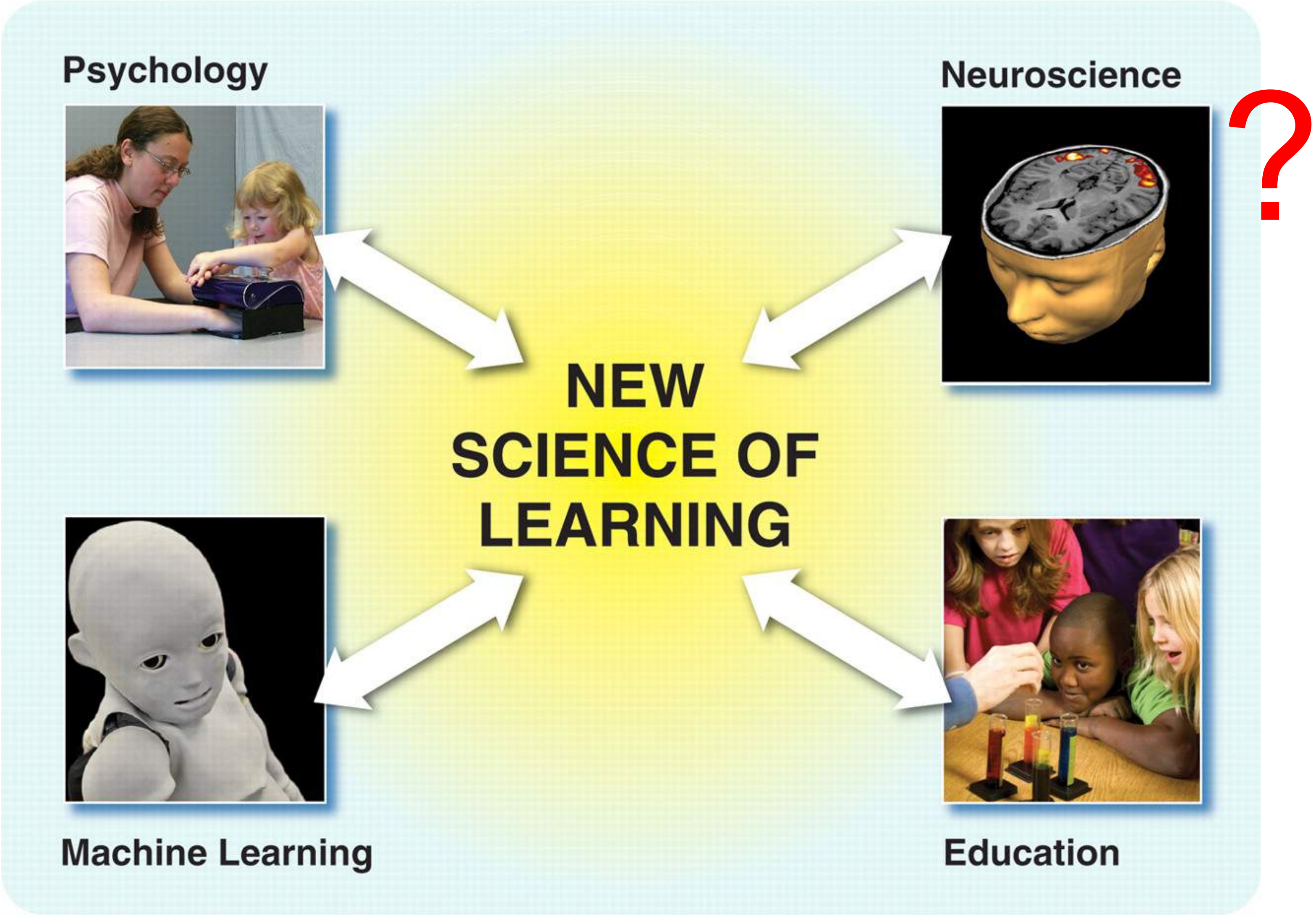
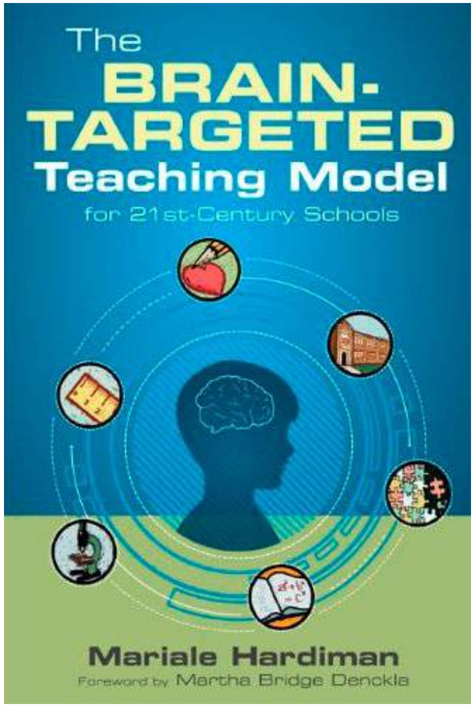
Promise & Pitfalls of Neuroeducation

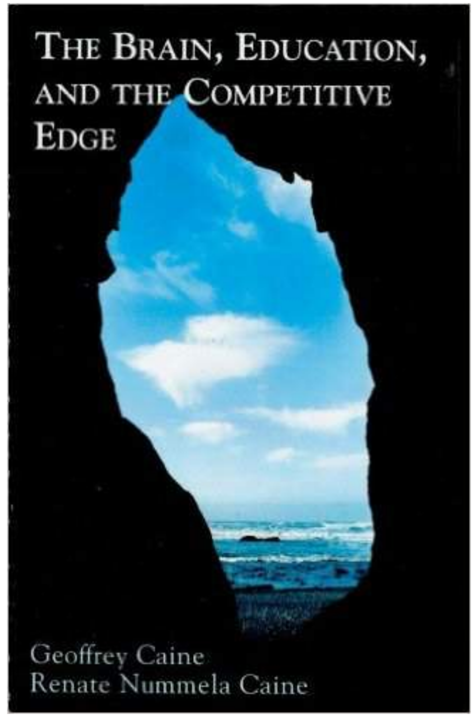
John Gabrieli
Department of Brain and Cognitive Sciences &
Martinos Imaging Center at the
McGovern Institute for Brain Research, MIT

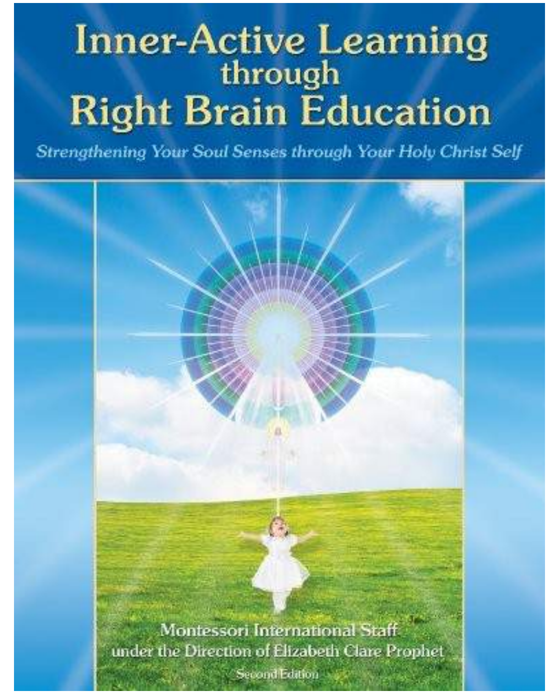
Science of Learning

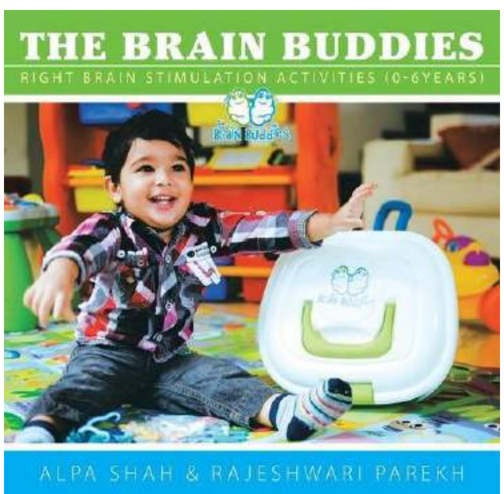


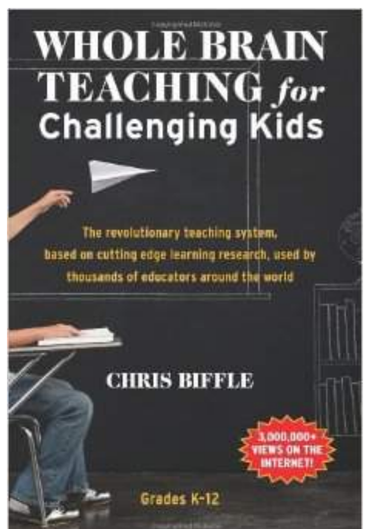
Meltzoff et al. *Science* 2009

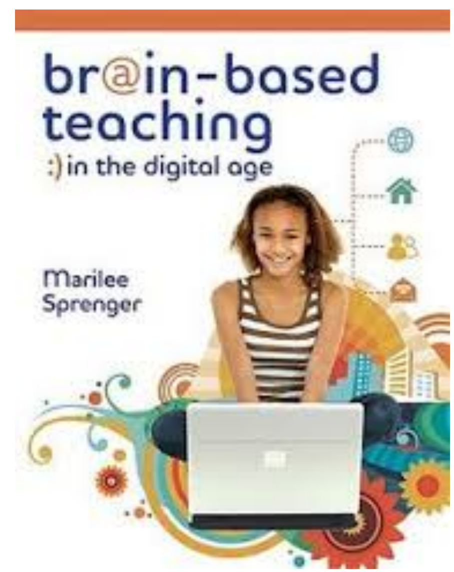

The
BRAIN-
TARGETED
Teaching Model
for 21st-Century Schools
Mariale Hardiman
Foreword by Martha Bridge Denckla


The Brain, Education, and the Competitive Edge
Geoffrey Caine
Renate Nummela Caine


Inner-Active Learning through Right Brain Education
Strengthening Your Soul Senses through Your Holy Christ Self
Montessori International Staff
under the Direction of Elizabeth Clare Prophet
Second Edition


THE BRAIN BUDDIES
RIGHT BRAIN STIMULATION ACTIVITIES (0-6YEARS)
ALPA SHAH & RAJESHWARI PAREKH


WHOLE BRAIN TEACHING for Challenging Kids
The revolutionary teaching system, based on cutting edge learning research, used by thousands of educators around the world
CHRIS BIFFLE
3,000,000+ VIEWS ON THE INTERNET!
Grades K-12


br@in-based teaching
:) in the digital age
Marilee Sprenger

Education and the Brain: A Bridge Too Far

John T. Bruer

Educational Researcher, Vol. 26, No. 8, pp. 4–16

Brain science fascinates teachers and educators, just as it fascinates all of us. When I speak to teachers about applications of cognitive science in the classroom, there is always a question or two about the right brain versus the left brain and the educational promise of brain-based curricula. I answer that these ideas have been around for a decade, are often based on misconceptions and overgeneralizations of what we know about the brain, and have little to offer to educators (Chipman, 1986). Educational applications of brain science may come eventually, but as of now neuroscience has little to offer teachers in terms of informing classroom practice. There is, however, a science of mind, cognitive science, that can serve as a basic science for the development of an applied science of learning and instruction. Practical, well-founded examples of putting cognitive science into practice already exist in numerous schools and classrooms. Teachers would be better off looking at these examples than at speculative applications of neuroscience.

The teachers' questions arise out of the perennial interest in the brain and neuroscience that has always existed at the margin of educational research and reform discussions. Recently, however, interest in how neuroscience might improve education has moved from the margins to center stage. Educators and education policy experts are the most vocal enthusiasts. Educational writers, likewise fascinated by the brain but puzzled by the mind, have picked up on this enthusiasm. Over the past year, there have been numerous books, journal articles, policy studies, and stories in the media about how our emerging understanding of brain development and neural function could revolutionize educational practice.[1] Neuroscientists, while interested in how their research might find application outside the laboratory and clinic, are more guarded in their claims. Often they are puzzled by the neuroscientific results educators choose to cite, by the interpretations educators give those results, and by the conclusions educators draw from them.

This article examines those results, interpretations, and conclusions—a set of claims that I will call the neuroscience and education argument. The negative conclusion is that the argument fails. The argument fails because its advocates are trying to build a bridge too far. Currently, we do not know enough about brain development and neural function to link that understanding directly, in any meaningful, defensible way to instruction and educational practice. We may never know enough to be able to do that. The positive conclusion is that there are two shorter bridges, already in place, that indirectly link brain function with educational practice. There is a well-established bridge, now nearly 50 years old, between education and cognitive psychology. There is a second bridge, only around 10 years old, between cognitive psychology and neuroscience. This newer bridge is allowing us to see how mental functions map onto brain structures. When neuroscience does begin to provide useful insights for educators about instruction and educational practice, those insights will be the result of extensive traffic over this second bridge. Cognitive psychology provides the only firm ground we have to anchor these bridges. It is the only way to go if we eventually want to move between education and the brain.

