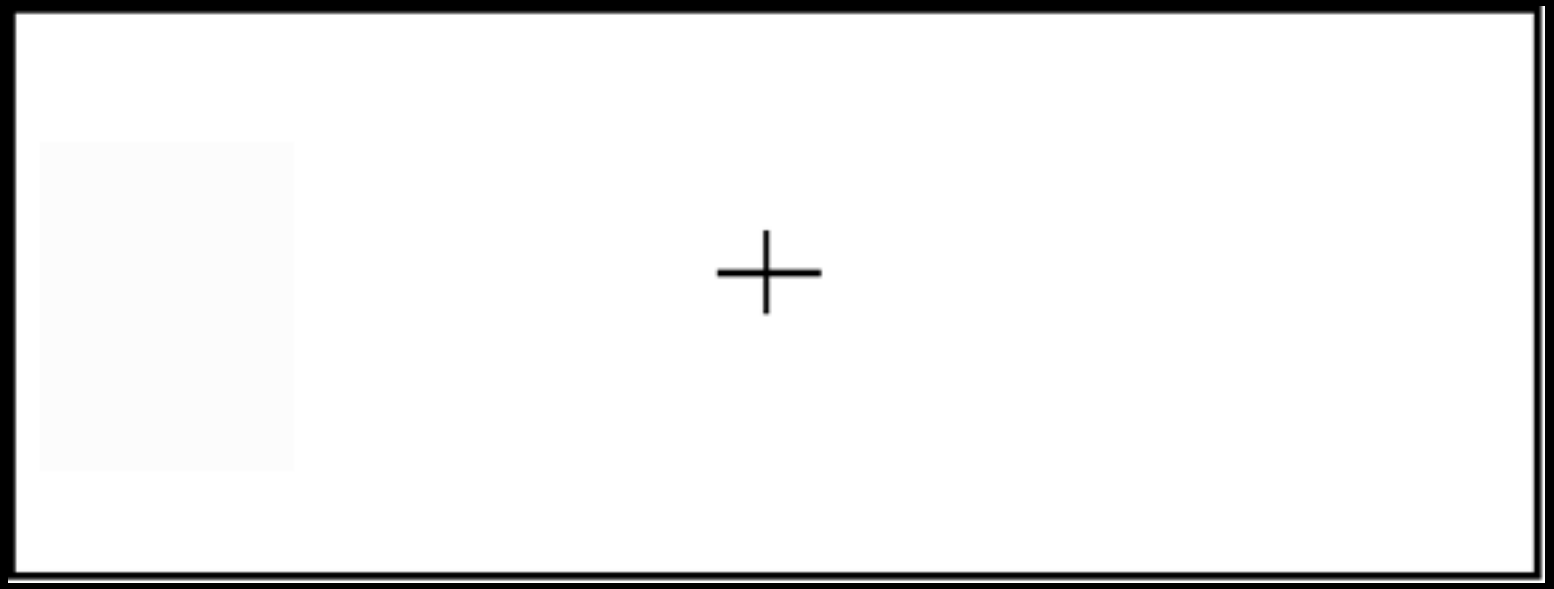
Remember:

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.

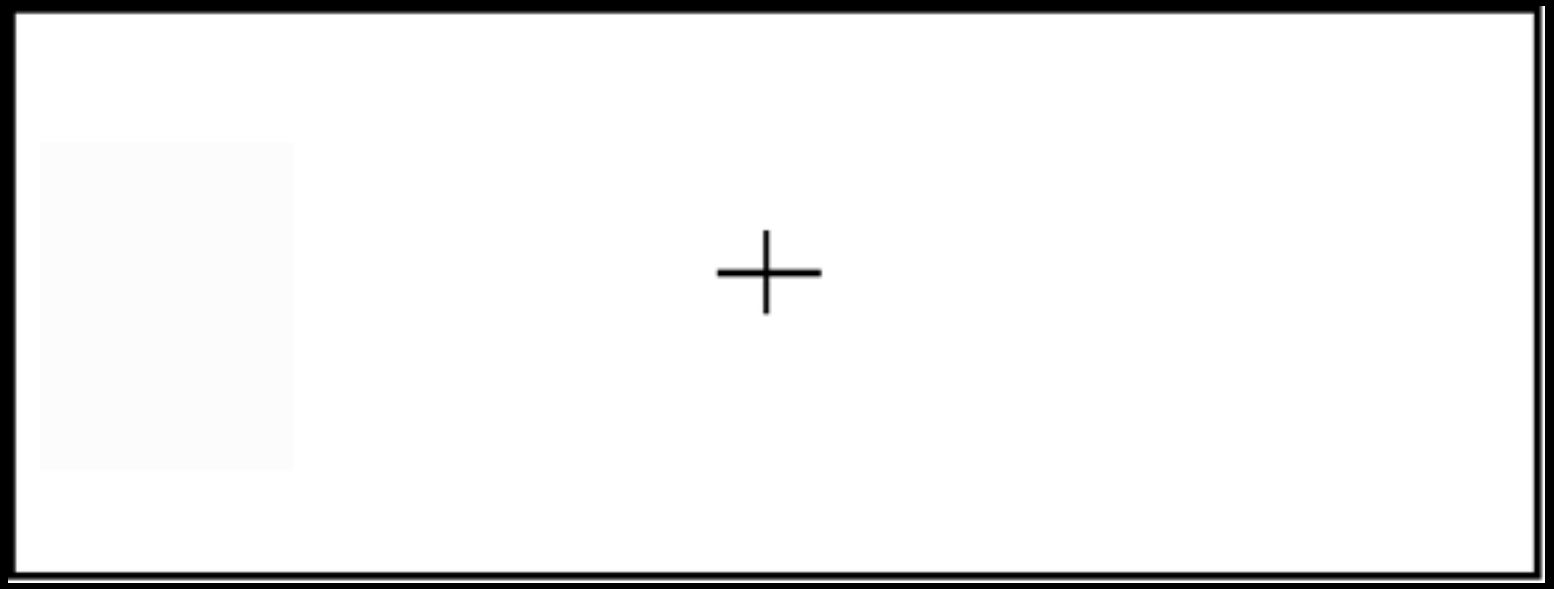
The rules stay the same:

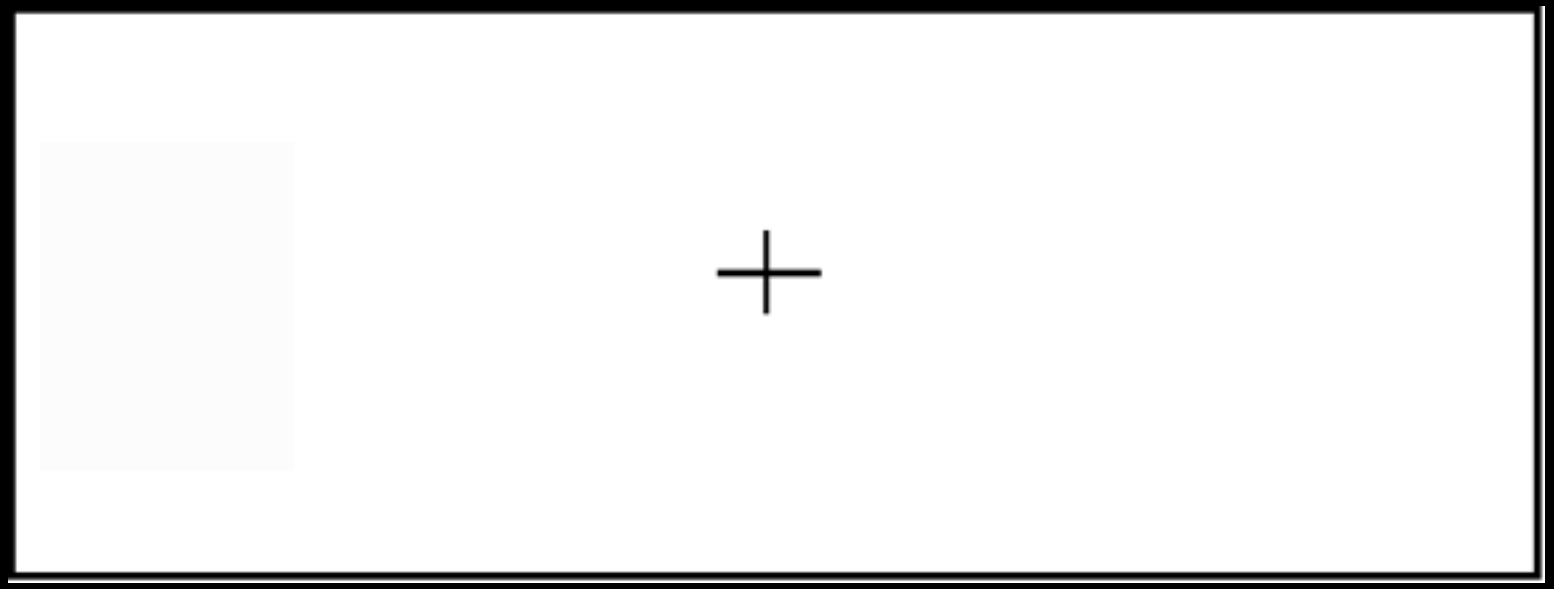
For HEARTS, press on the SAME side.

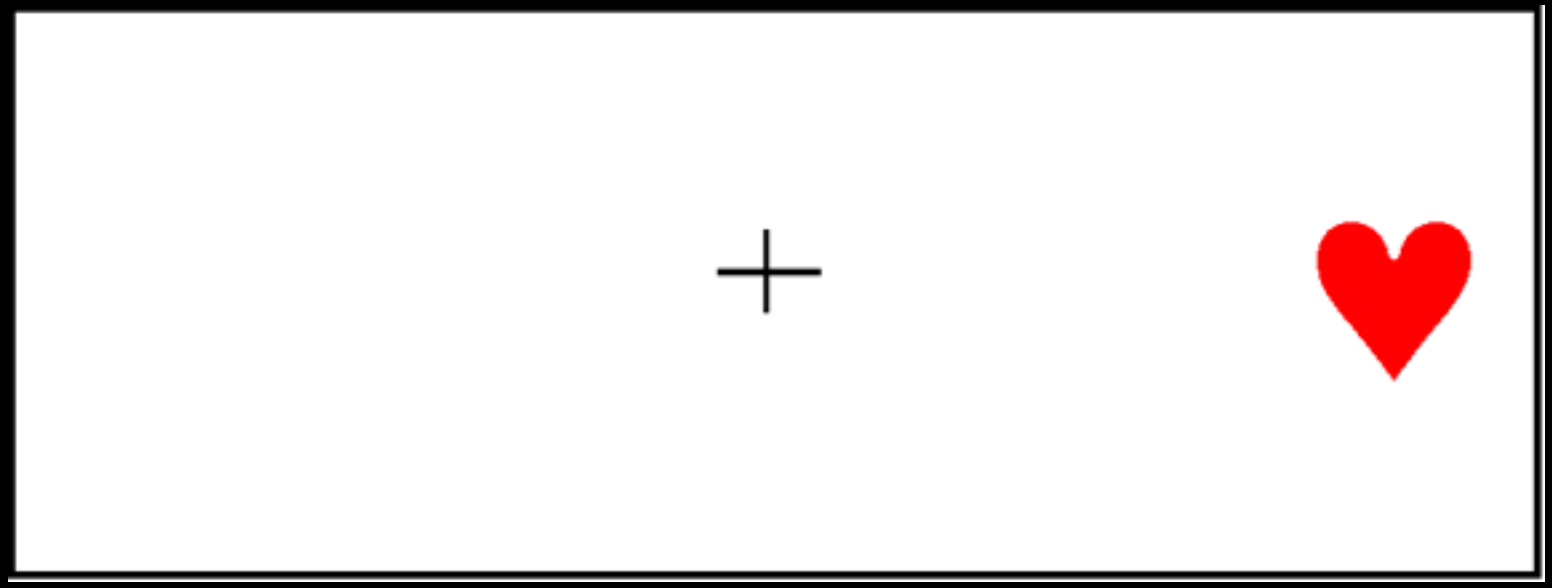
For FLOWERS, press on the OPPOSITE side.

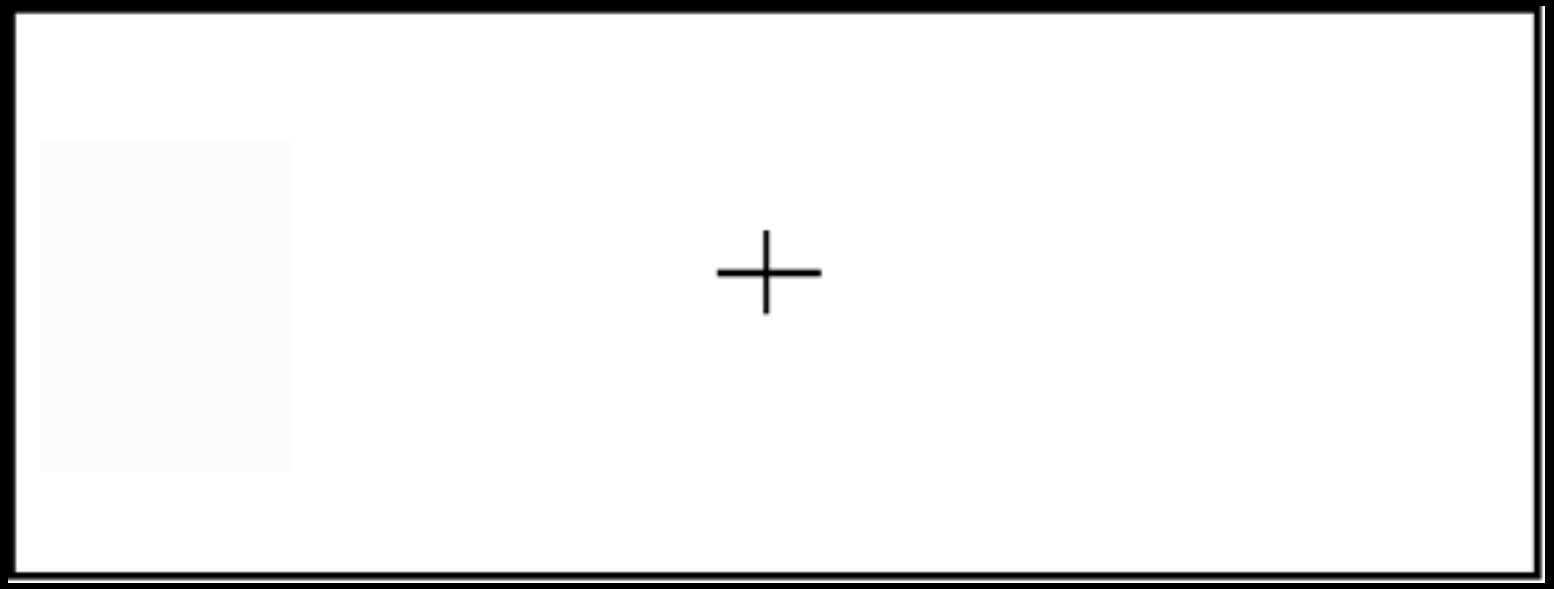
HEARTS – SAME SIDE

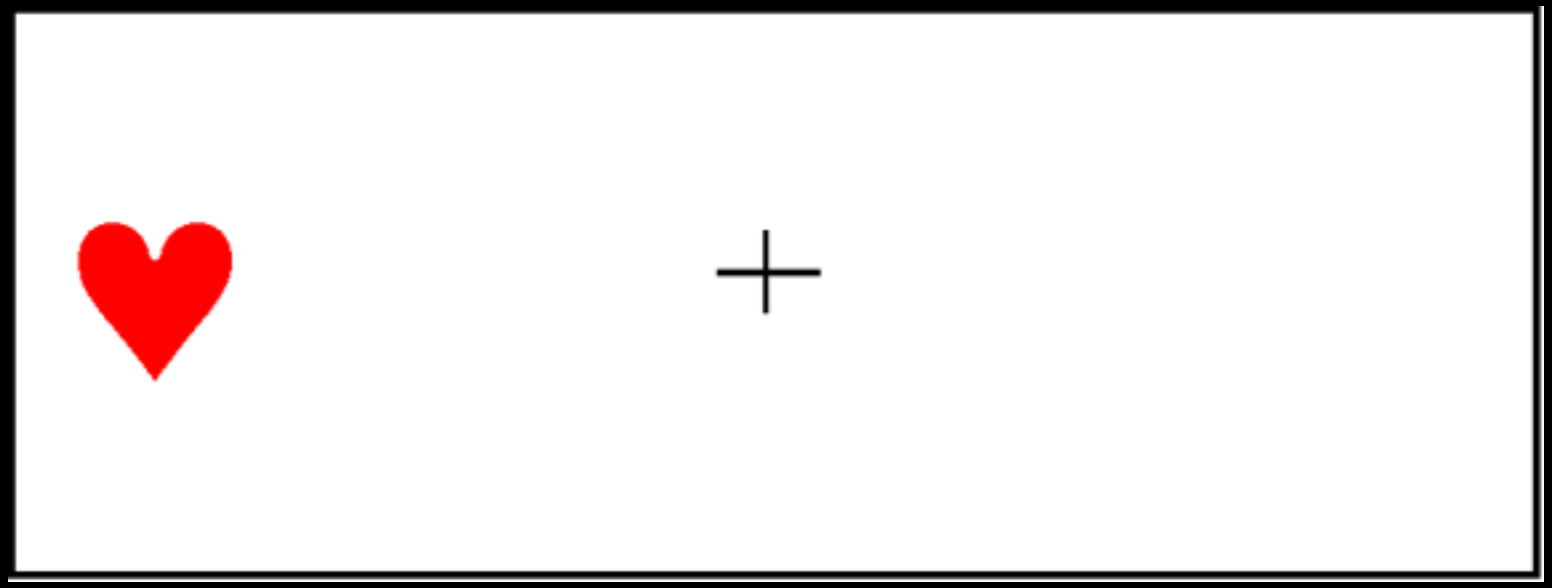
FLOWERS – OPPOSITE SIDE

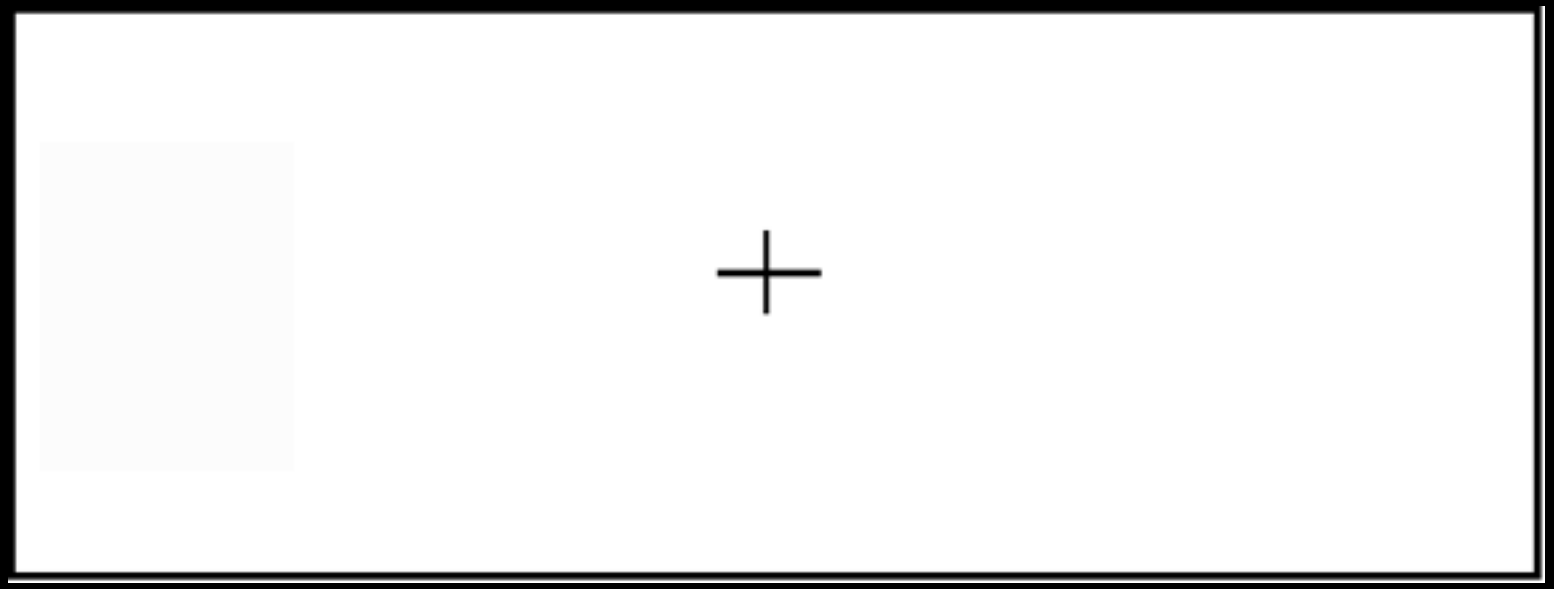


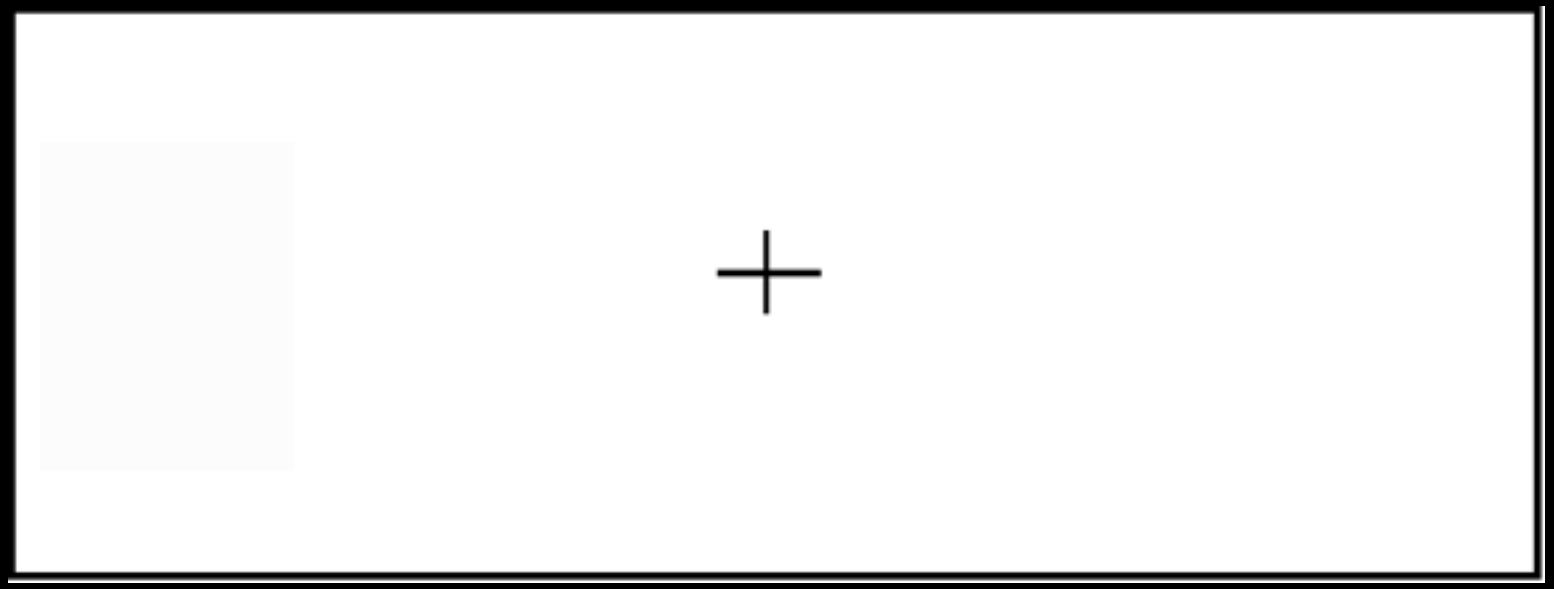


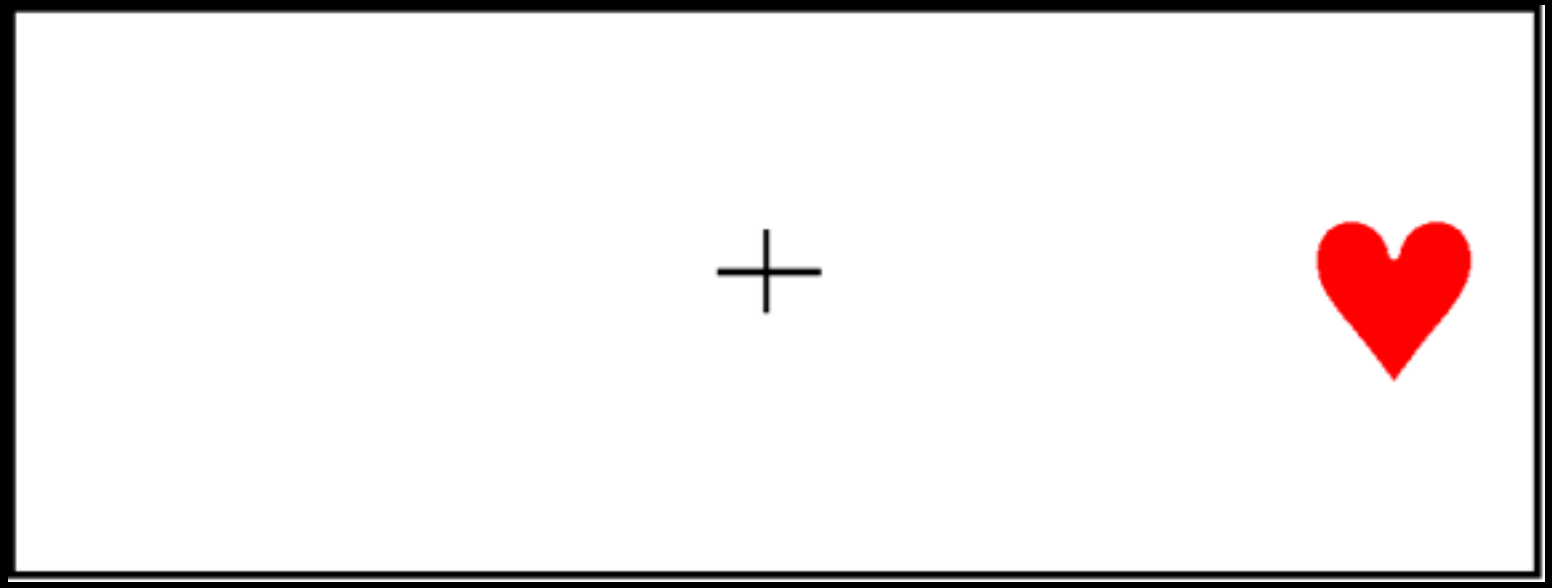












It is *not* that children forget the rules.

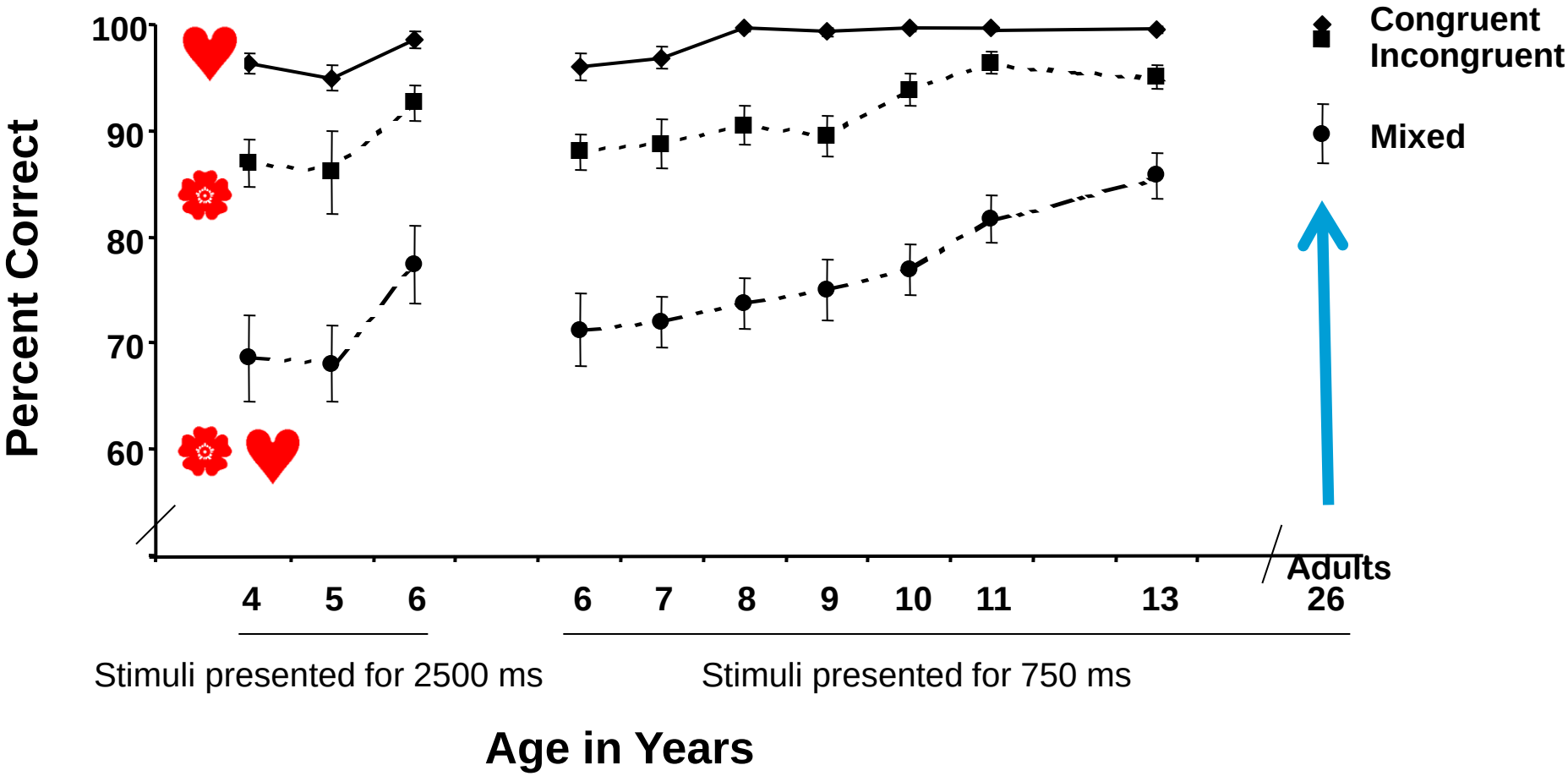
Indeed, children often call out the correct higher-order rule on trials in the mixed condition (e.g., “same,” “opposite,” “opposite,” “same”) even as they are making errors.