The Neuroscience and Education Argument

The neuroscience and education argument relies on and embellishes three important and reasonably well-established findings in developmental neurobiology. First, starting in infancy and continuing into later childhood, there is a dramatic increase in the number of synapses that connect neurons in the brain. This synaptic proliferation (synaptogenesis) is followed by a period of synaptic elimination. Second, there are experience-dependent critical periods in the development of sensory and motor systems. Third, in rats at least, complex, or enriched, environments cause new synapses to form.

The argument runs as follows. Starting in early infancy, there is a rapid increase in the number of synapses or neural connections in children's brains. Up to age 10, children's brains contain more synapses than at any other time in their lives. Early childhood experiences fine-tune the brain's synaptic connections. In a process that we might describe as synaptic pruning, childhood experiences reinforce and maintain synapses that are repeatedly used, but snip away the unused synapses. Thus, this time of high synaptic density and experiential fine-tuning is a critical period in a child's cognitive development. It is the time when the brain is particularly efficient in acquiring and learning a range of skills. During this critical period, children can benefit most from rich, stimulating learning environments. If, during this critical period, we deprive children of such environments, significant learning opportunities are lost forever. As one popular article put it, "with the right input at the right

John T. Bruer *is president of the James S. McDonnell Foundation, 1034 S. Brentwood Blvd., Suite 1850, St. Louis, MO 63117; phone 314-721-2068; e-mail* **bruer@jsmf.org**. *He specializes in cognitive science and the philosophy of science.*

1997

Psychological Review
2016, Vol. 123, No. 5, 600–612

0033-295X/16/$12.00 http://dx.doi.org/10.1037/rev0000025

THEORETICAL NOTE

The Practical and Principled Problems With Educational Neuroscience

Jeffrey S. Bowers
University of Bristol

The core claim of educational neuroscience is that neuroscience can improve teaching in the classroom. Many strong claims are made about the successes and the promise of this new discipline. By contrast, I show that there are no current examples of neuroscience motivating new and effective teaching methods, and argue that neuroscience is unlikely to improve teaching in the future. The reasons are twofold. First, in practice, it is easier to characterize the cognitive capacities of children on the basis of behavioral measures than on the basis of brain measures. As a consequence, neuroscience rarely offers insights into instruction above and beyond psychology. Second, in principle, the theoretical motivations underpinning educational neuroscience are misguided, and this makes it difficult to design or assess new teaching methods on the basis of neuroscience. Regarding the design of instruction, it is widely assumed that remedial instruction should target the underlying deficits associated with learning disorders, and neuroscience is used to characterize the deficit. However, the most effective forms of instruction may often rely on developing compensatory (nonimpaired) skills. Neuroscience cannot determine whether instruction should target impaired or nonimpaired skills. More importantly, regarding the assessment of instruction, the only relevant issue is whether the child learns, as reflected in behavior. Evidence that the brain changed in response to instruction is irrelevant. At the same time, an important goal for neuroscience is to characterize how the brain changes in response to learning, and this includes learning in the classroom. Neuroscientists cannot help educators, but educators can help neuroscientists.

Keywords: educational neuroscience, education, instruction, neuroscience, mind, brain, and education

Psychological Review
2016, Vol. 123, No. 5, 613–619

0033-295X/16/$12.00 http://dx.doi.org/10.1037/rev0000034

COMMENTARY

The Promise of Educational Neuroscience: Comment on Bowers (2016)

John D. E. Gabrieli
Massachusetts Institute of Technology

Bowers (2016) argues that there are practical and principled problems with how educational neuroscience may contribute to education, including lack of direct influences on teaching in the classroom. Some of the arguments made are convincing, including the critique of unsubstantiated claims about the impact of educational neuroscience and the reminder that the primary outcomes of education are behavioral, such as skill in reading or mathematics. Bowers' analysis falls short in 3 major respects. First, educational neuroscience is a basic science that has made unique contributions to basic education research; it is not part of applied classroom instruction. Second, educational neuroscience contributes to ideas about education practices and policies beyond classroom curriculum that are important for helping vulnerable students. Third, educational neuroscience studies using neuroimaging have not only revealed for the first time the brain basis of neurodevelopmental differences that have profound influences on educational outcomes, but have also identified individual brain differences that predict which students learn more or learn less from various curricula. In several cases, the brain measures significantly improved or vastly outperformed conventional behavioral measures in predicting what works for individual children. These findings indicate that educational neuroscience, at a minimum, has provided novel insights into the possibilities of individualized education for students, rather than the current practice of learning through failure that a curriculum did not support a student. In the best approach to improving education, educational neuroscience ought to contribute to basic research addressing the needs of students and teachers.

Keywords: educational neuroscience, education, instruction, neuroscience, mind, brain, and education

Human Cognitive Neuroscience

- ***Brain & Psychology***
  perception, learning & memory,
  thinking, emotion, social cognition
- ***Brain & Mental Health***
  psychiatric disorders &
  neurodevelopmental disorders
- ***Brain & Education***

Human Cognitive Neuroscience

- **functional and structural neural architecture of the human brain**
- **variation of that architecture – development, personality, sex, culture, socioeconomic status**
- **differences of that architecture in neurodevelopmental and neuropsychiatric disorders**

but, whose life is better?