The problem seems to be in quickly translating the rule into the correct response.

It is not enough to know the right thing to do, you need to get yourself to behave accordingly.

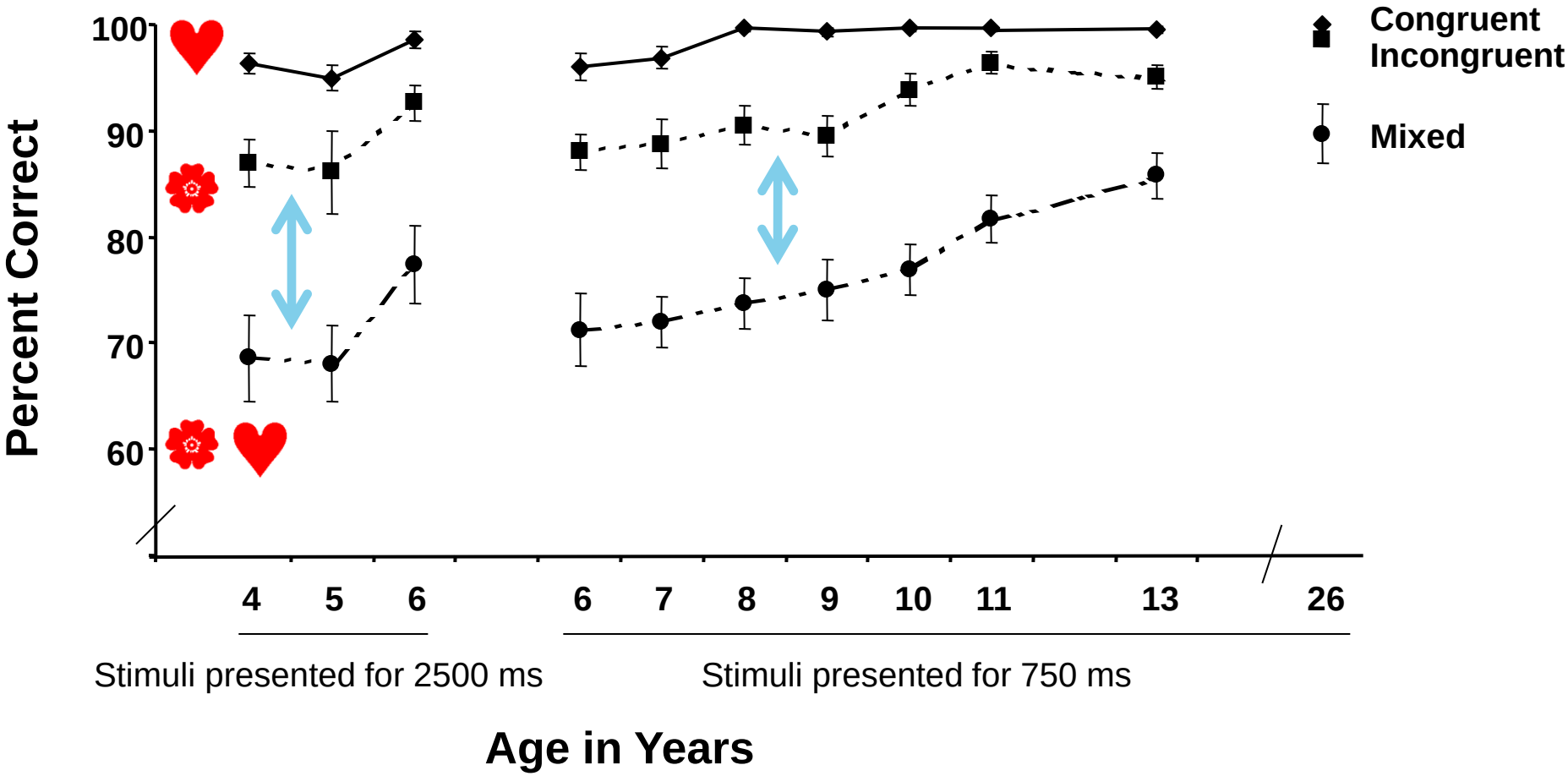
Sometimes children know the right answer but cannot demonstrate that in their behavior.

Hearts and Flowers Task: Accuracy



Davidson et al. (2006). Neuropsychologia, 44, 2037 - 2078

Dots Conditions: Accuracy



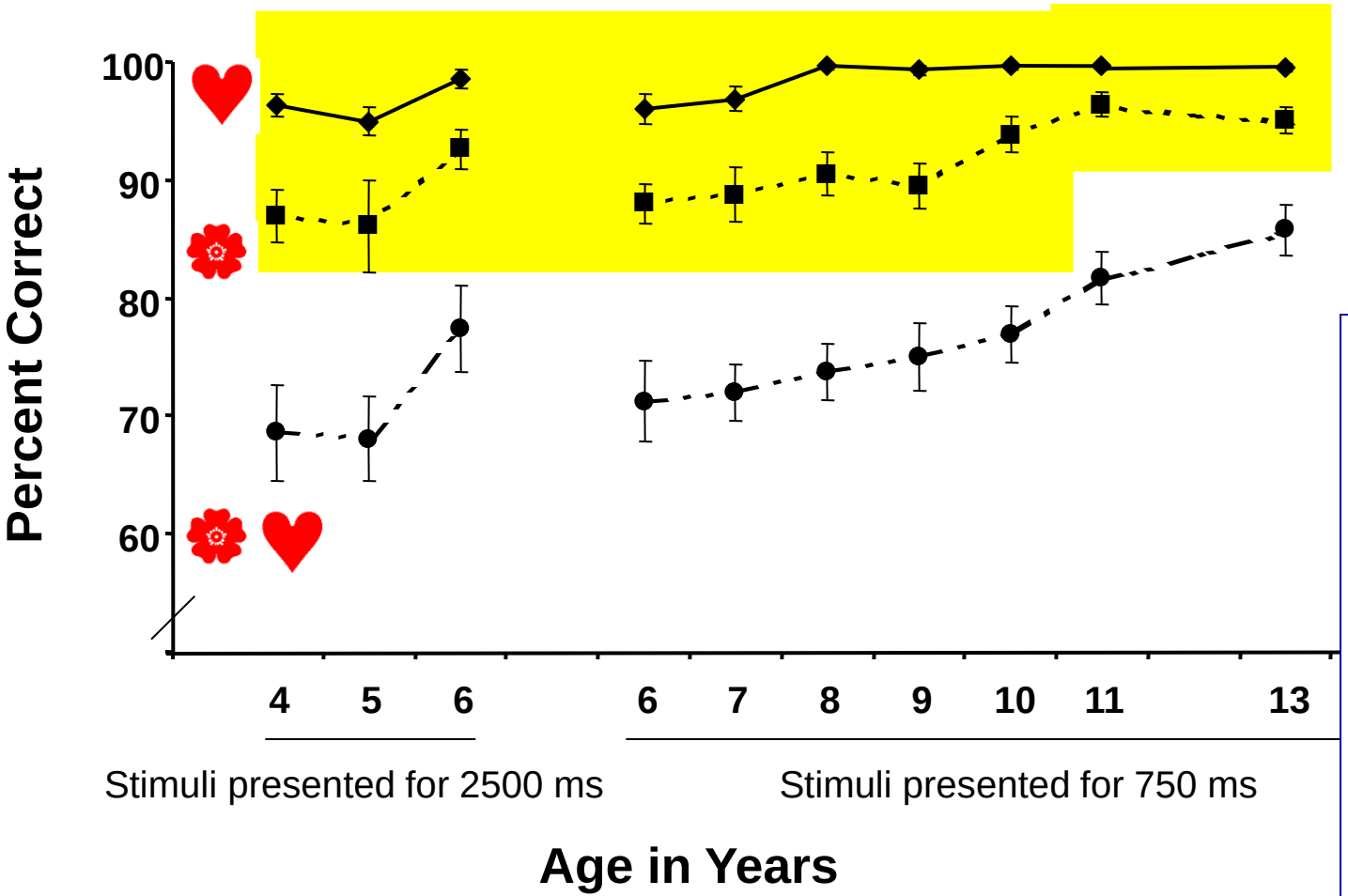
Davidson et al. (2006). Neuropsychologia, 44, 2037 - 2078

The Mixed Block is much harder for everyone -- adults and children of all ages are slower and less accurate on the mixed block.

It's not that hard to keep doing what you have been doing, even if that is counterintuitive or counter to your initial inclination.

What's hard is to flip back and forth between doing one thing and another.

Hearts and Flowers Task: Accuracy

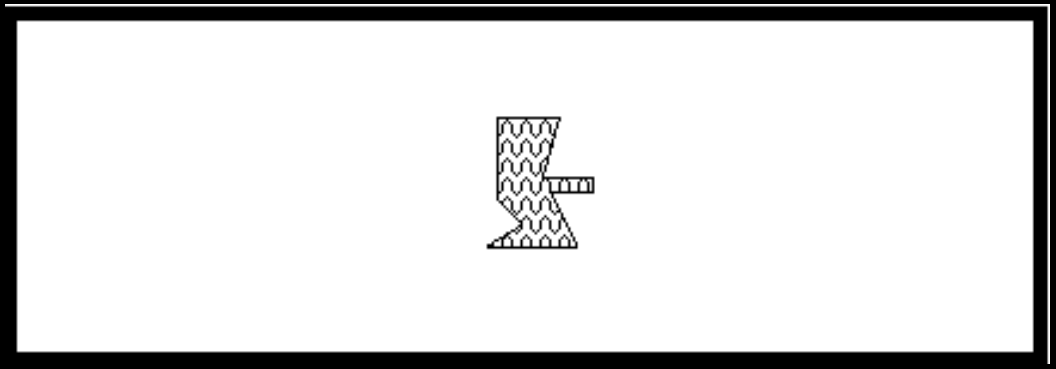


At every age studied, children were slower & less accurate on the Flower block than on the Heart block.

That effect is *completely* absent in adults.

Even very young children have excellent memories, however. Inhibition is a far greater challenge for them than holding information in mind.

Abstract Figures - Center Presentation



Push Left

Push Right

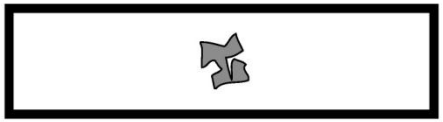
ABSTRACT SHAPES TEST:
A MEMORY LOAD TASK

Press Left

Press Right

Press Right

Press Right



Press Left

Press Left

Increasing demands on INHIBITION (the Flower block vs. the Heart block) is more difficult for children (ages 4-9 years) than increasing demands on how much information they must hold in mind (2 to 6 items).

The opposite is true for us adults:

Increasing MEMORY demands is far more difficult for us than increasing demands on inhibition.

The costs associated with increasing MEMORY demands are greater for adults,

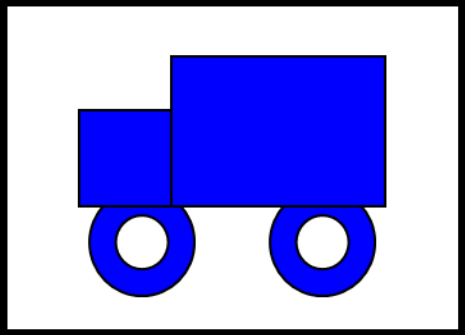
the costs associated with increasing INHIBITORY demands are greater for young children.

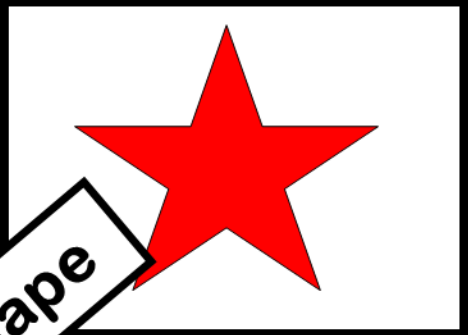
We adults may not appreciate how inordinately difficult inhibition is for young children because it is so much less taxing for us.

Cognitive Flexibility appears years later than working memory or inhibition.

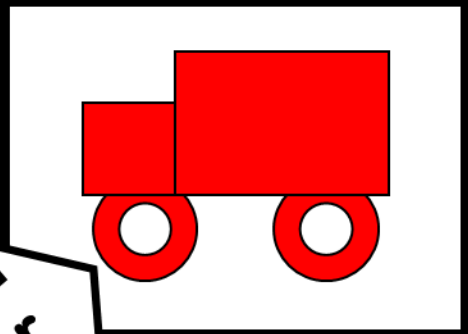
Dimensional Change Card Sort

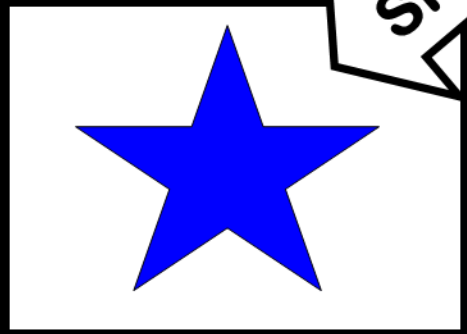
(Zelazo, Frye, & Rapus, 1996)





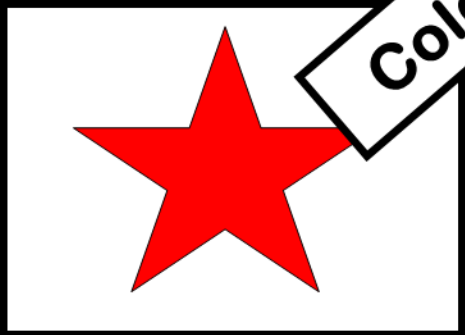
Target Cards

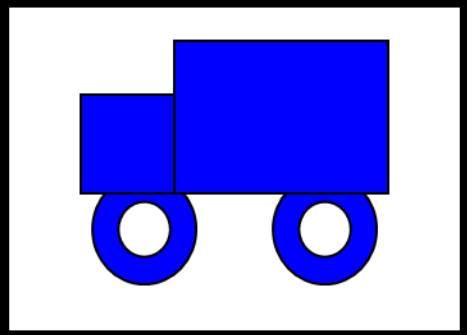




Shape

Color

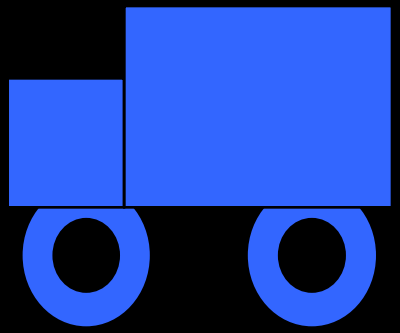




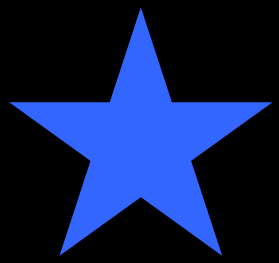
Holding two rules in mind, and inhibiting the tendency to continue sorting by the first dimension

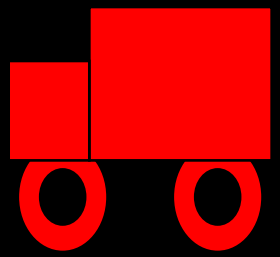
When sorting by COLOR, Correct Response is the Blue Star.

Card to be sorted:



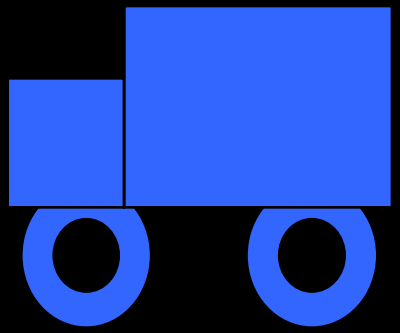
Model Cards:



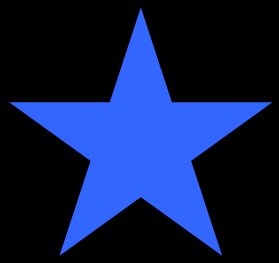


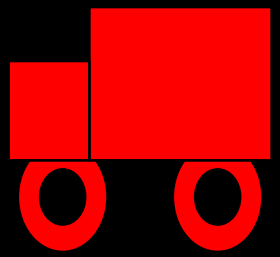
When sorting by SHAPE, Correct Response is the Red Truck.

Card to be sorted:



Model Cards:



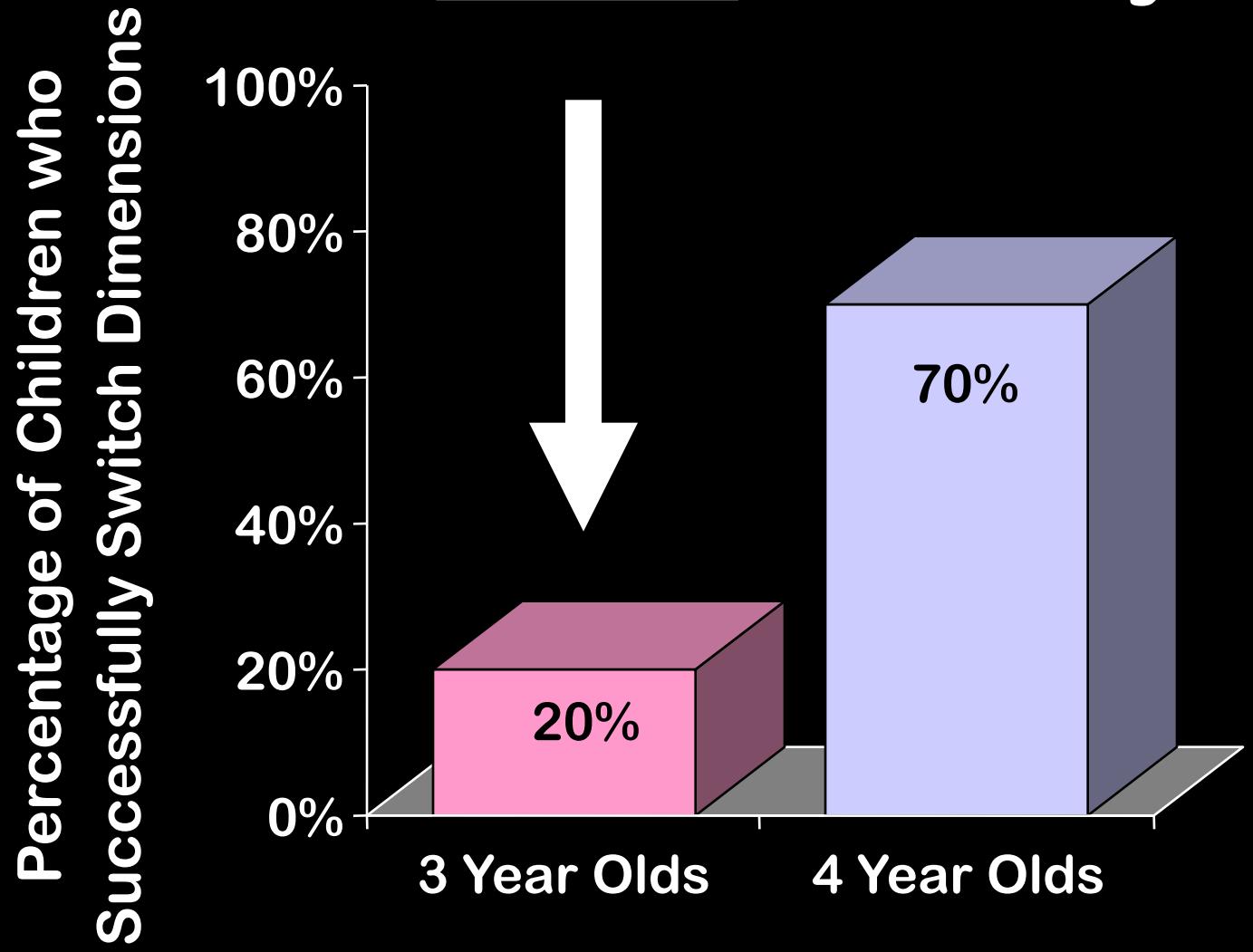


3-year-olds sort the cards perfectly

by either

color or shape

but, very few 3-yr-olds can switch how they sort



The child has clearly in mind what the new sorting criterion is and the appropriate rules for that dimension.

BEFORE the stimulus appears the child is all set to perform correctly.

Then a stimulus appears that is relevant to both tasks, in incompatible ways.

That CREATES a problem, triggering the mindset the child is trying to inhibit.

The core problem for 3-year-olds in switching appears to be:

Attentional Inertia

Once they have focused their attention on a dimension, their attention gets STUCK there. They need to disengage from, or inhibit, their previous way of thinking about the stimuli.

Helping Children Apply their Knowledge to their Behavior on a Dimension-Switching Task

Natasha Kirkham, Loren Cruess & Adele Diamond

Developmental Science
2003
vol 6, pages 449-467

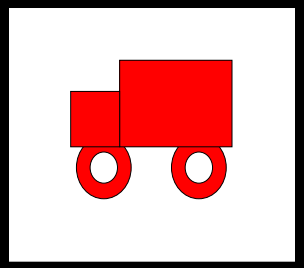
It is not enough to know something or remember it;

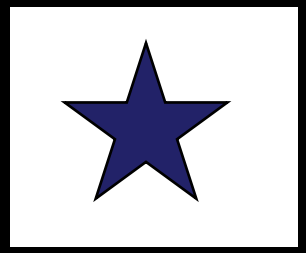
you must get that knowledge into your behavior.

Development proceeds by BOTH the acquisition of knowledge and skills and by the increasing ability to inhibit inappropriate reactions that get in the way of demonstrating what is already known.

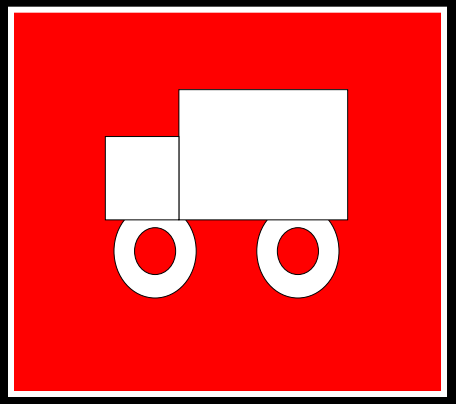
A child may know what he or she should do, and want to do that, but still not be able to act accordingly.

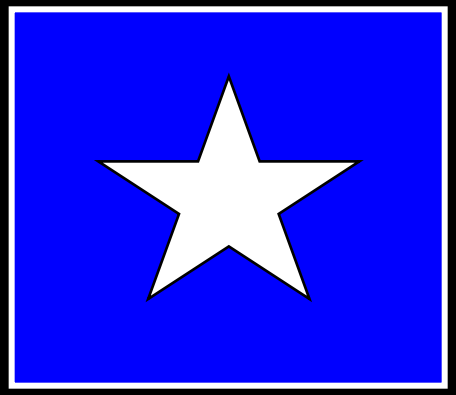
Each dimension is an intrinsic part of the stimulus object.