Gabrieli et al., *Neuron*, 2015

Neuropsychiatric Diseases & Neuroimaging

- MRI studies 1995-2016 (PubMed)
  - about 20,000 publications

schizophrenia – 5983

depression – 6254

anxiety – 3105

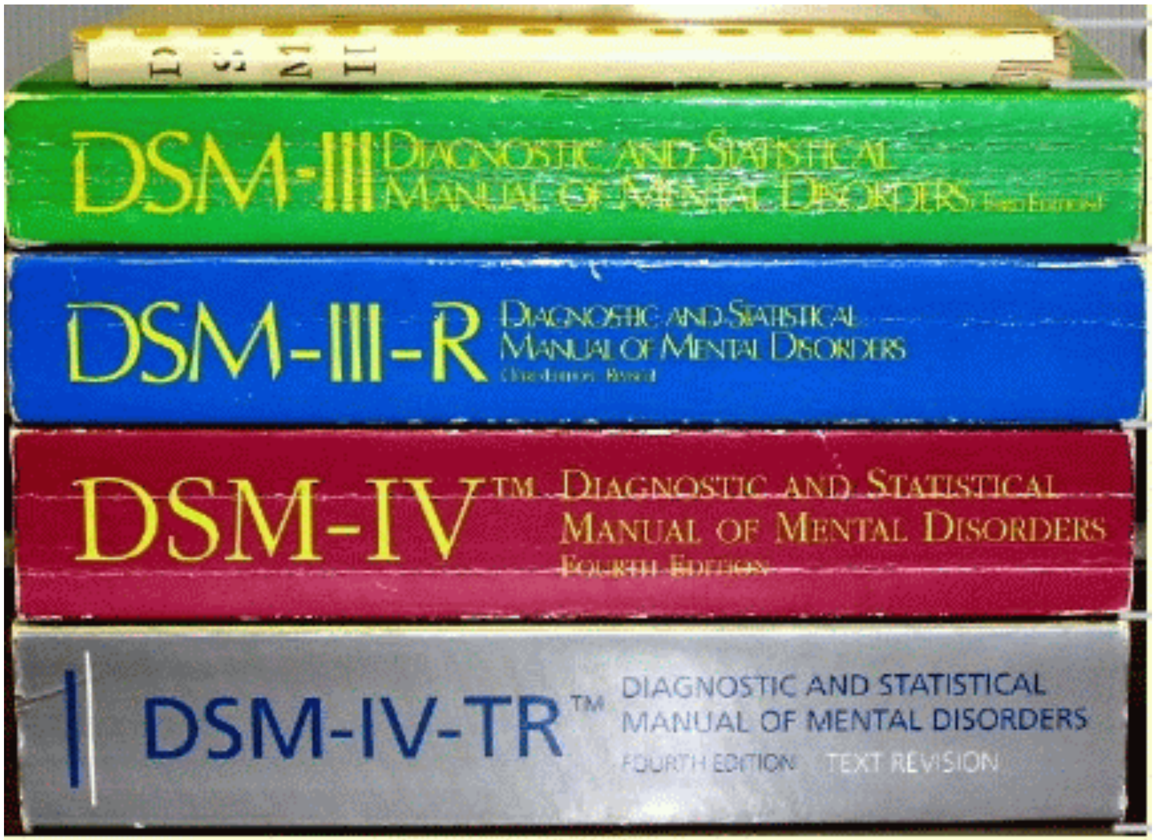
autism – 1849

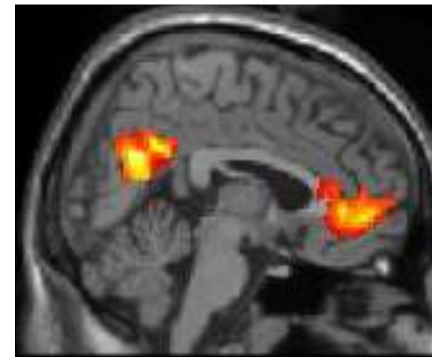
ADHD – 1303

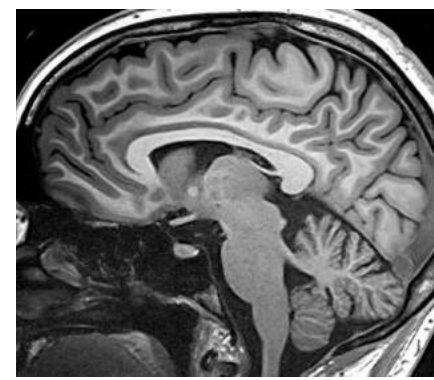
dyslexia – 655

OCD – 704

Neuropsychiatry & Neuroimaging & Genetics







DSM V – May 2013

Neuroeducation

- Basic neurocognitive research about learning

- Neurocognitive research about educational outcomes

- When brain measures outperform conventional behavioral measures

Biomedicine

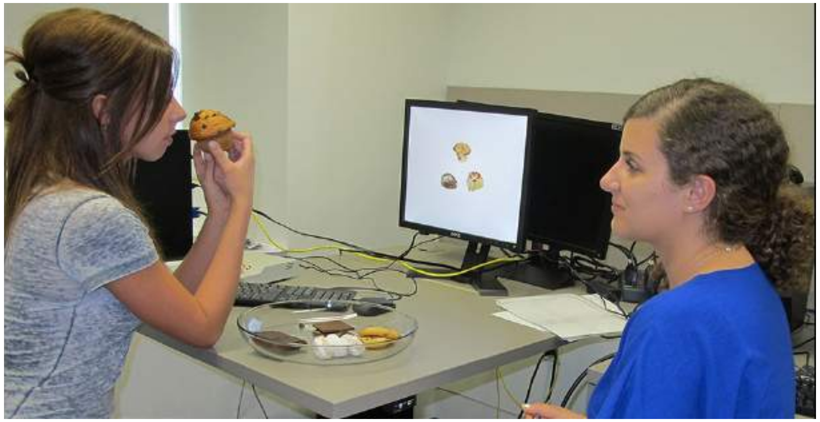
Basic Research ⟷ **Clinical Care**

academic medical centers

Education

Basic Research

Education



learning
psychology & neuroscience

education
schools of education

Education Research

Inputs → *Outcomes*

Curriculum

Teachers

Class Size

Technology

Learning Time

Test Scores

Educational Attainment

Education Research

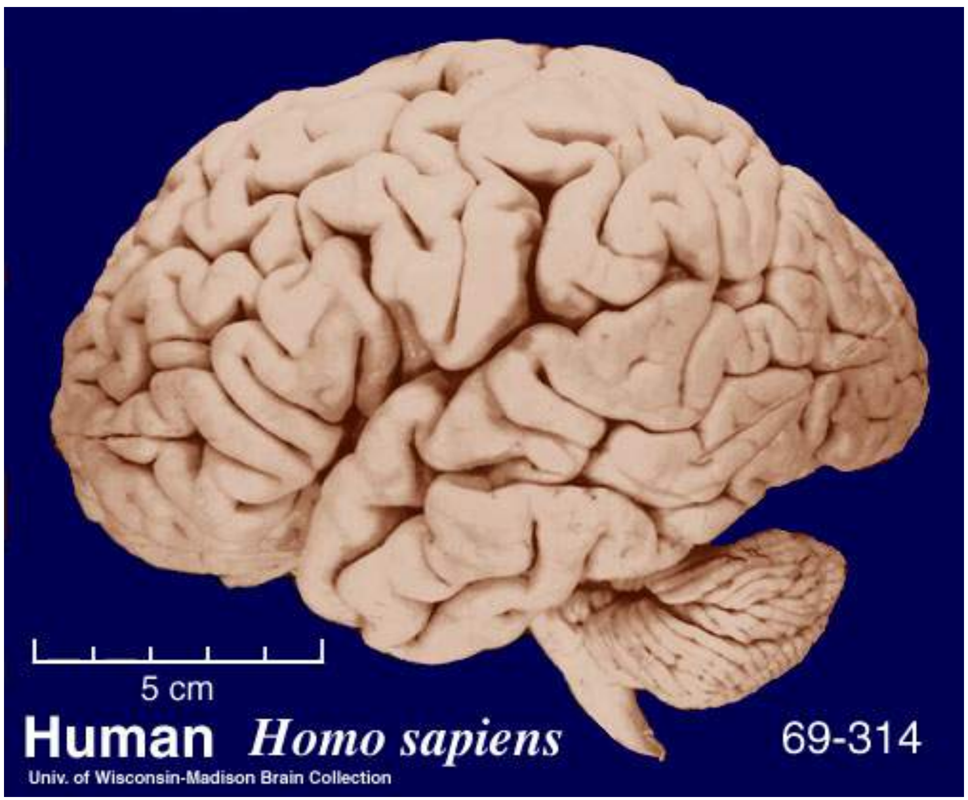
Inside the Student Mind & Brain

Cognition

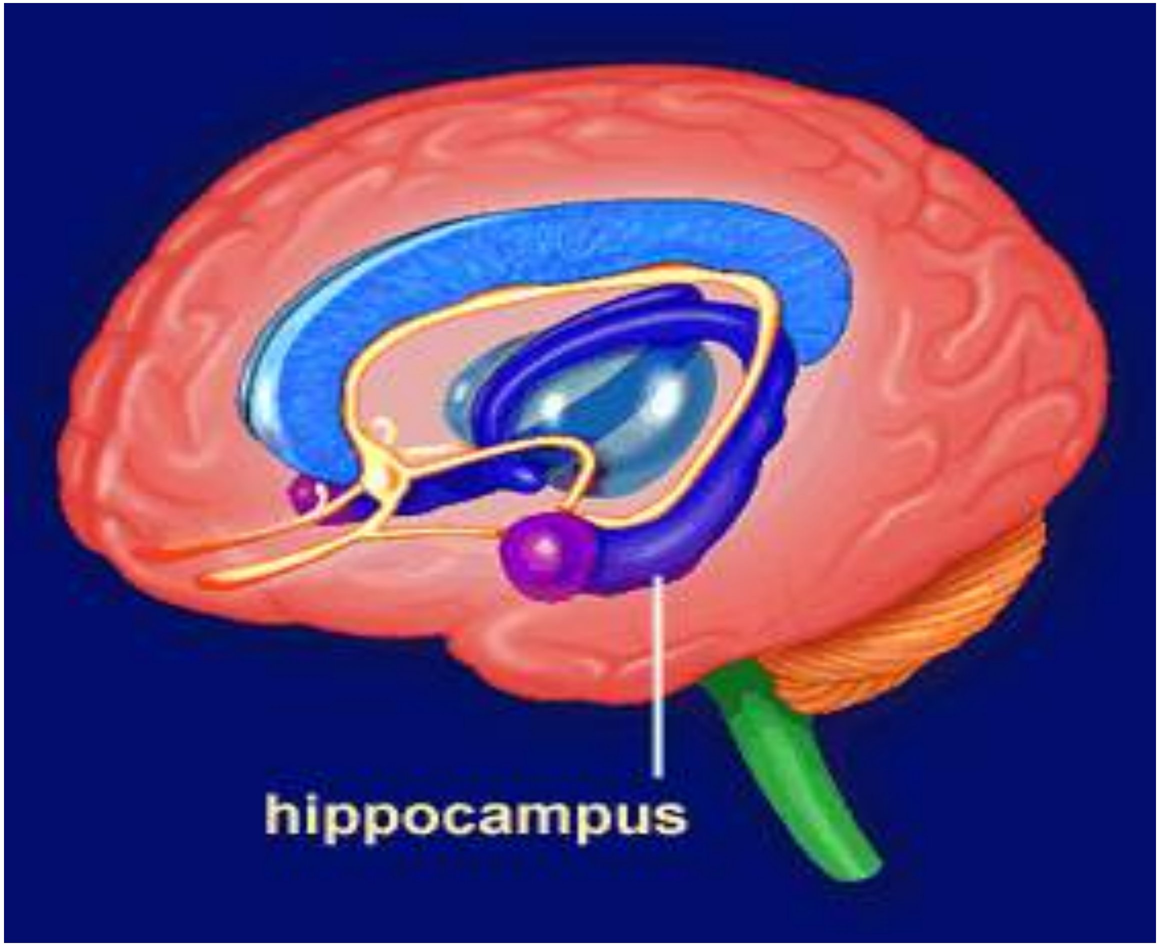
Socio-Emotional

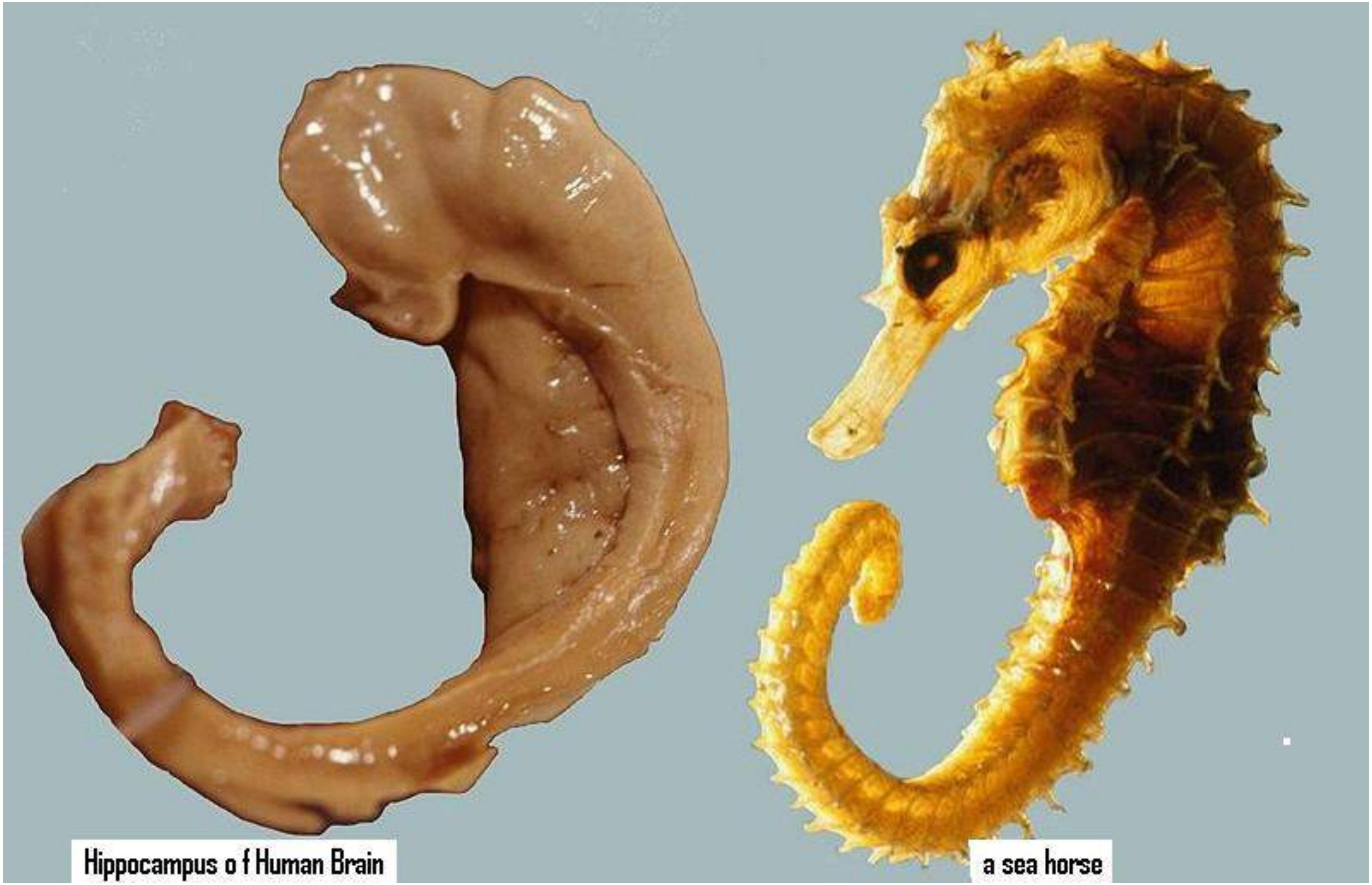
Declarative (Explicit) Memory Neural Systems

- medial temporal lobe
- dorsolateral prefrontal cortex



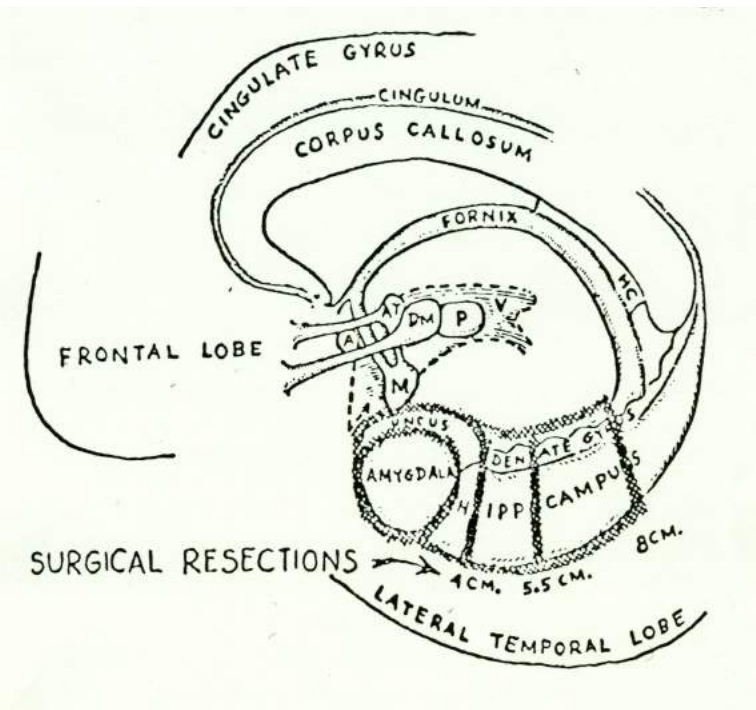
Location of hippocampus




Hippocampus o f Human Brain
a sea horse

THE AMNESIC PATIENT H.M.

1926	**Birth**
1942	**Age 16, First major seizure**
1953	**Age 27, Bilateral medial temporal-lobe resection**
1955	**Report of pervasive and profound anterograde amnesia by Dr. Brenda Milner**
1962	**Neuropsychological examinations characterizing the amnesic syndrome**



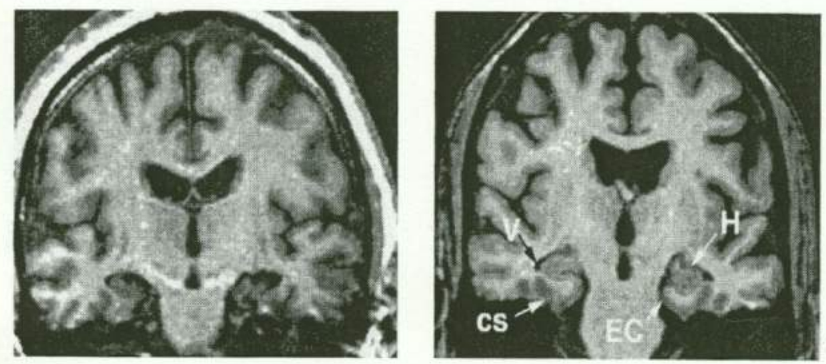
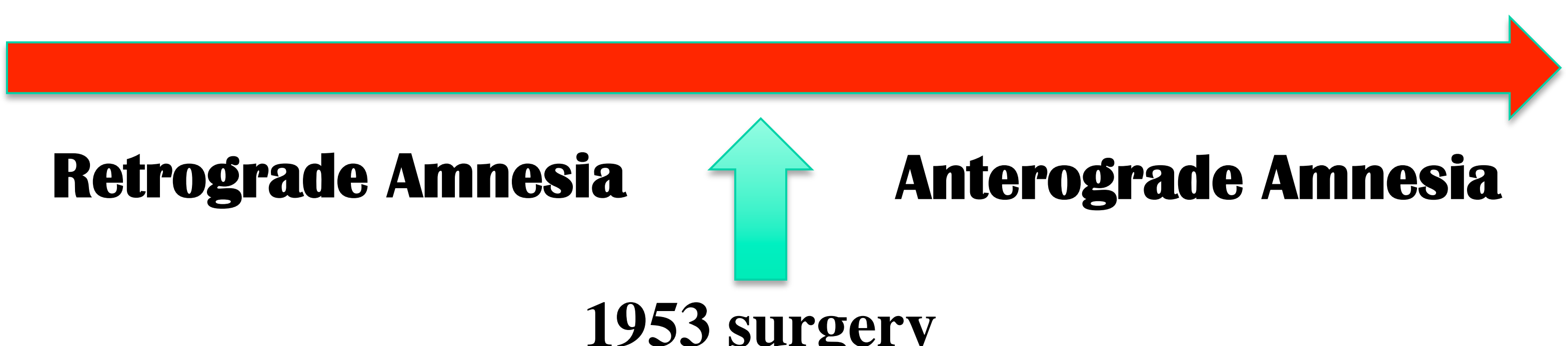


Figure 14.20 The hippocampus of H.M. The hippocampus (H) and entorhinal cortex (EC) are present in the brain of a normal subject (right), but absent bilaterally in the brain of H.M. (left).
➤ *What were the consequences of bilateral removal of H.M.'s hippocampus? (p. 441)*