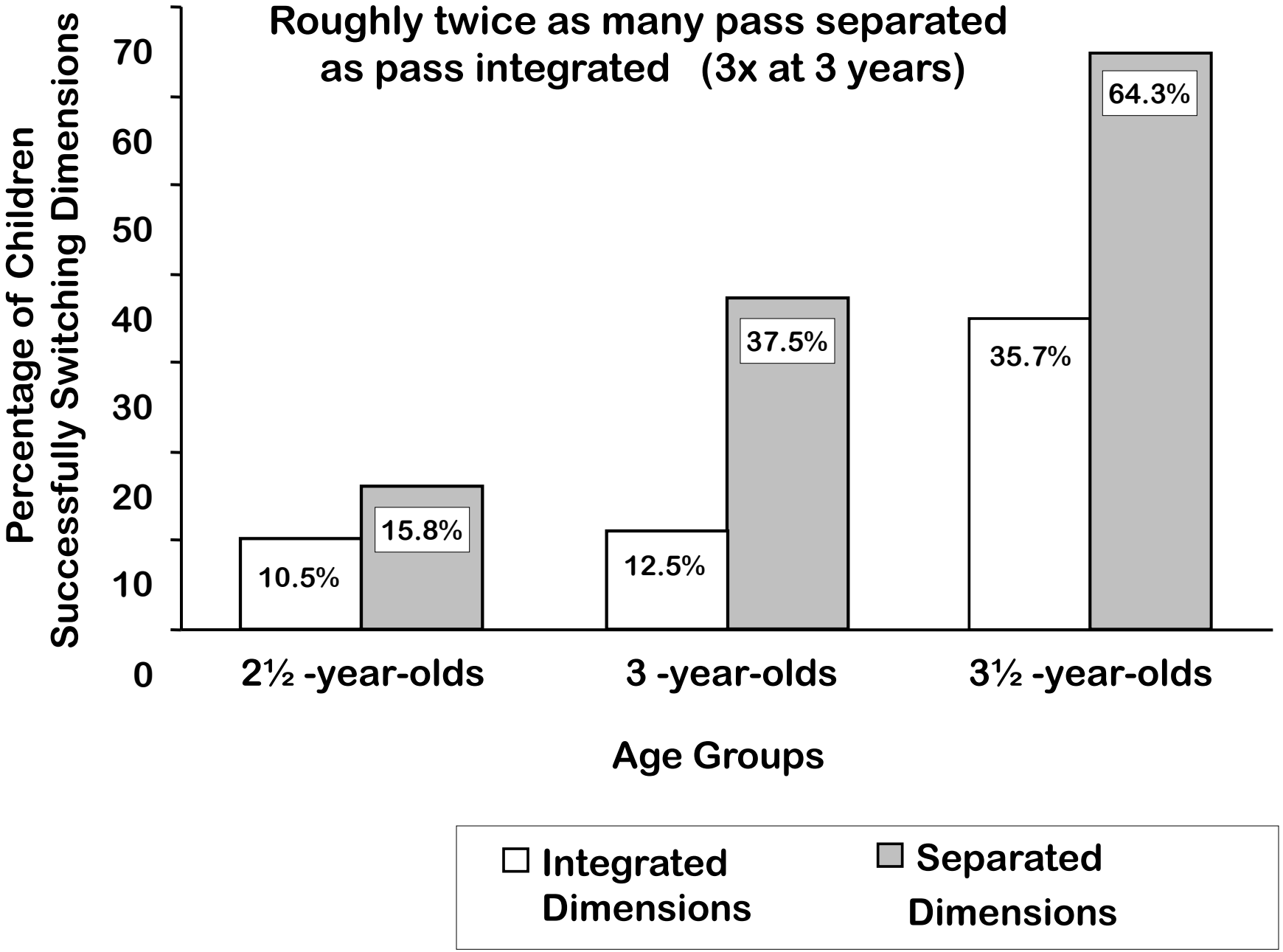


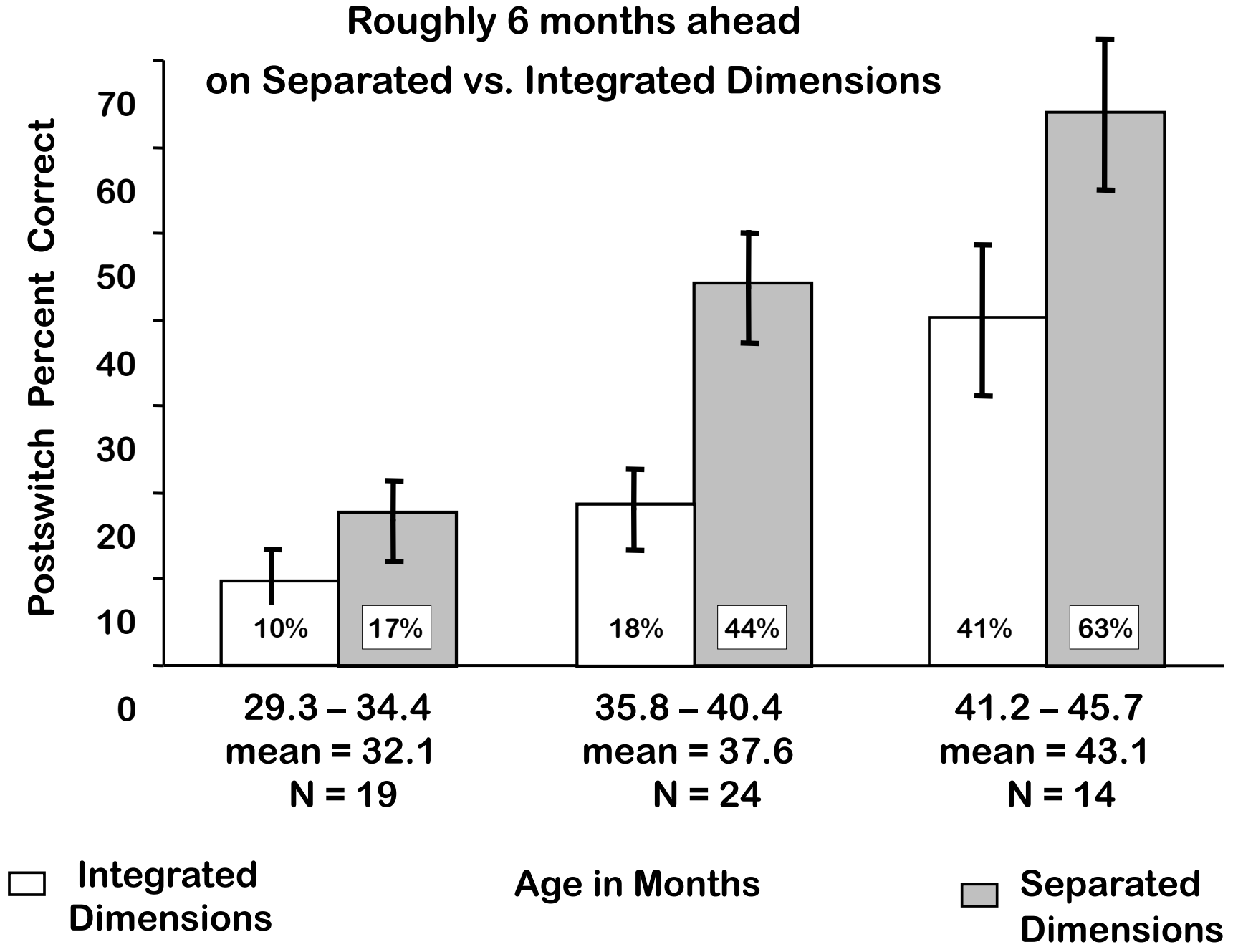


What if both dimensions are not properties of the stimulus?






Roughly twice as many pass separated as pass integrated (3x at 3 years)
Percentage of Children Successfully Switching Dimensions
70
60
50
40
30
20
10
0
10.5%
15.8%
12.5%
37.5%
35.7%
64.3%
2½ -year-olds
3 -year-olds
3½ -year-olds
Age Groups
Integrated Dimensions
Separated Dimensions


Roughly 6 months ahead
on Separated vs. Integrated Dimensions
Postswitch Percent Correct
70
60
50
40
30
20
10
0
10%
17%
18%
44%
41%
63%
29.3 – 34.4
mean = 32.1
N = 19
35.8 – 40.4
mean = 37.6
N = 24
41.2 – 45.7
mean = 43.1
N = 14
Integrated Dimensions
Age in Months
Separated Dimensions

Children's performance on dimensional change card sort task:

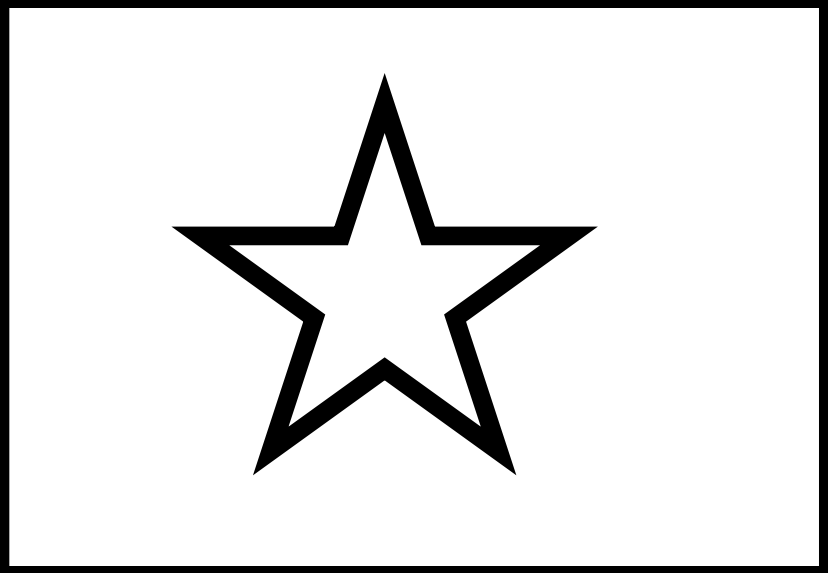
Separation aids ability to switch dimensions

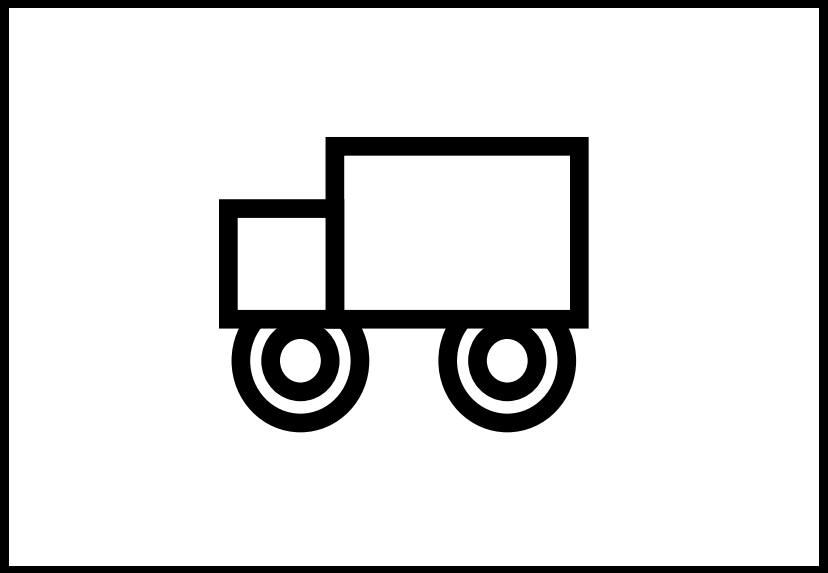
Adele Diamond,
Stephanie Carlson, & Danielle Beck

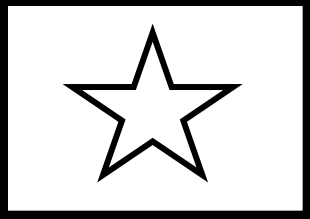
(2005)

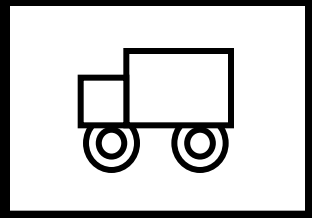
Developmental Neuropsychology

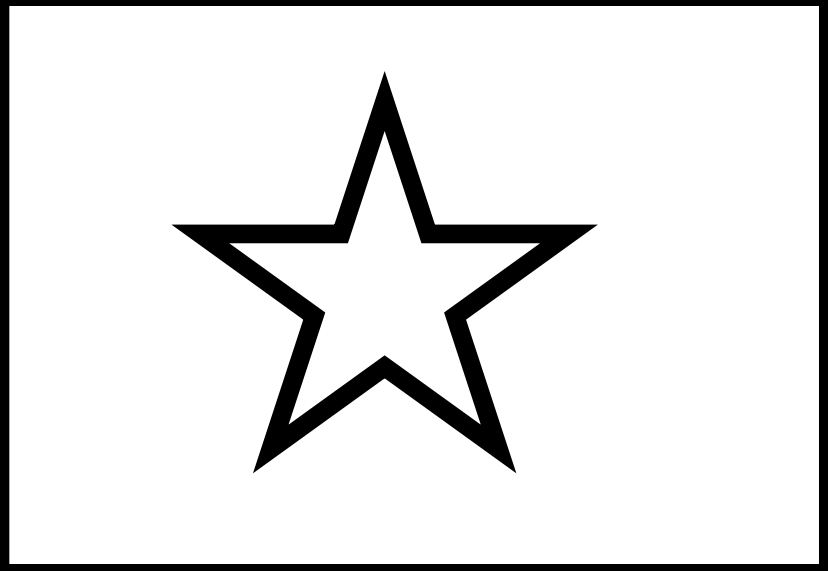
vol 28, p.689-729

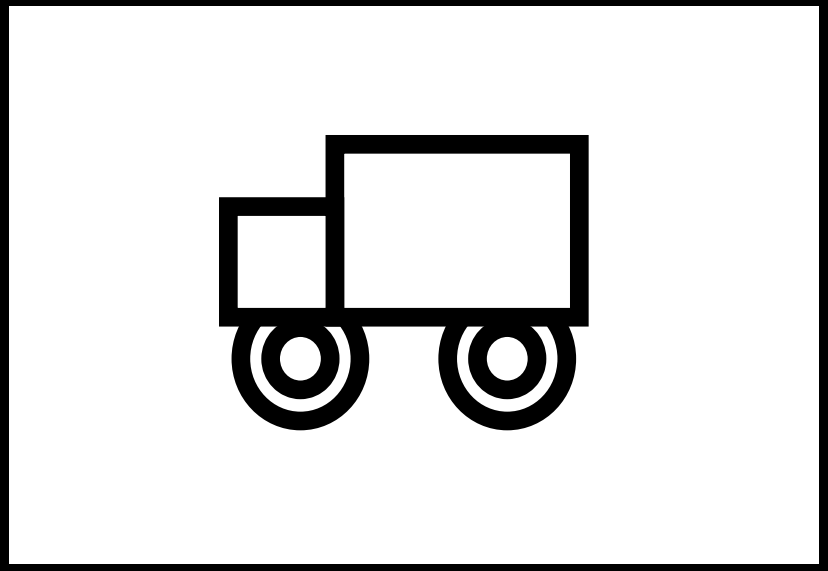


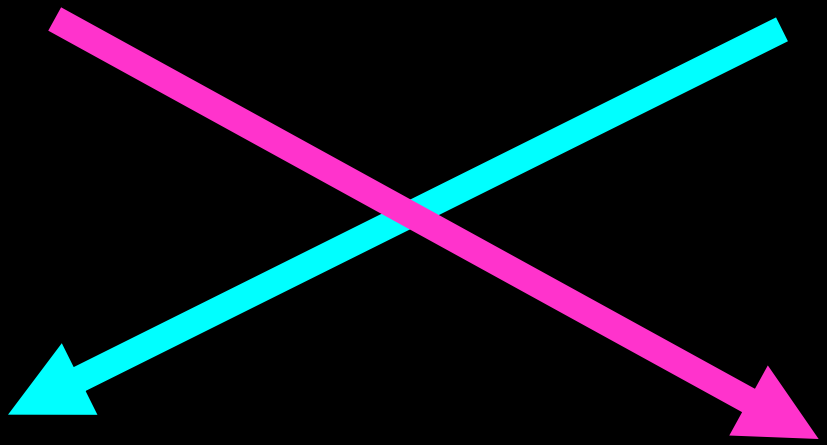


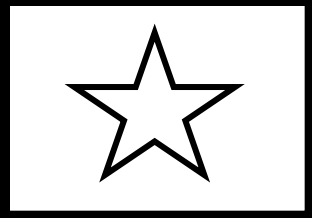


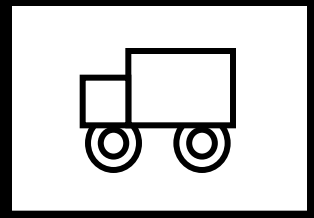












- Patricia Brooks, Julie B. Hanauer, Barbara Padowska, & Heidy Rosman
(2003)
The role of selective attention in preschoolers' rule use in a novel dimensional card sort.
Cognitive Development
vol 117, p 1-21

- Josef Perner & Birgit Lang
(2002)
What causes 3-year olds' difficulty on the dimensional change card sorting task?
Infant & Child Development
vol 11, p. 93-105