HM: Global Anterograde Amnesia

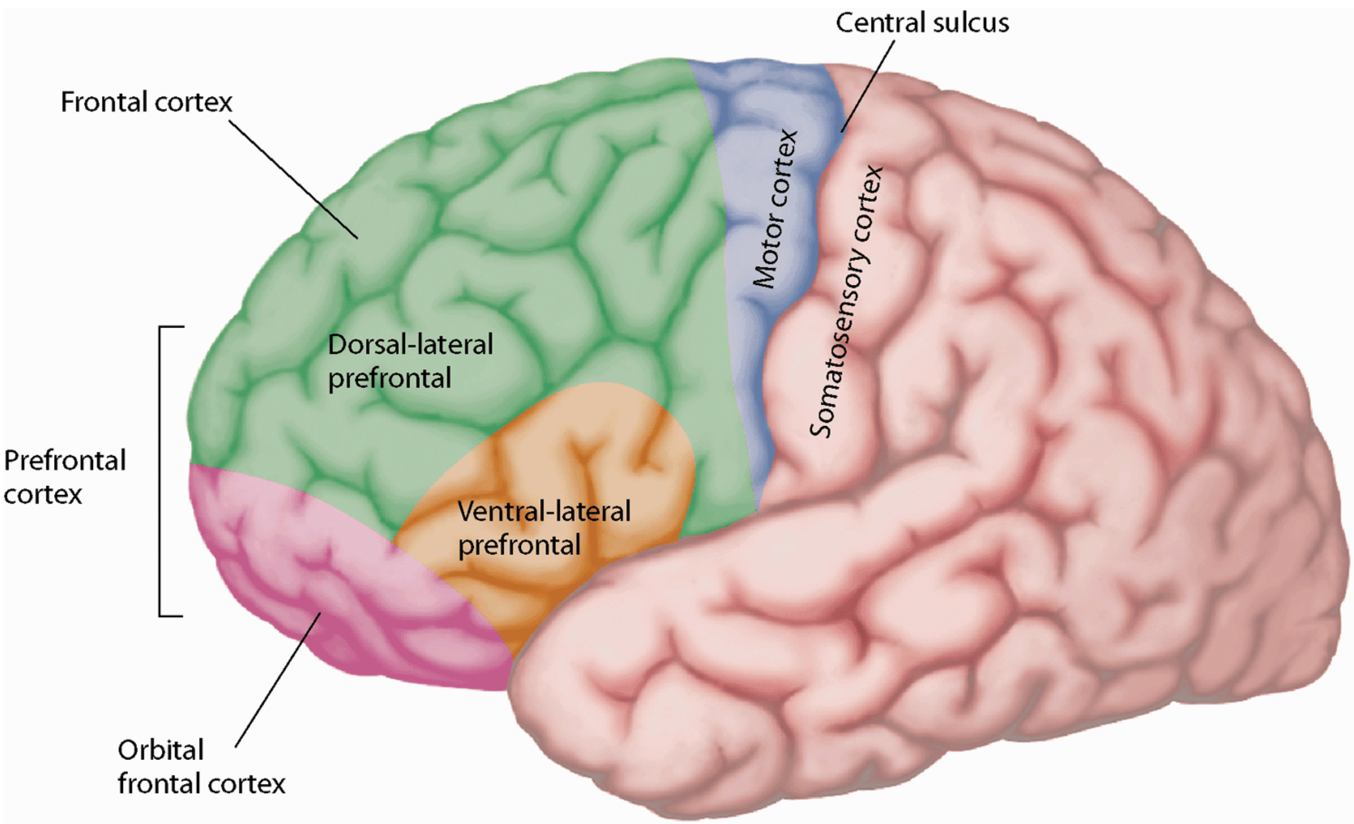
- **High Average Intelligence**
- **Intact Short Term Memory (7 digits)**
- **Normal Conversation, Math Performance**
- **Good Memory of Distant Past (his name, his school, his parents)**
- **Personality Maintained**
- ***Unable to Acquire New Memories for Events & Facts (people, places, news)***
  - ***all modalities***
  - ***all materials (verbal & nonverbal)***



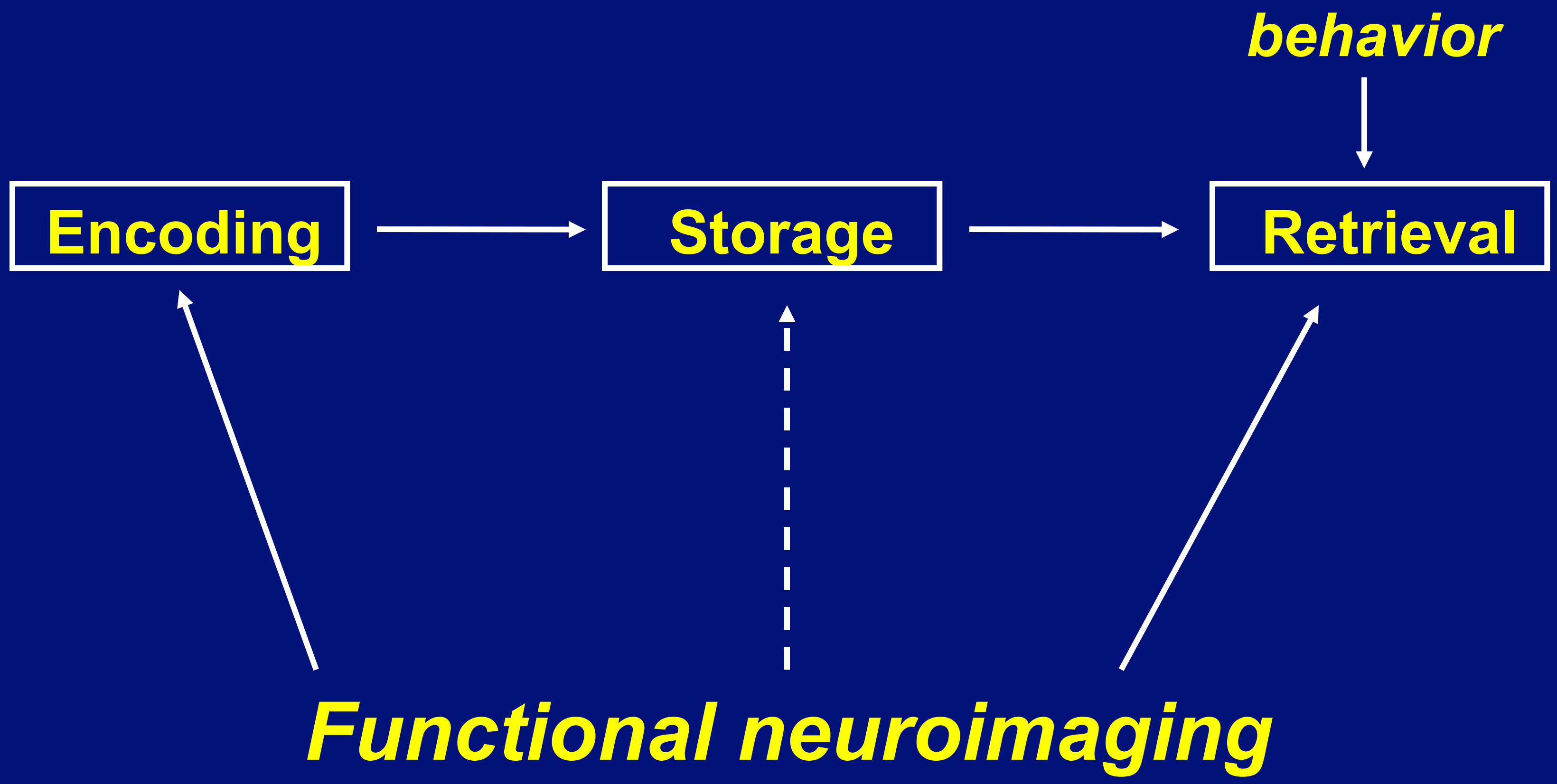
Declarative (Explicit) Memory Neural Systems

- **dorsolateral prefrontal cortex**

(deficits in source, recency, frequency)



Stages of Memory



Google™ Google™

Google™ Google™

Google™ Google™

Visual Encoding Task

Event-Related Design For Subsequent Memory

Separate response recorded for each stimulus

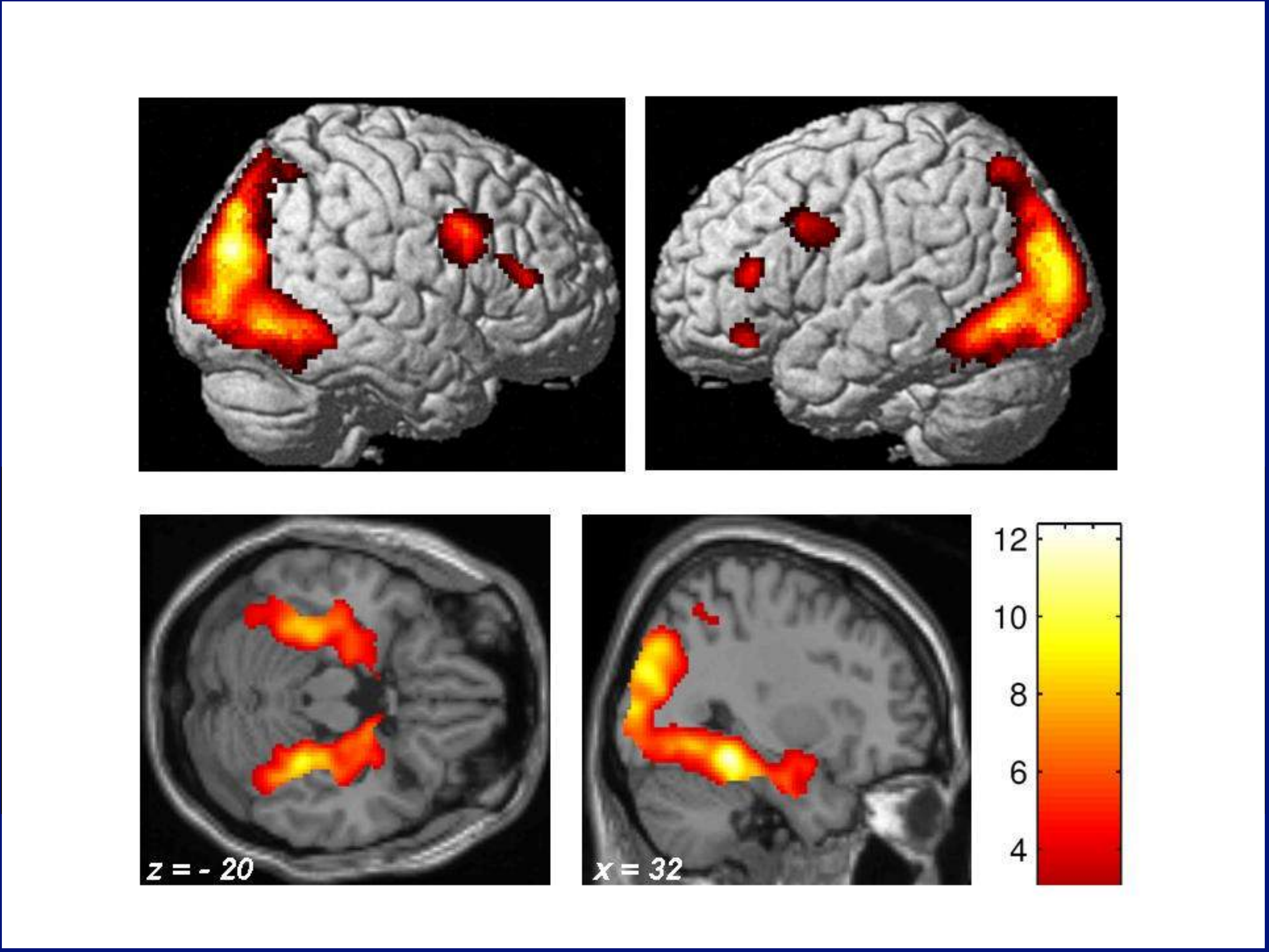
↓

Later memory test

↓

Compare fMRI responses leading to successful vs unsuccessful memory encoding

Making Memories: Remembered > Forgotten

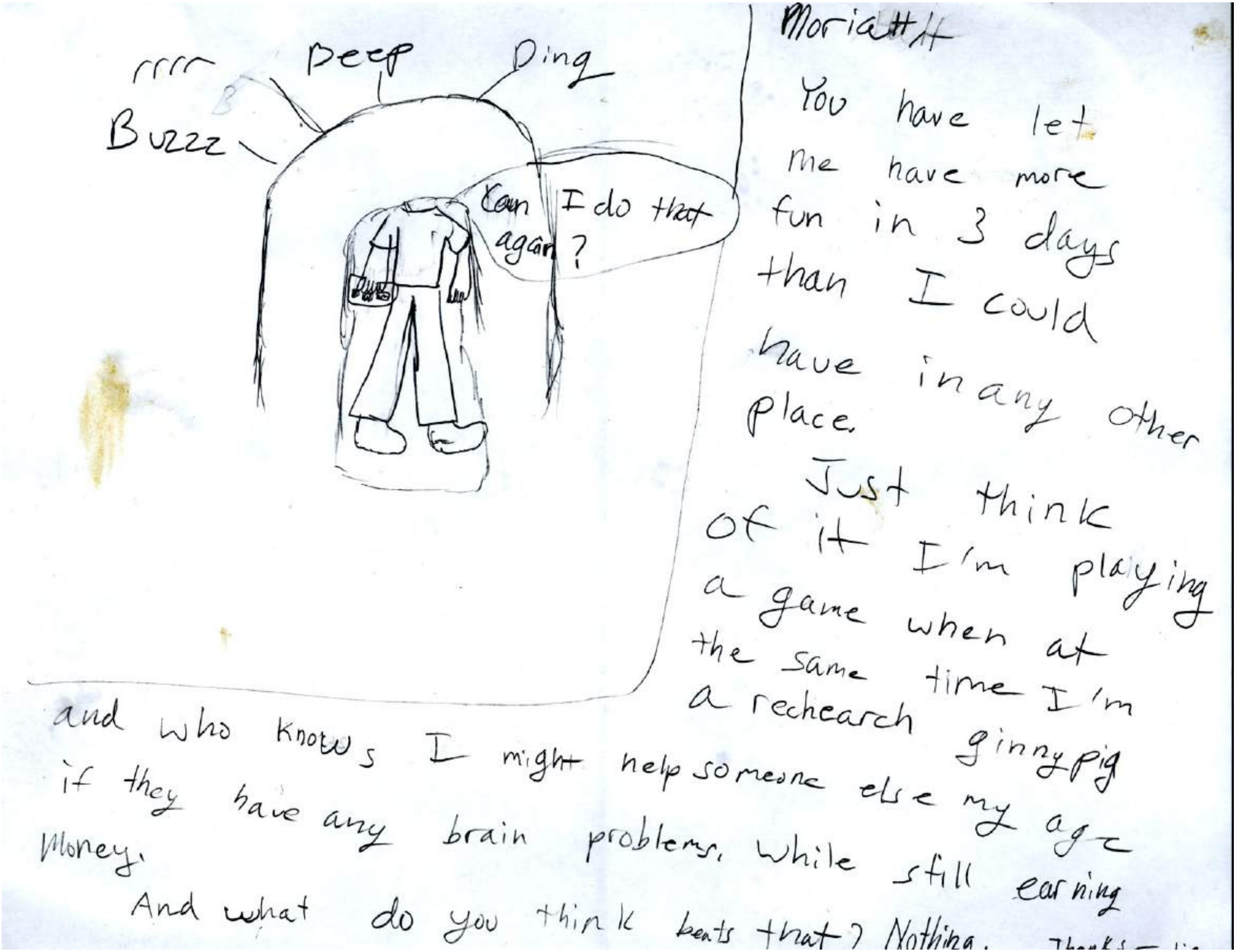


Brewer et al., *Science*, 1998; Ofen et al., *Nature Neuroscience*, 2007

How do declarative memory systems develop in the brain?

Pediatric Neuroimaging

9.5 year old girl, scanned 3 times over 6 months



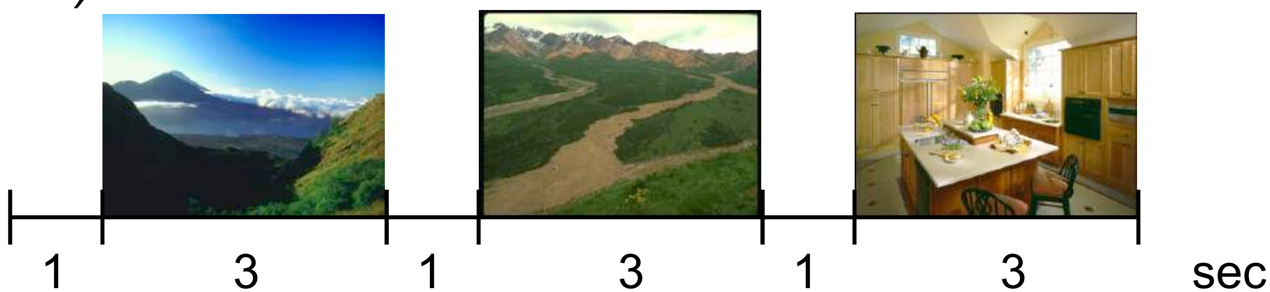
Experimental Design

<u>Participants:</u> 14 adults (ages 19-24 years), 35 children (ages 8-17 years)

<u>Memory Task:</u>

Encoding (scanned):

250 scenes

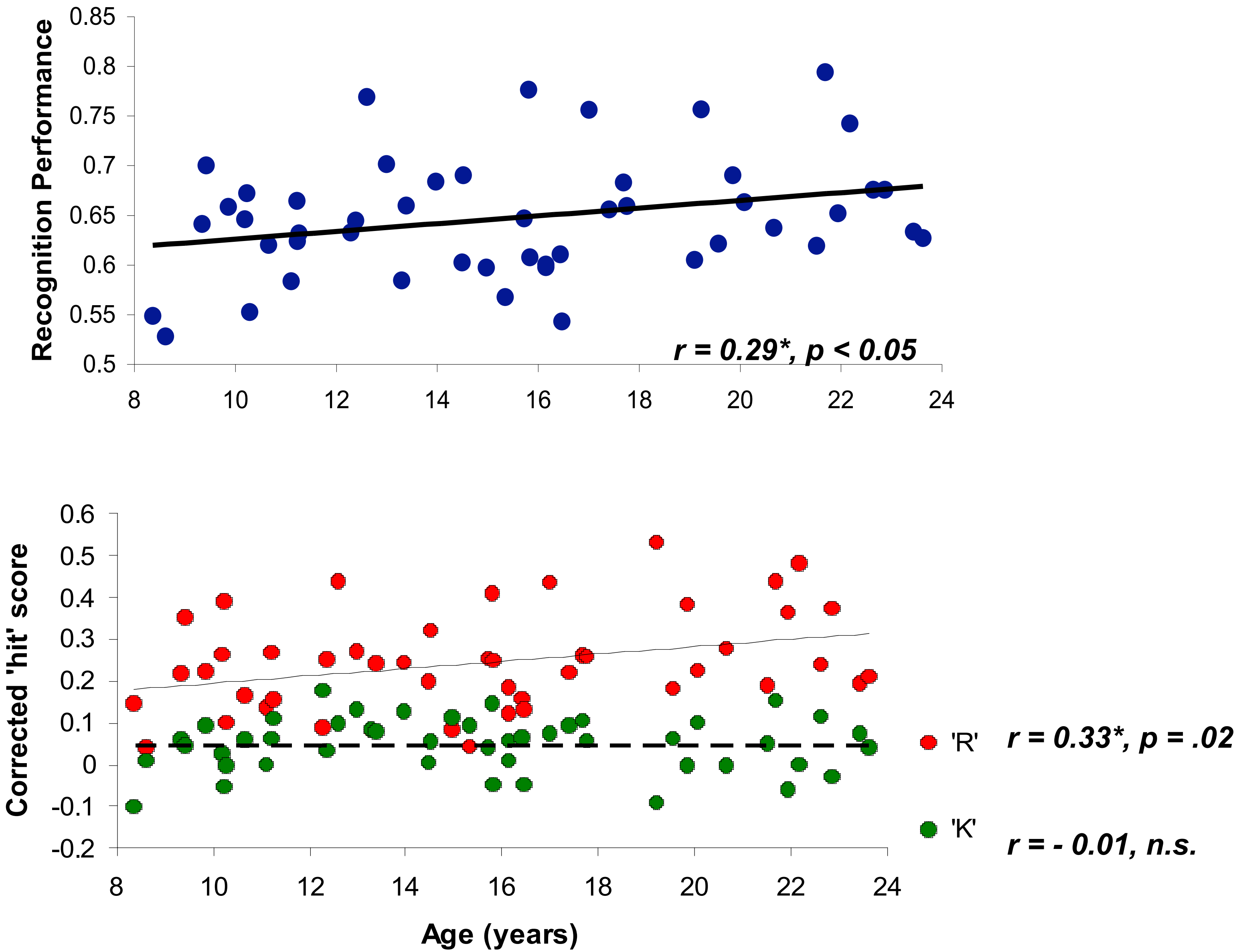


Recognition test:

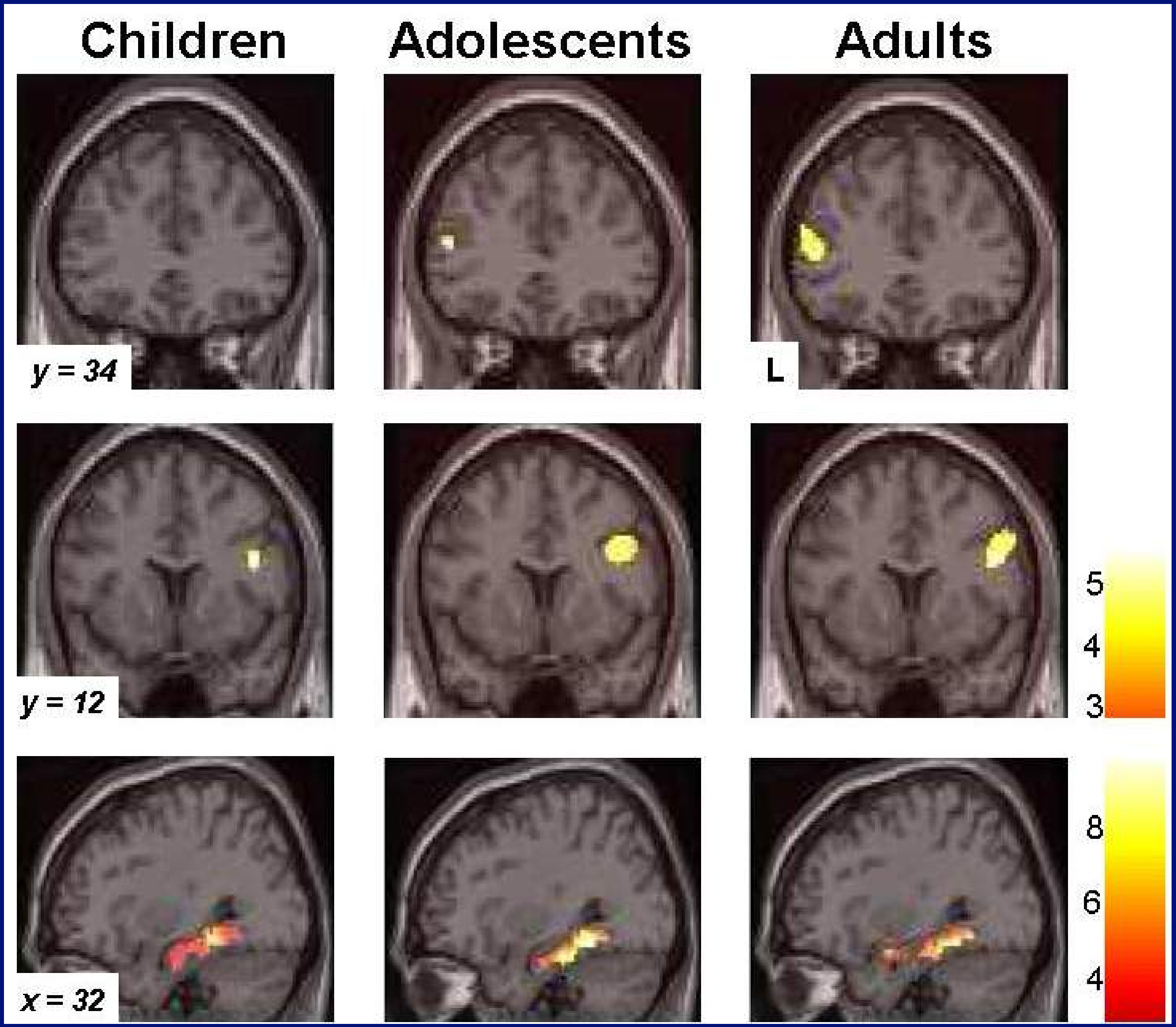
500 scenes

Item	*Response*	*Condition*
	Old; Remembered	**R**
	Old; Familiar	**K**
	New	**F**