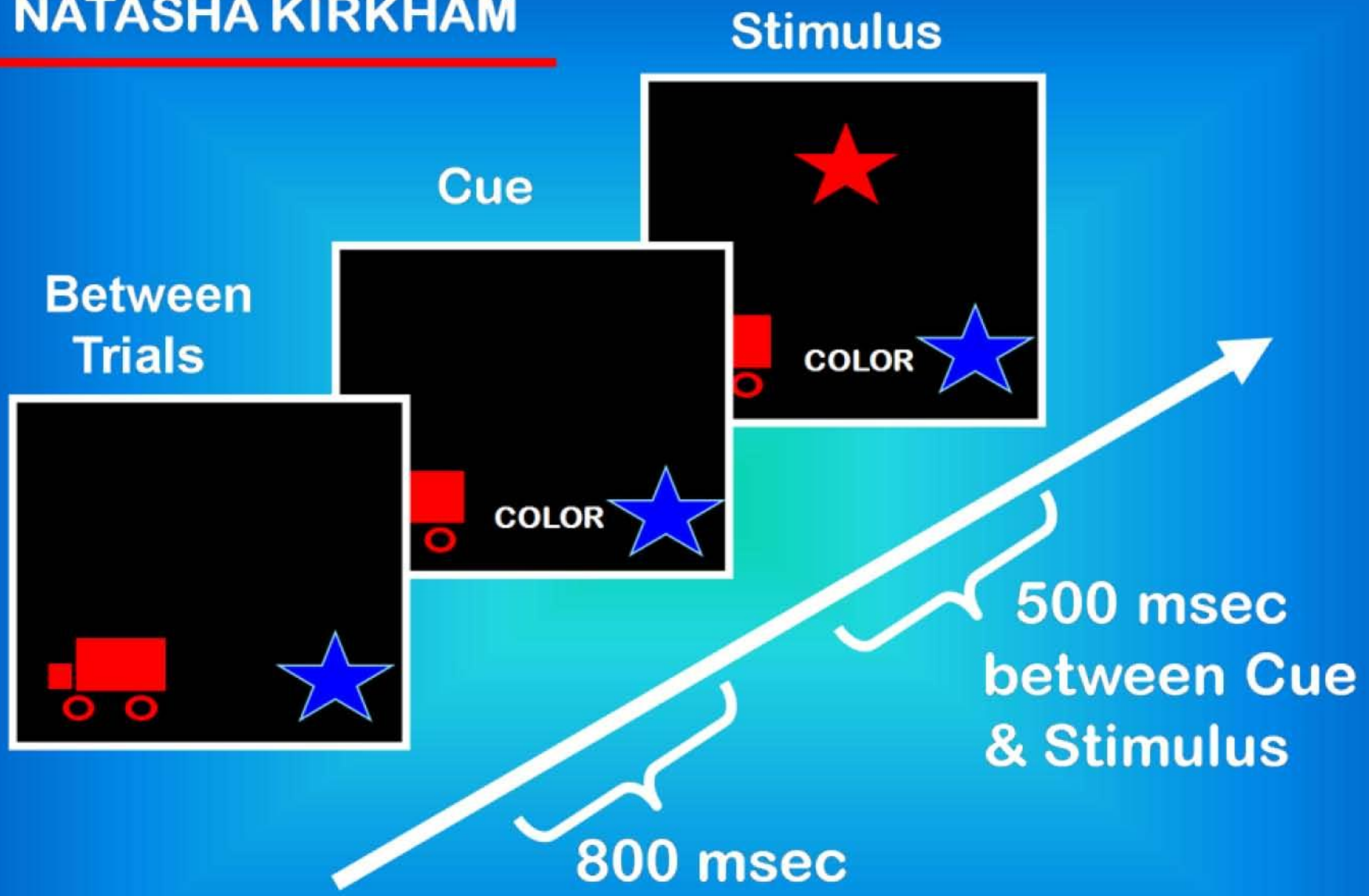
Developmental Progression

Succeed at….	at Age
Reversals (intra-dimensional shift)	2½
- extra-dimensional switches (1 dimen. to another) -	
DCCS - Separated Dimensions	3½
DCCS (Standard) - Integ. Dimen.	4½
DCCS - Mixed Block…… (switching dimensions randomly across trials)	7½

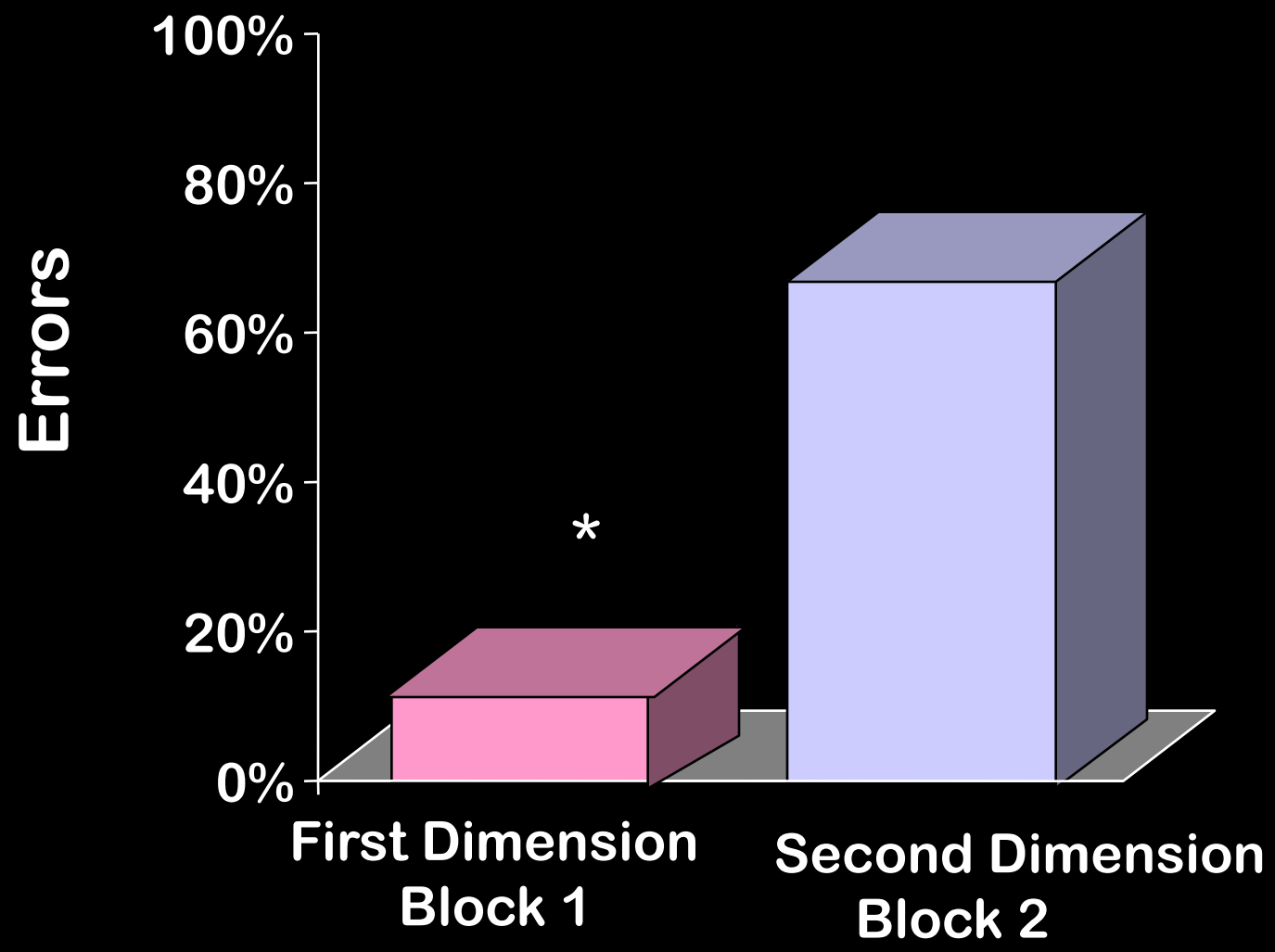
On the one hand, adults may not appreciate how inordinately difficult inhibition is for young children because it is much less taxing for us.

On the other hand, adults are also *more* like young children than we adults would often like to admit.

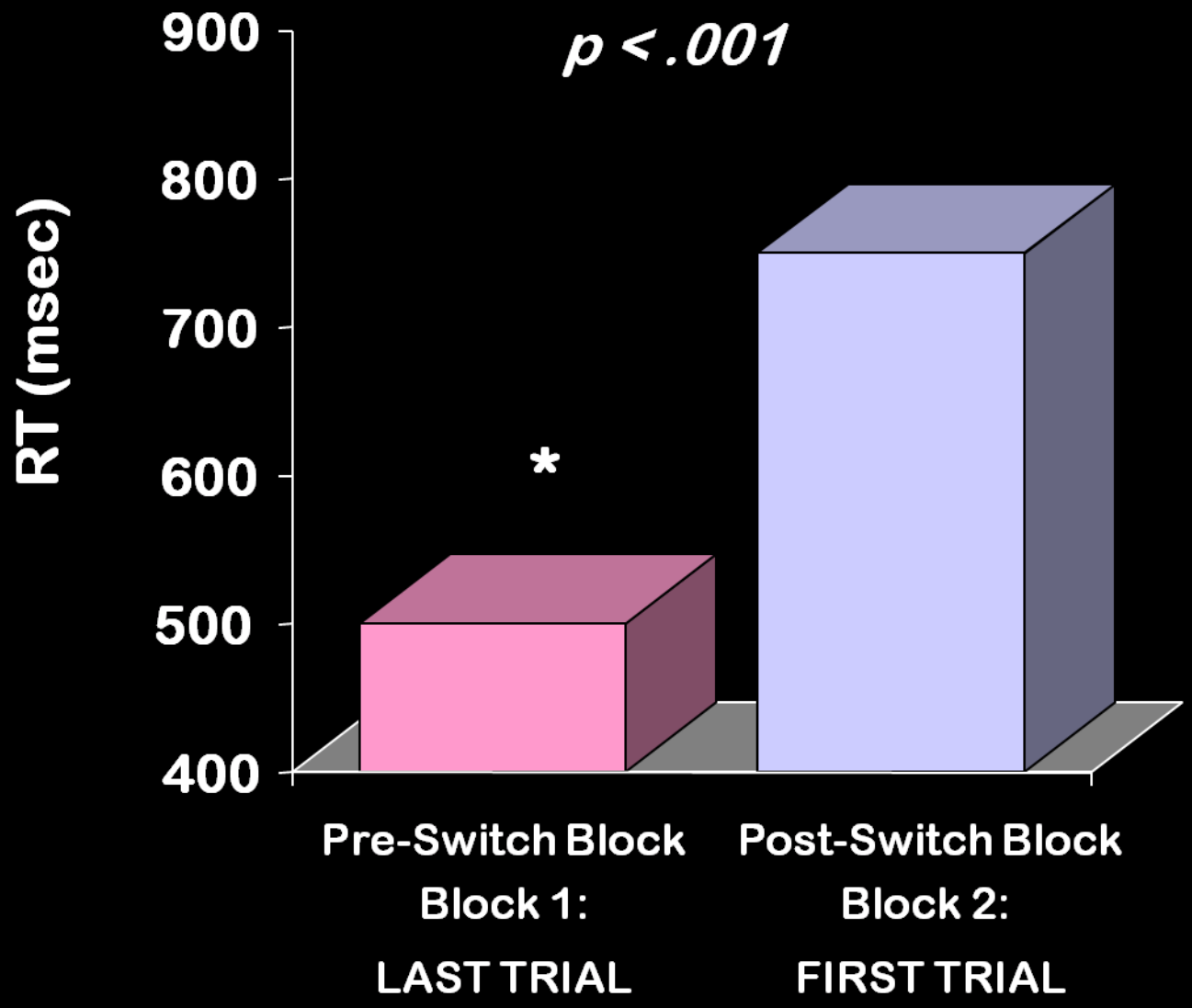
NATASHA KIRKHAM



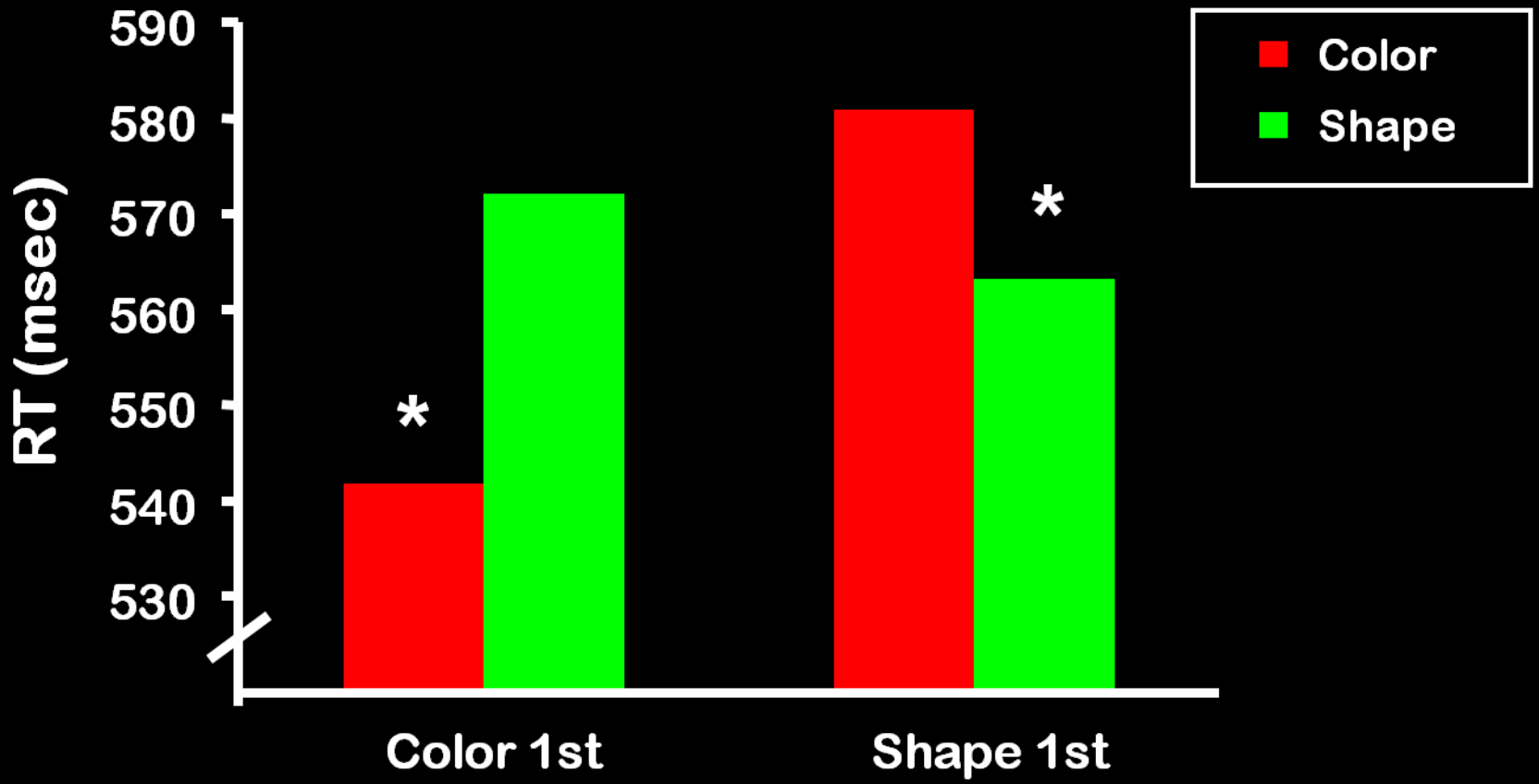
Percentage of Errors by Children of 3 Years on the First and Second Dimension



ADULTS
Last Trial in Block 1 vs. First Trial in Block 2



Effect of First Dimension Sorted on Performance throughout the Entire Session



The first dimension sorted effects performance over all blocks. E.g., If you started with Color, you are Faster on Color for the rest of the session, and Slower on Shape than if you had started with Shape first.

Adults show the same cognitive biases that characterize infants and young children.

Though, in adults, these biases are more subtle and held more in check. We are able to inhibit them.

Adele Diamond & Natasha Kirkham

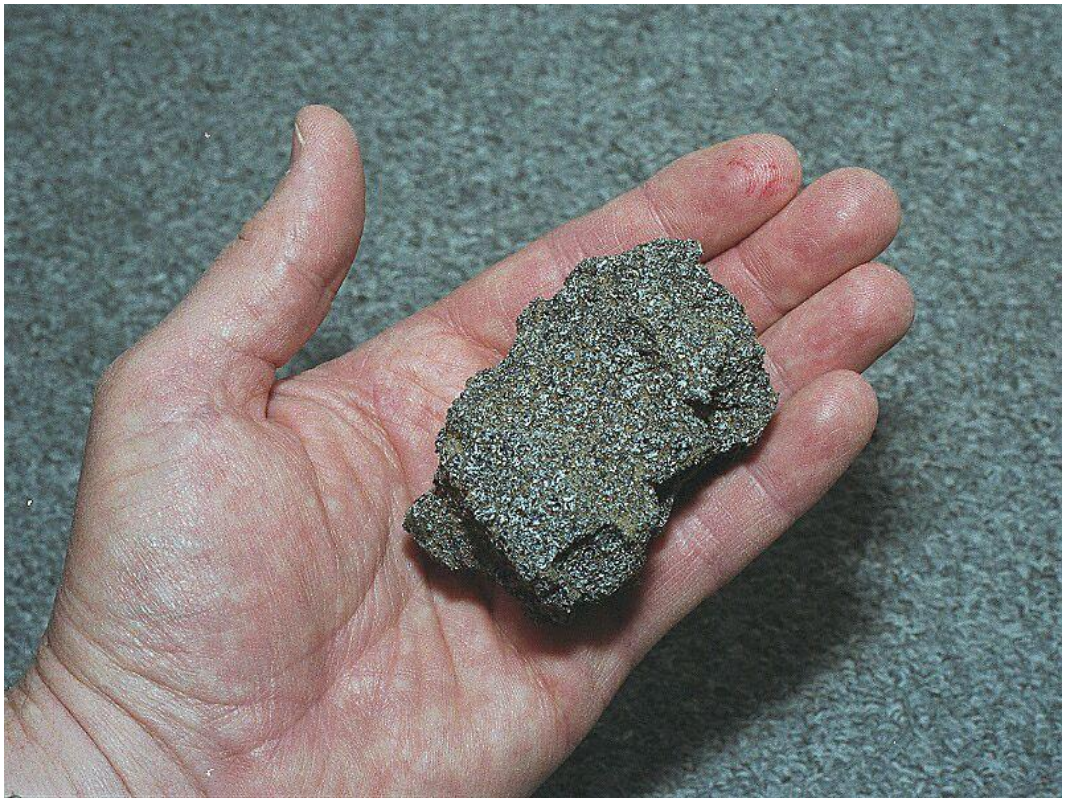
(2005)

Not quite as grown-up as we like to think: Parallels between cognition in childhood and adulthood.

Psychological Science
vol 16, 291-297

Appearance-Reality Tasks

ROCK



SPONGE

Children have to hold in mind two superficially contradictory things:

-- what an object looks like, and

-- what the object really is

PLUS

-- inhibit the perceptual pull to say that the object is what it looks like it is

Adults pass those tasks, but a discomfort with ambiguity and difficulty in seeing both sides of an issue, or two perspectives on the same thing, remains.

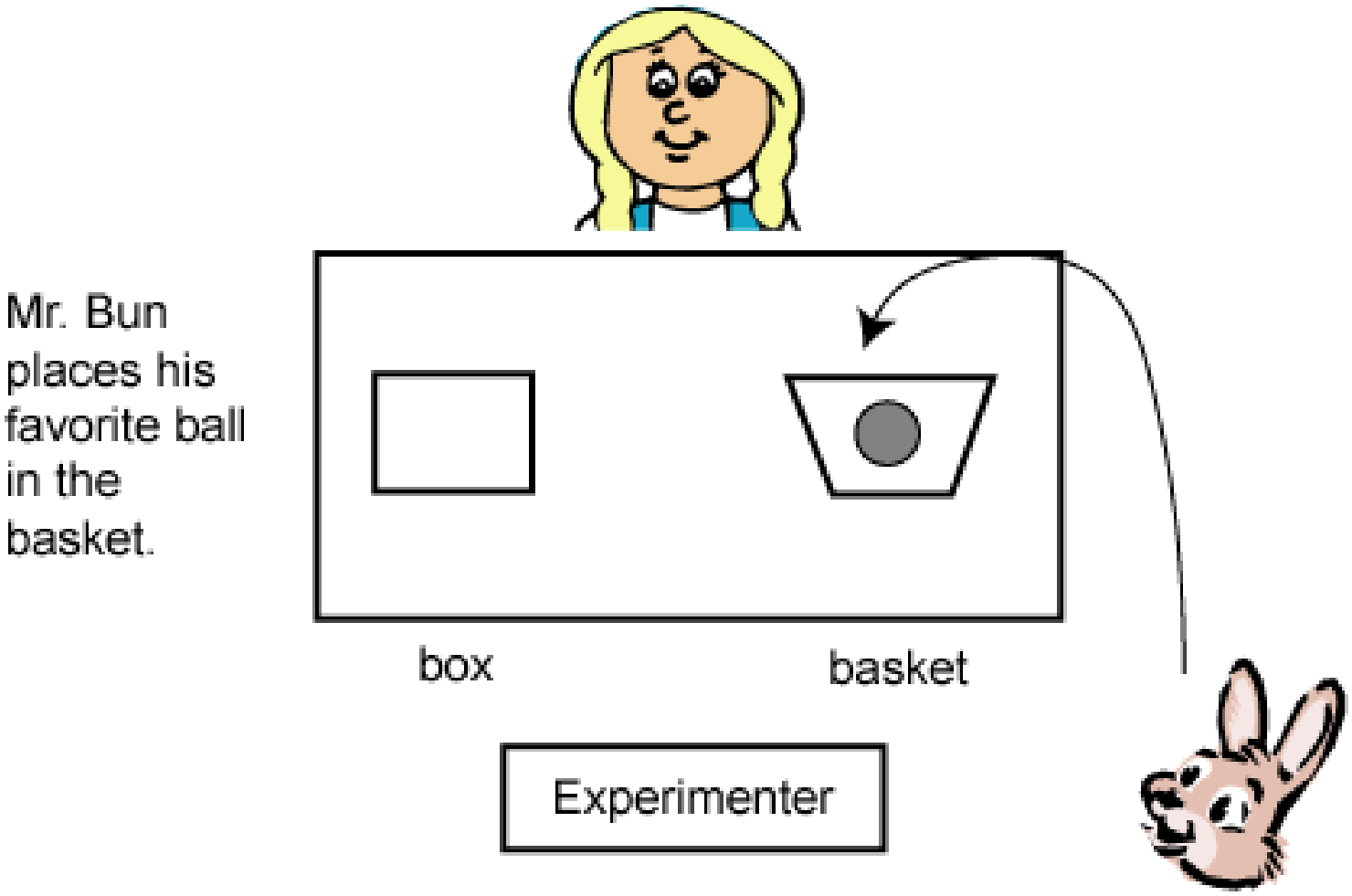
Even adults have difficulty accepting that good people (or good nations) sometimes act wrongly or that people who disagree with us might be right about something.

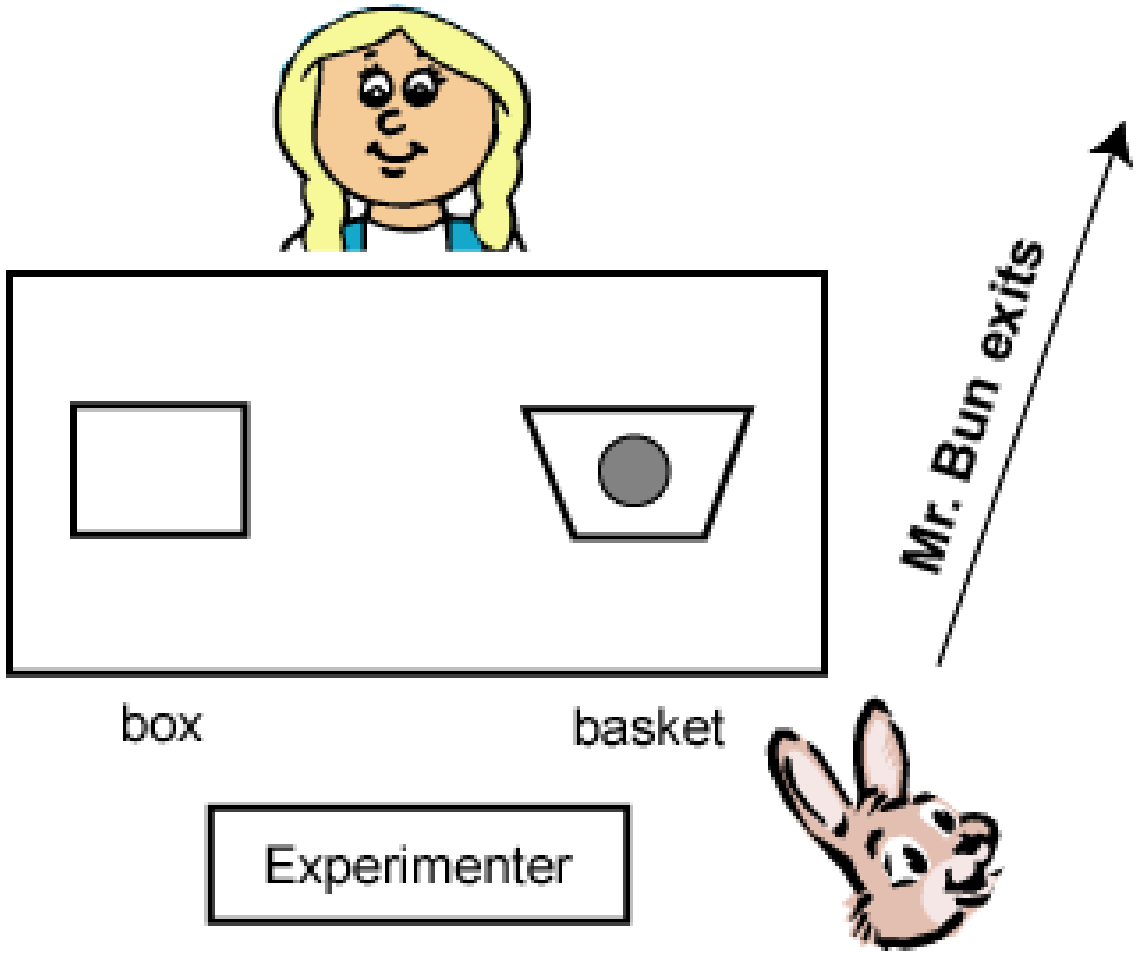
“False Belief” Tasks

require holding in mind a true and a false belief (the false belief being what you had previously thought)

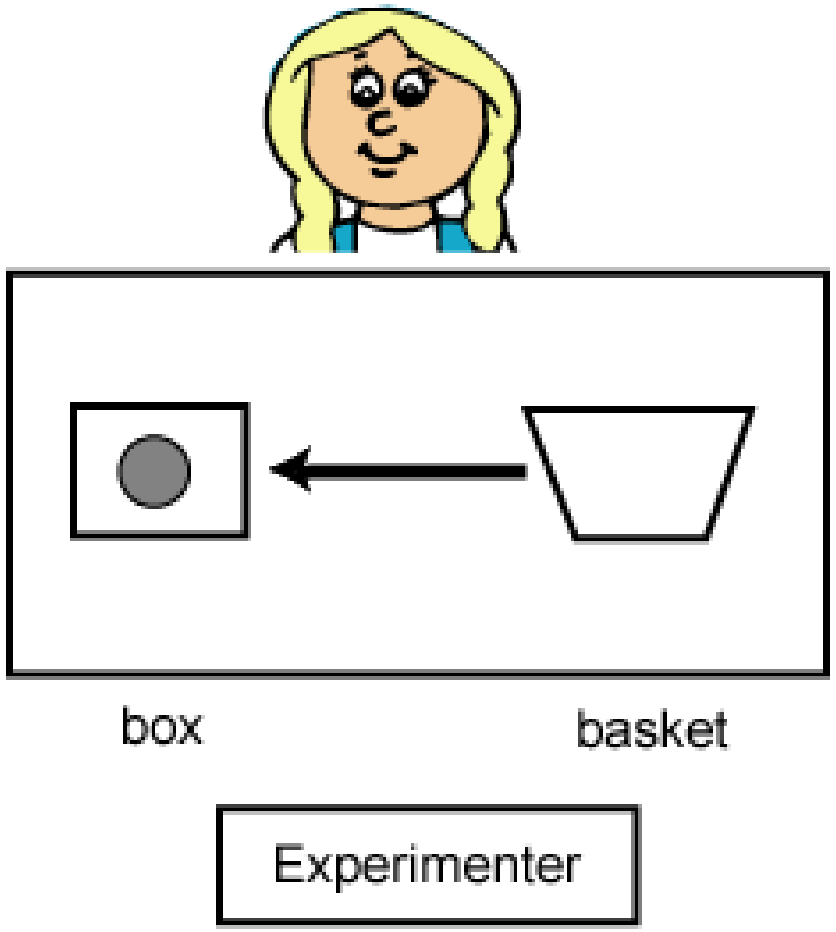
and inhibiting the impulse to want to appear as smart as possible

Illustration of a Typical Theory of Mind Task




Mr. Bun exits
box
basket
Experimenter

Experimenter and child transfer Mr. Bun's ball to the box.



Was Mr. Bun in the room when we moved his ball?