Development of Remembrance



Remembered > Forgotten



Ofen et al., *Nature Neuroscience*, 2007

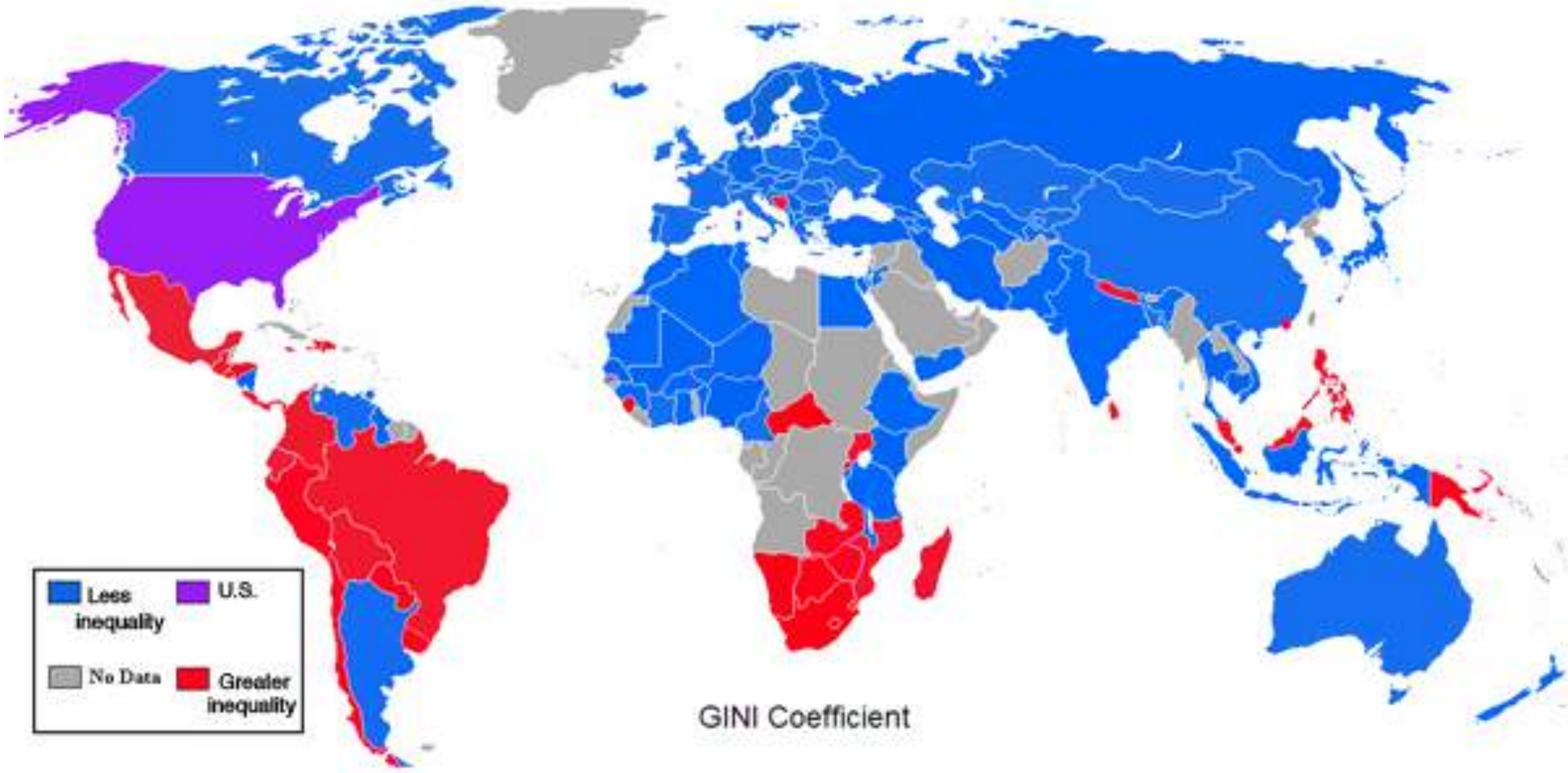
Neuroeducation

- Basic neurocognitive research about learning

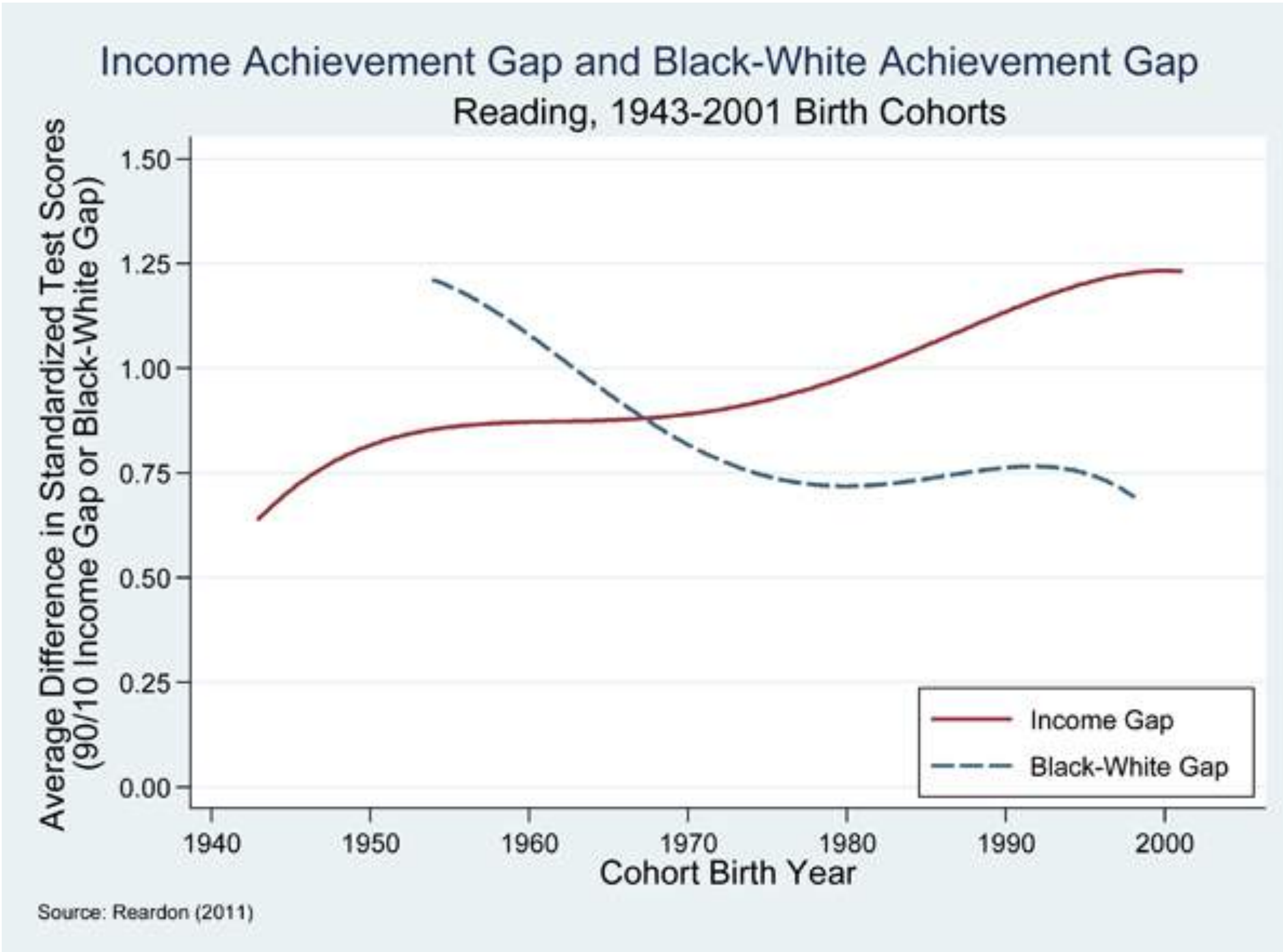
- Neurocognitive research about educational outcomes

- When brain measures outperform conventional behavioral measures

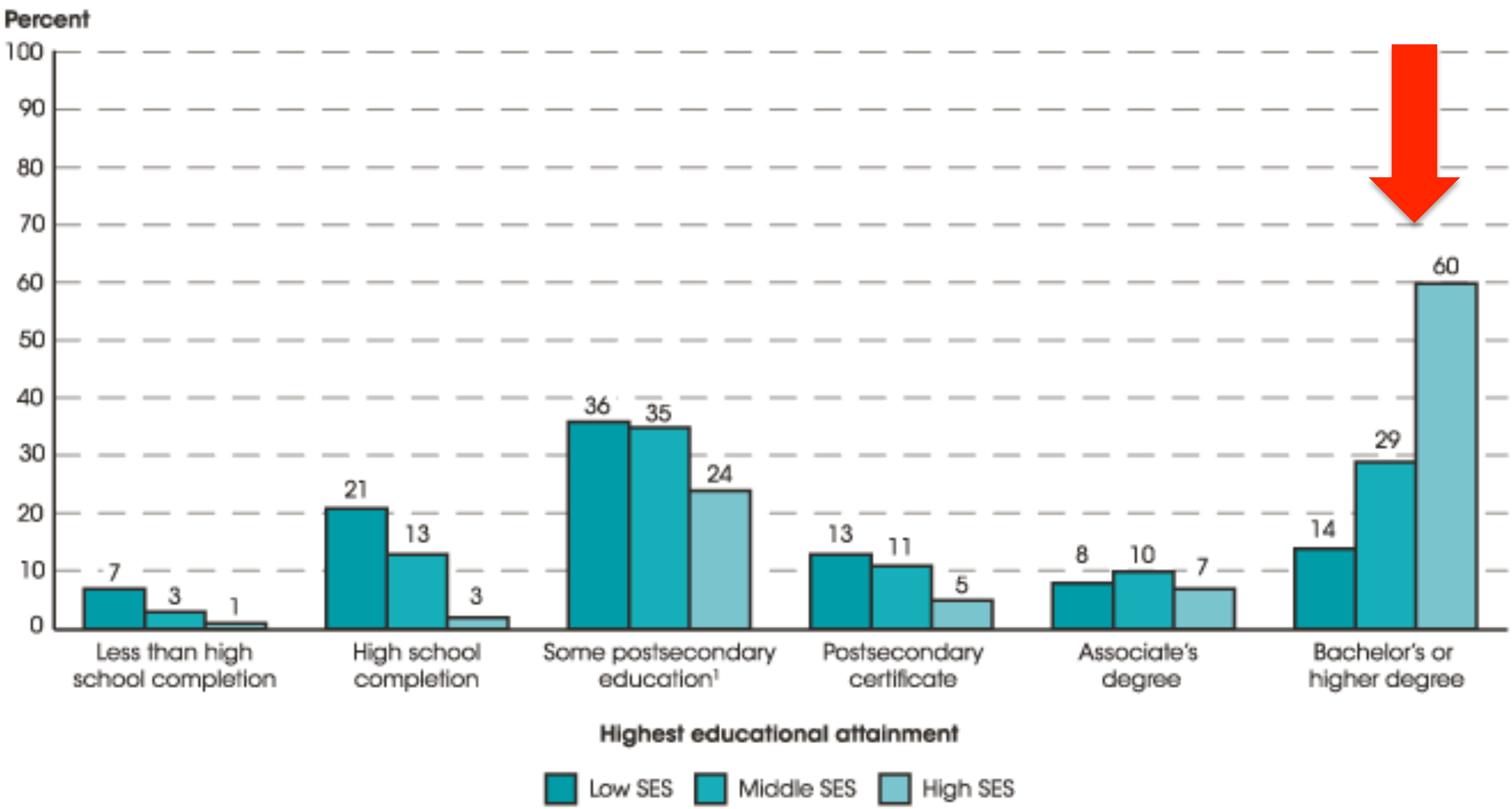
Global Income Inequality



Widening Academic Achievement Gap Between the Rich and the Poor

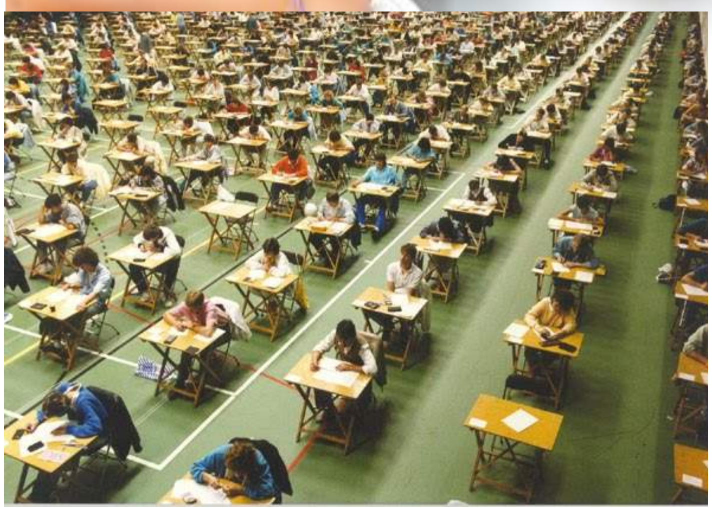


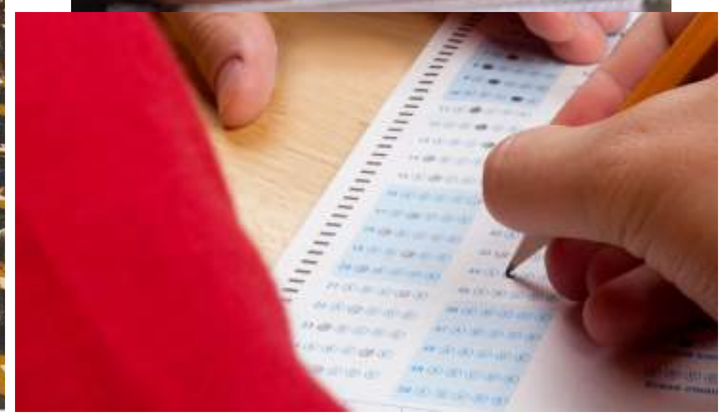
SES & Educational Attainment



U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002

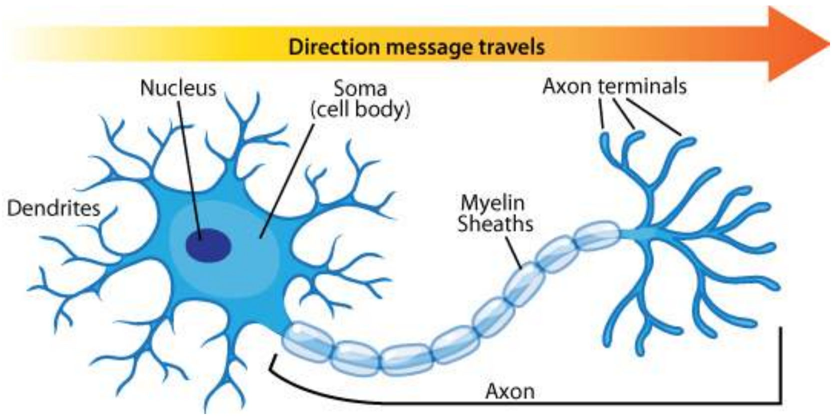
High-Stakes Statewide Standardized Tests

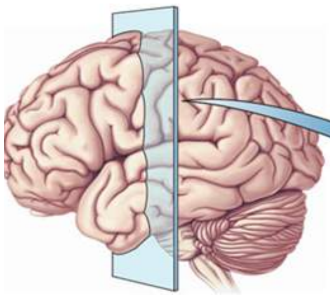


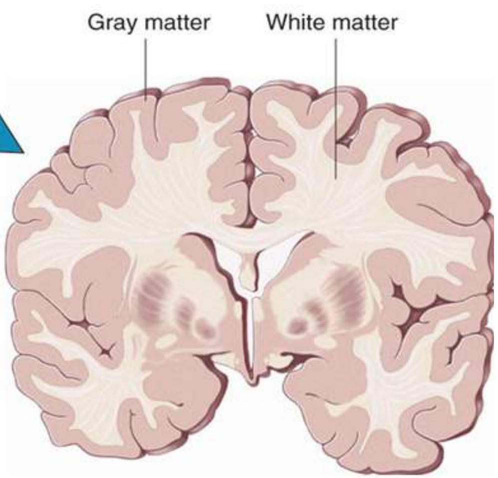


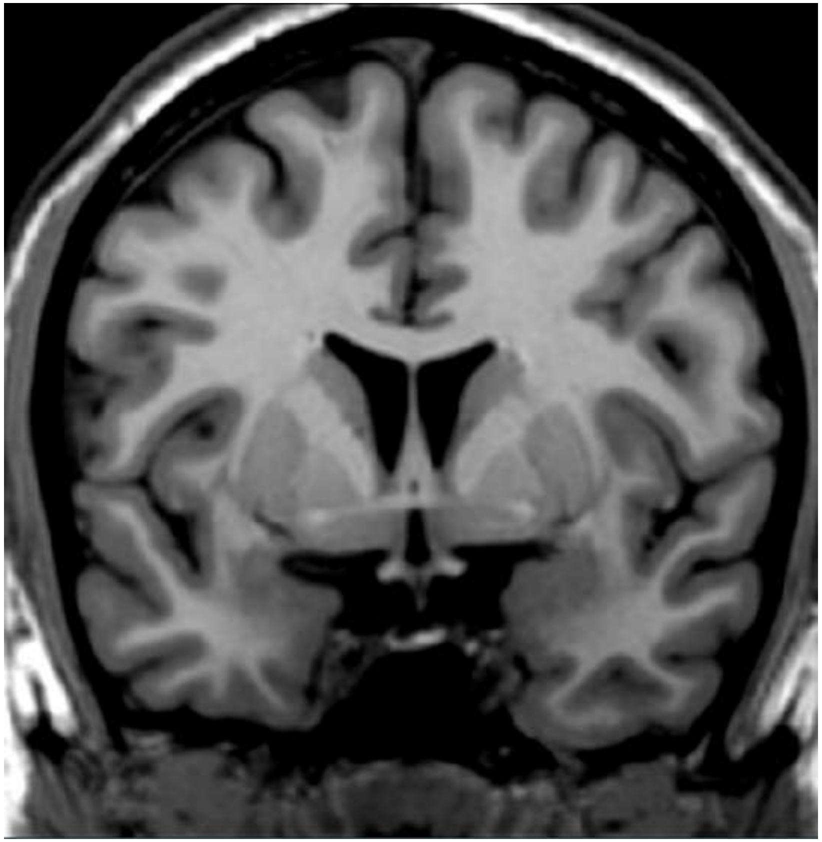
Massachusetts Comprehensive Assessment System
MCAS – Math & ELA