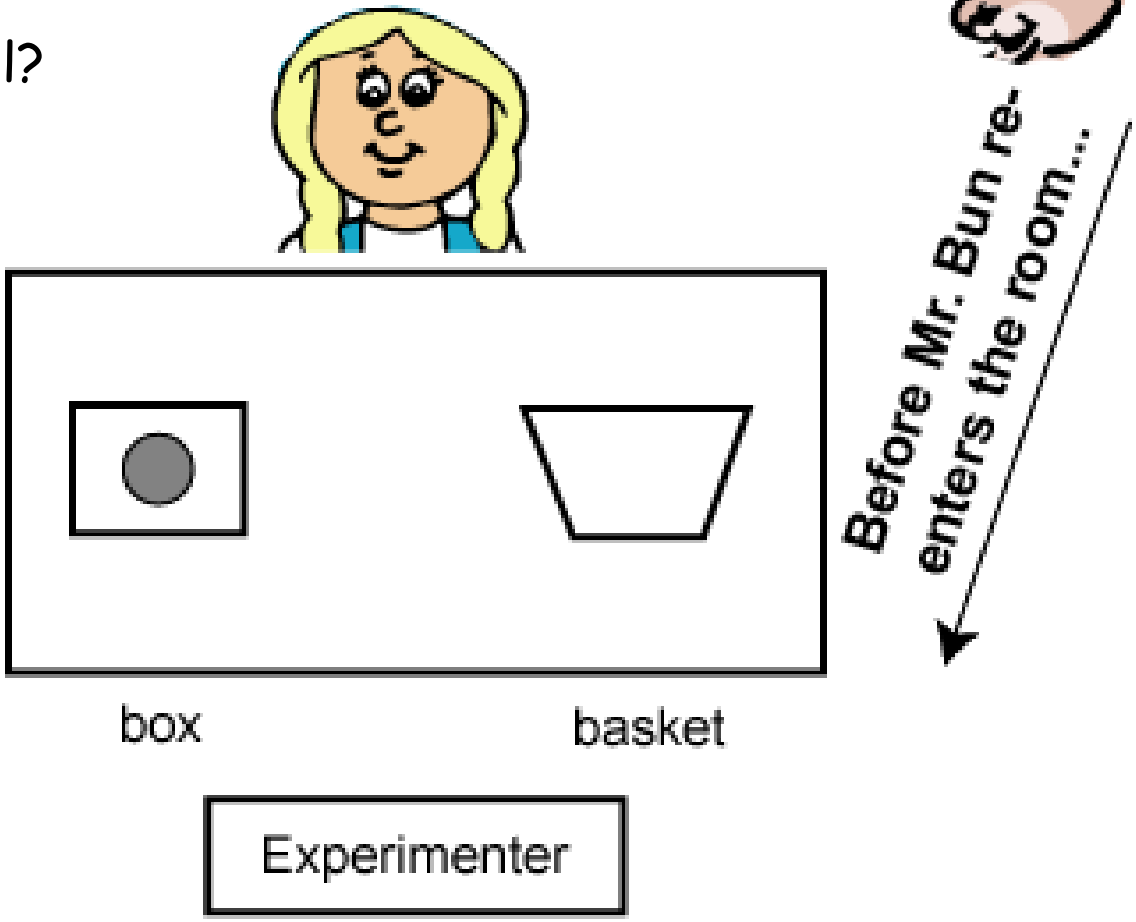
No.

Did he see us move his ball?

No.

Does he know that we moved his ball?

Yes.



Where will Mr. Bun look for his ball?

3-year-olds point to the CORRECT location, NOT the place where Mr. Bun last saw his ball placed.

Adults, too, show a tendency to attribute what we know to someone less knowledgeable.

We have difficulty inhibiting / ignoring what we know when making assessments about what someone who does not know that would do.

Epley, N., Keysar, B., Van Boven, L., & Gilovich, T. (2004). Perspective taking as egocentric anchoring and adjustment. *Journal of Personality and Social Psychology, 87*, 327-339.

Keysar, B., Lin, S., & Barr, D. J. (2003). Limits on theory of mind use in adults. *Cognition, 89*, 25-41.

The Curse of Knowledge in Reasoning About False Beliefs

Susan Birch and Paul Bloom

Psychological Science

2007

The Curse of Expertise: The effects of expertise and de-biasing methods on prediction of novice performance.

Hinds, P. J.

(1999)
Journal of Experimental Psychology: Applied, 5, 205-221

Other "False Belief" Tasks

(which are *not* Theory of Mind tasks)

also require holding in mind a true and a false belief (the false belief being what you had previously thought)

and inhibiting the impulse to want to appear as smart as possible

What do you think is in this box?

But crayons are what's really in the box.

What had you thought was in this box before I showed you?

3-year-olds answer:

CRAYONS

Adults don't claim that they earlier said that crayons would be in the Skittles box, but in analogous situations they claim that they earlier rated similarly unlikely outcomes as more probable than they actually had.

“knew it all along”

Fischhoff, B., & Beyth, R. (1975)

“I knew it would happen": Remembered probabilities of once-future things.

Organizational Behavior & Human Decision Processe

13, 1-16.

Hindsight bias:
A by-product of knowledge updating?

Hoffrage, U, Hertwig, R, & Gigerenzer, G.

(2000)

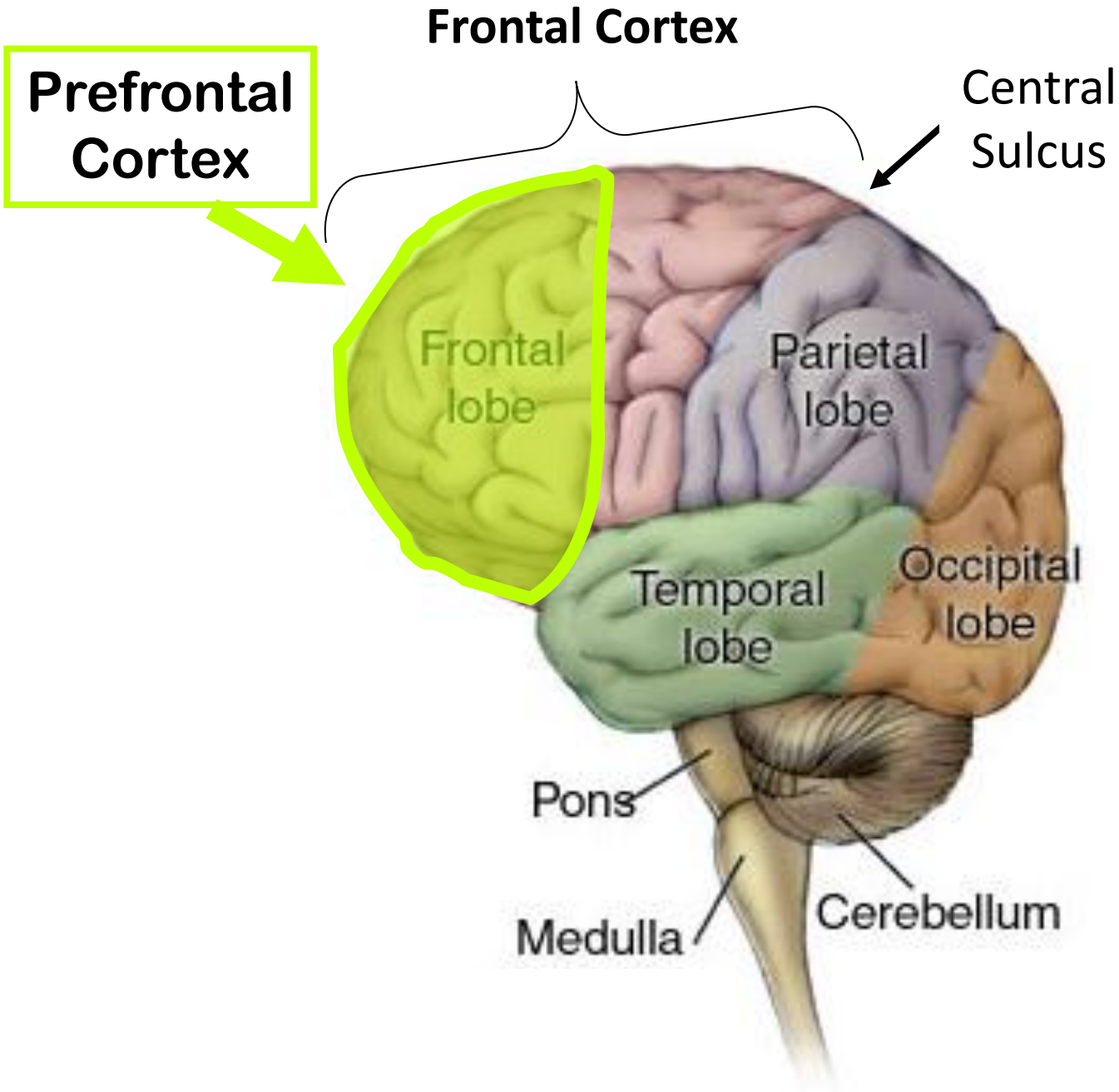
Journal of Experimental Psychology: Learning, Memory, & Cognition
26, 566-581

"Brain-based" does NOT mean fixed or unchangeable.

Experience and activity change the brain.

EFs depend on the brain --
but they can be improved
by the proper activities

"Executive Functions" depend on Prefrontal Cortex and the other neural regions with which PFC is interconnected.

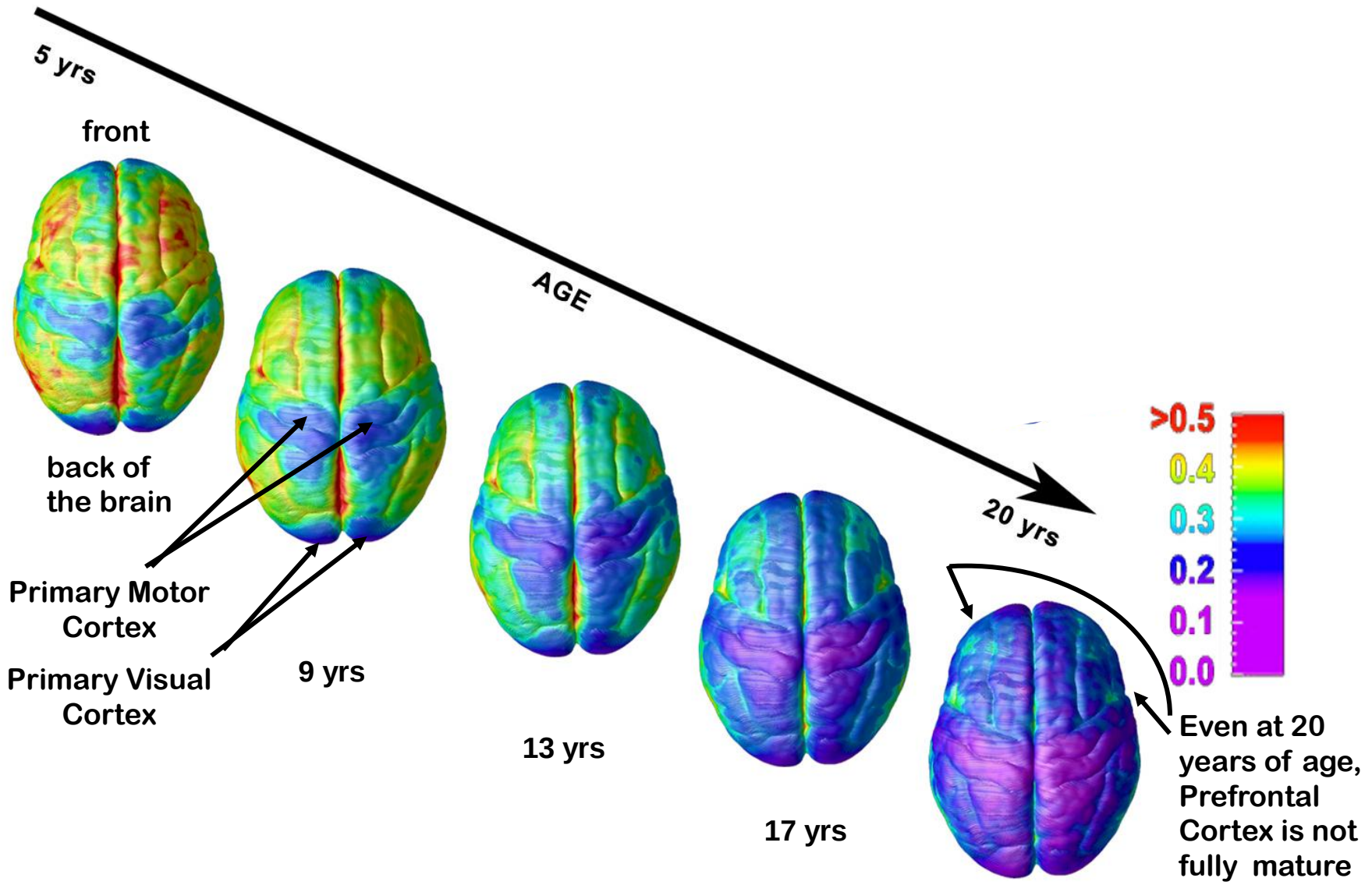

Frontal Cortex
Prefrontal Cortex
Central Sulcus
Frontal lobe
Parietal lobe
Temporal lobe
Occipital lobe
Pons
Medulla
Cerebellum

EF skills can be improved
even in very young children

without computers or highly
technical equipment

by properly trained teachers

Human Brain Development



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.

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

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

Kovács AM, Mehler J. (2009)

Cognitive gains in 7-month-old bilingual infants.

Proceedings of the National Academy of Sciences.

vol 106, p. 6556-6560

Language aids EF development.

e.g., private speech – telling yourself what you should (& should not) do

The cognitive skills most vulnerable to (most affected by) SES differences are:

- Language
- EFs

Less advantaged children often start school behind on both.

EFs, especially inhibitory control, tend to develop earlier in girls than in boys.

For little boys, it can feel like torture to have to sit still to long periods, and they can feel defeated by their inability to do that.

Young children - especially boys - are not built to sit still for long periods.

Preschool expulsion rates are 3 times higher than for grades K–12, and 4.5 times as many boys as girls are being expelled.

(Walter Gilliam [2005] survey of 40 states)

Feedback Loops

Consider the negative feedback loop beginning with poor initial EFs:

Poor EFs lead to problems paying attention in class, completing assignments, and inhibiting impulsive behaviors.

School is less fun…
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.

On the other hand, children who have better EFs 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.

2 feedback loops going in opposite directions

one child wants out & does not expect to succeed

one child wants in & fully expects to succeed

Small differences at the beginning can lead to bigger and bigger differences over time.

A little boy,

- especially if he is at the young end of the age group,
- and especially if his language development is a bit delayed because of hearing problems

might benefit greatly from starting school a year later

Finland – children start at age 7 – but way outperform US children by 4th grade

Powerful Role of Expectations (by others AND yourself) and Attitude

Pygmalion in the Classroom -- powerful role of expectations Robert Rosenthal

Stereotype threat - female performance on math exams Claude Steele

“Treat people as if they were what they ought to be and you help them become what they are capable of being.”

– Johann W. van Goethe

Questions?