Grey Matter = Cell Bodies
White Matter = Myelinated Axons

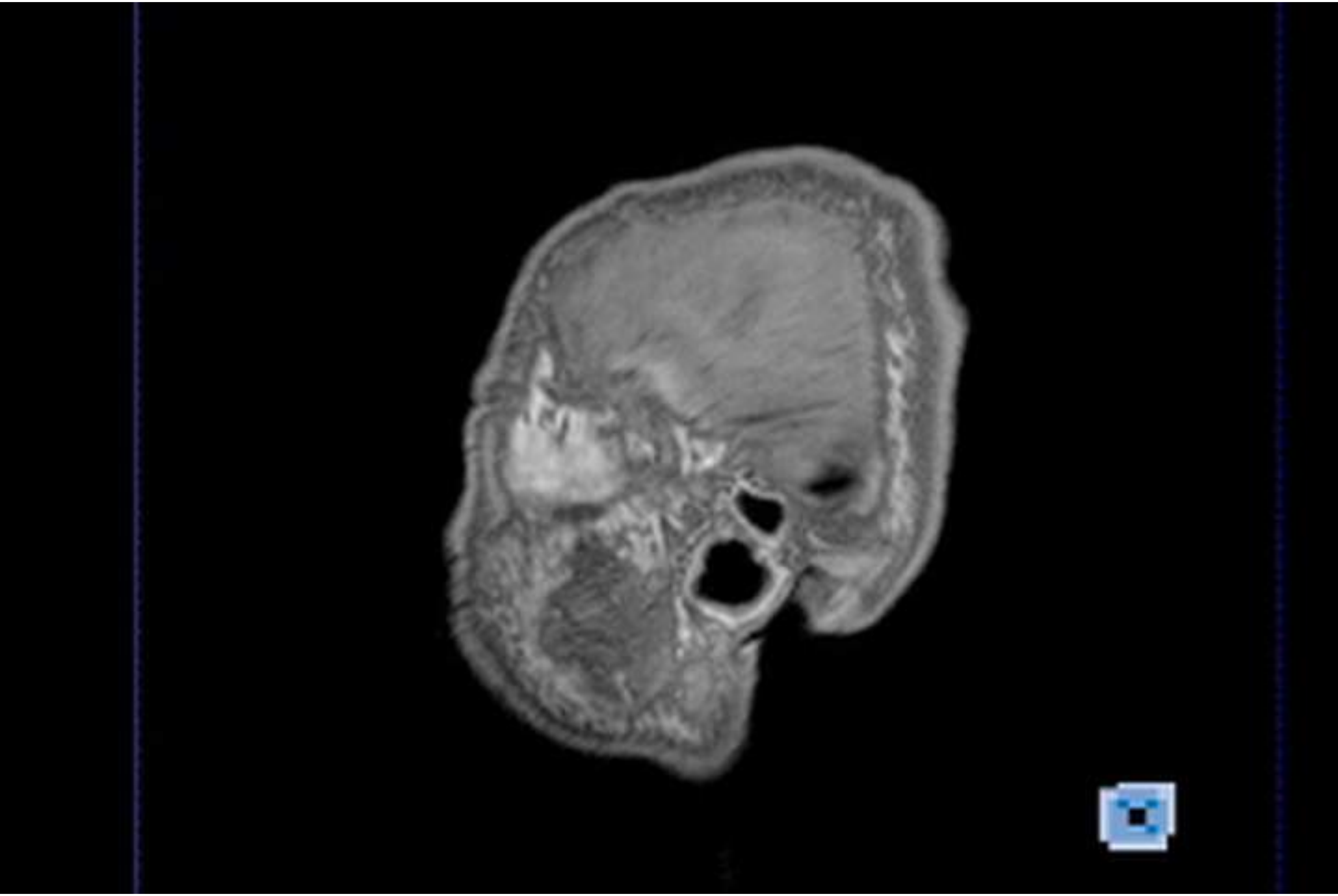




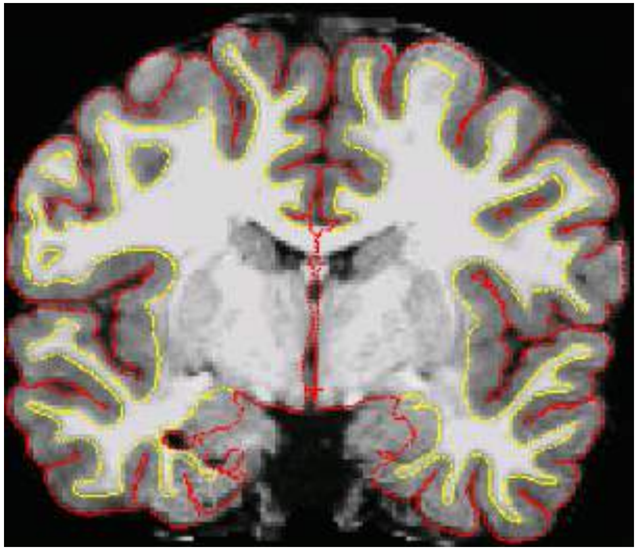


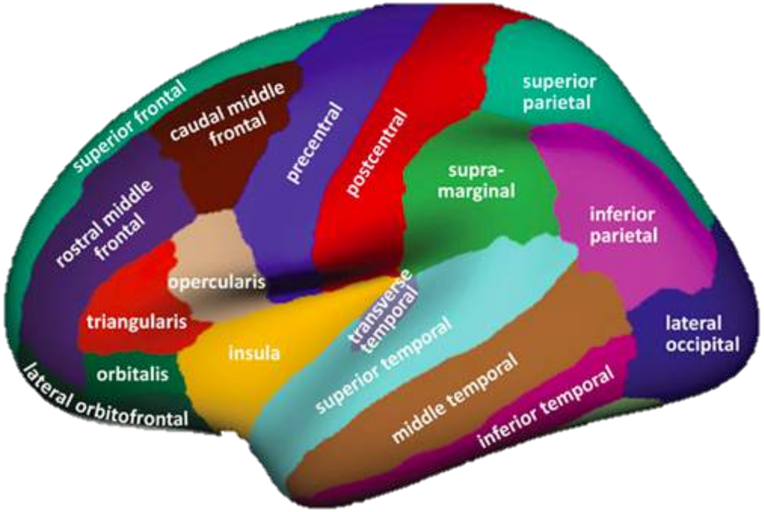


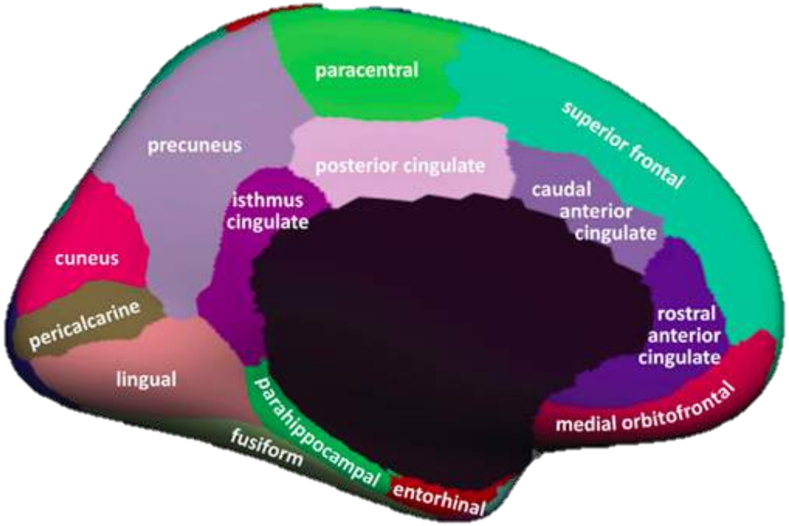
MRI – Lateral Views



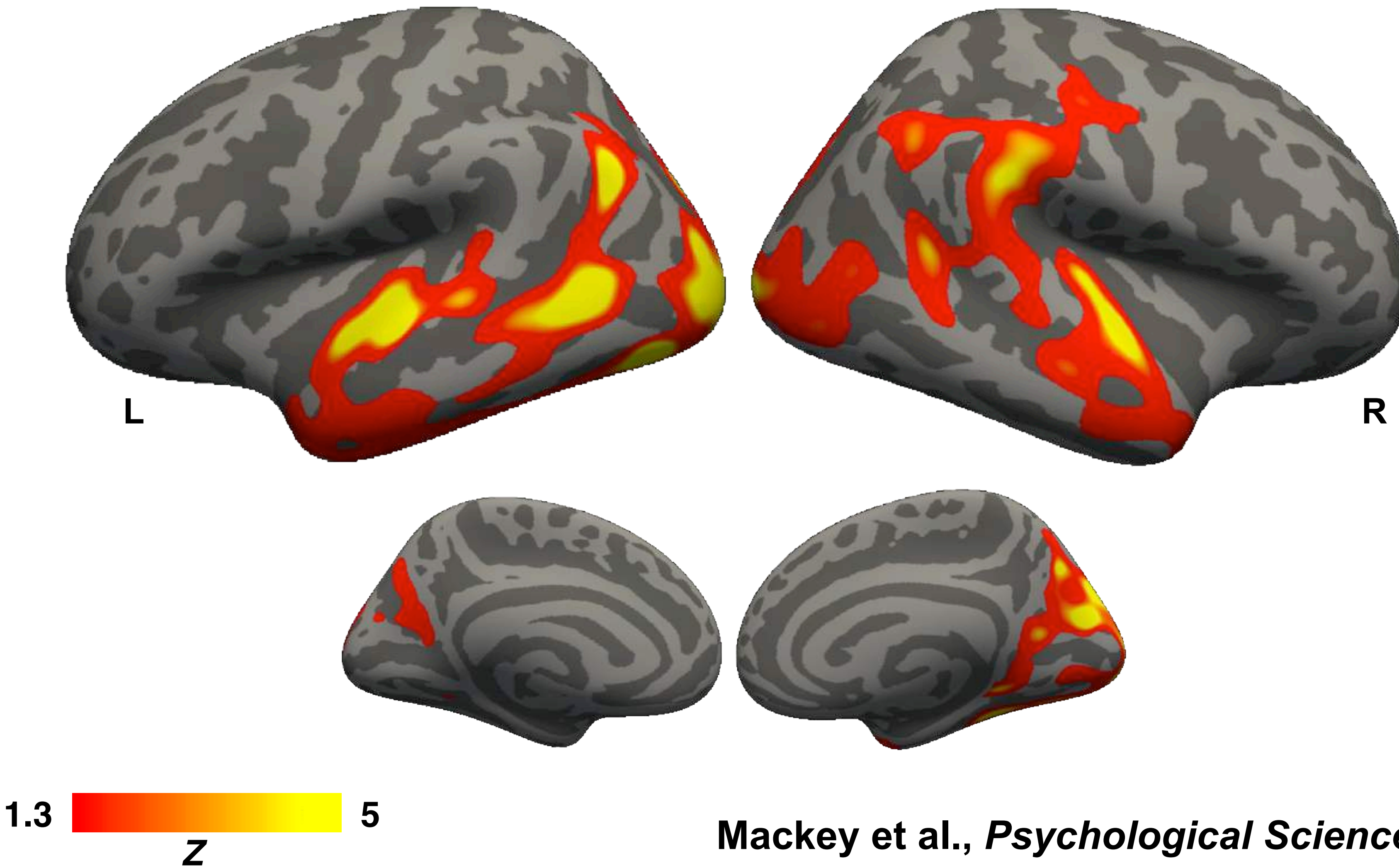
Cortical Thickness Analysis





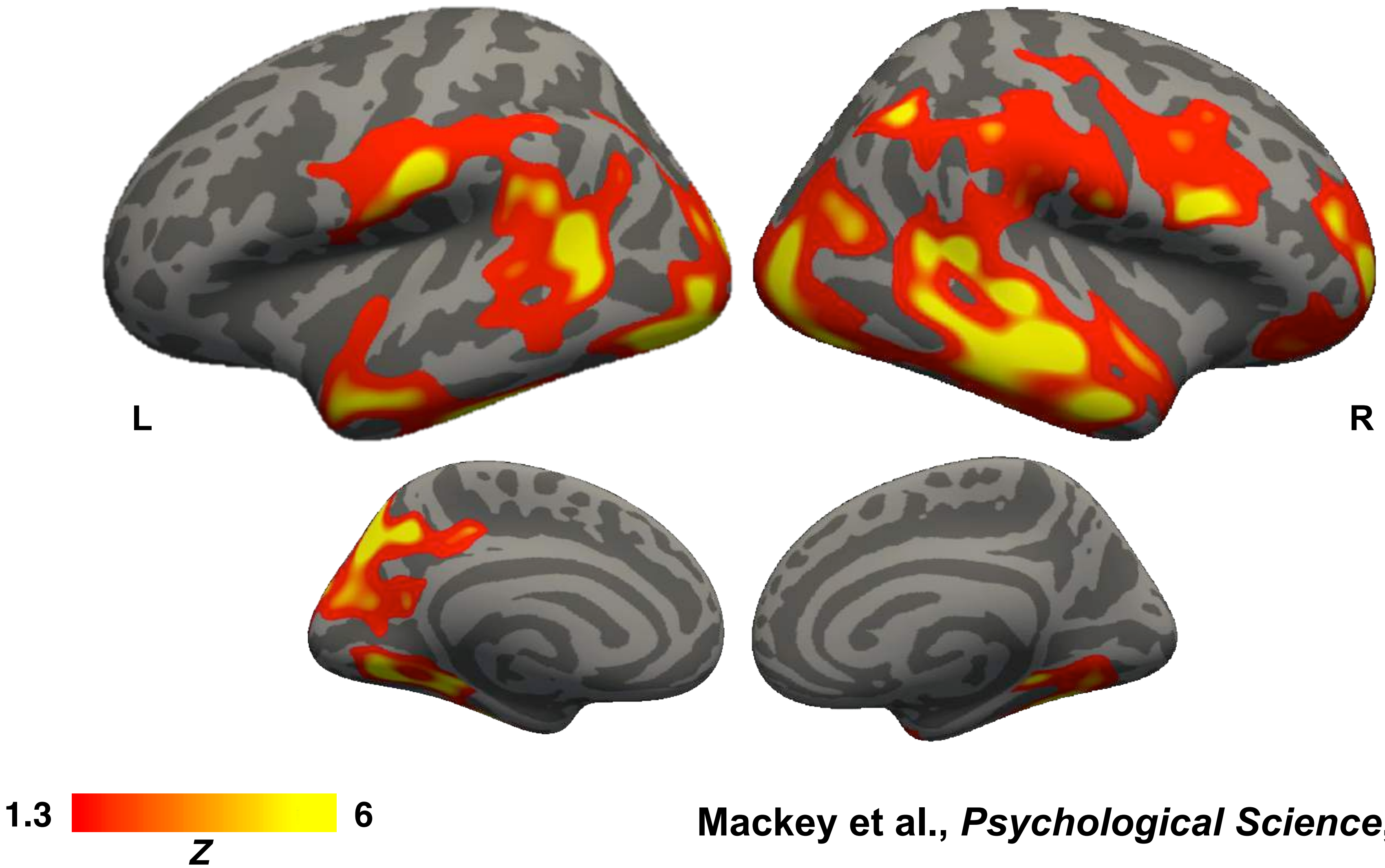


Greater Cortical Thickness Correlates with Better Standardized Test Scores



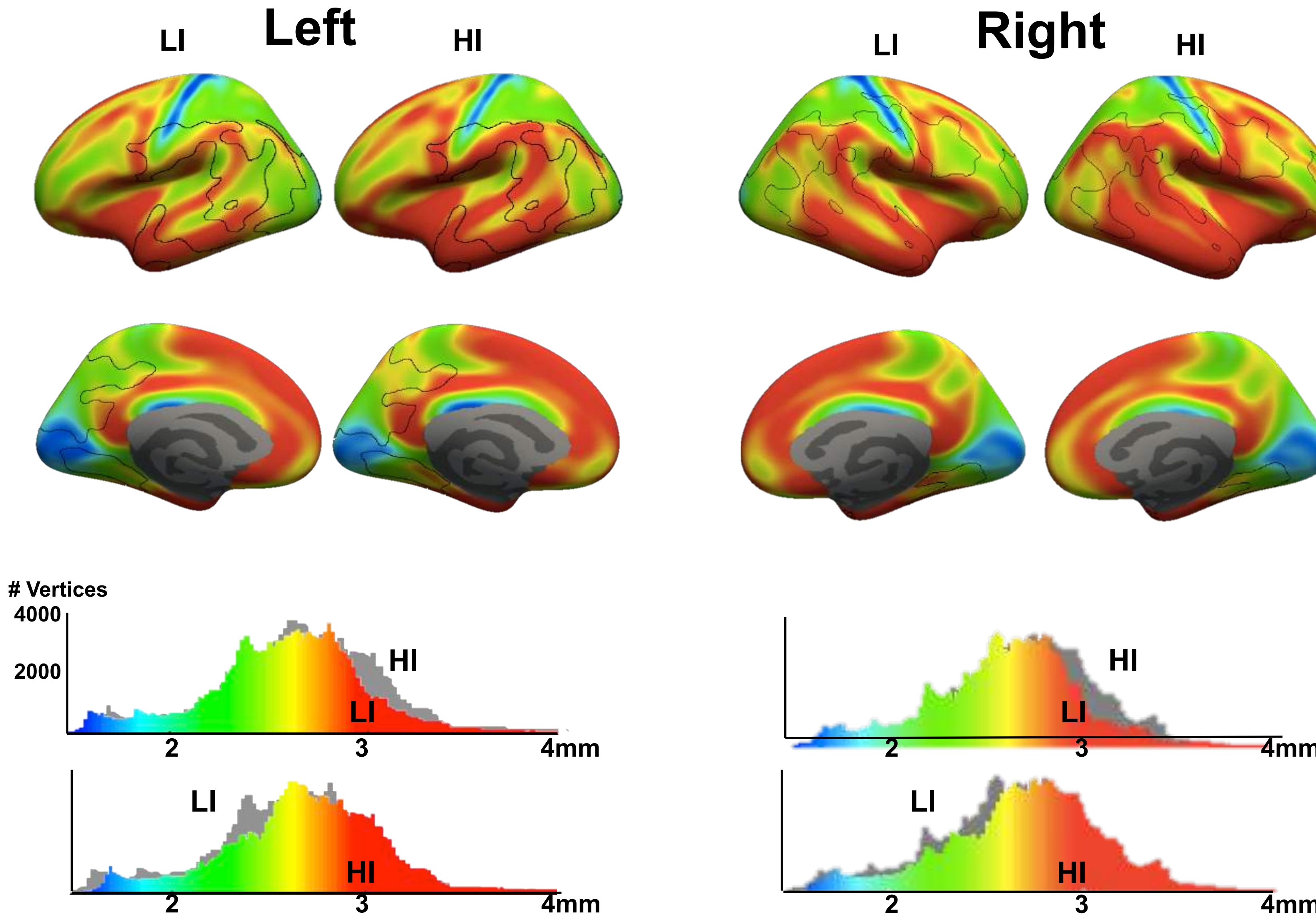
Mackey et al., *Psychological Science*, 2015

Greater Cortical Thickness With Higher SES
(Paid Lunch > Free Lunch)

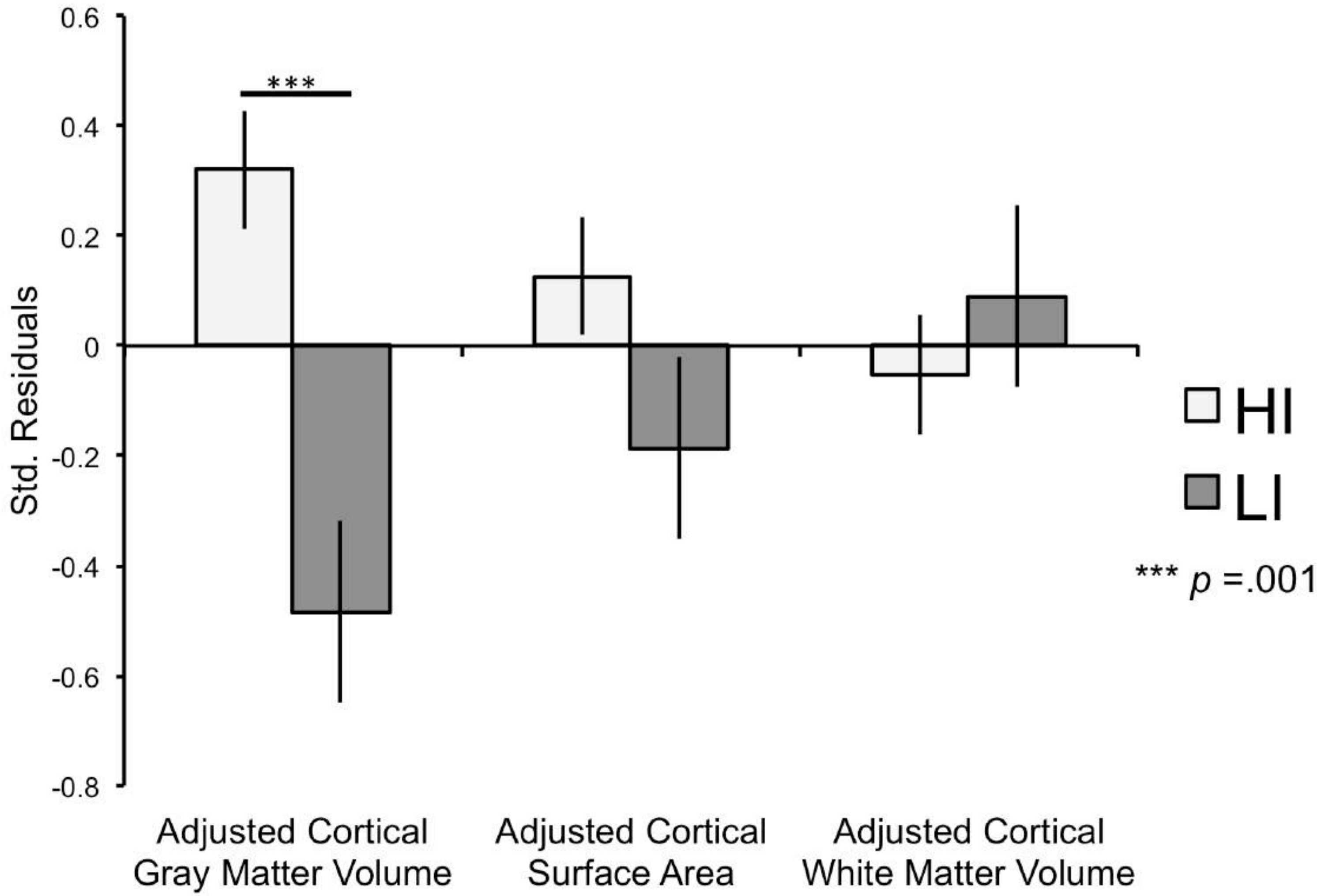


Mackey et al., *Psychological Science*, 2015

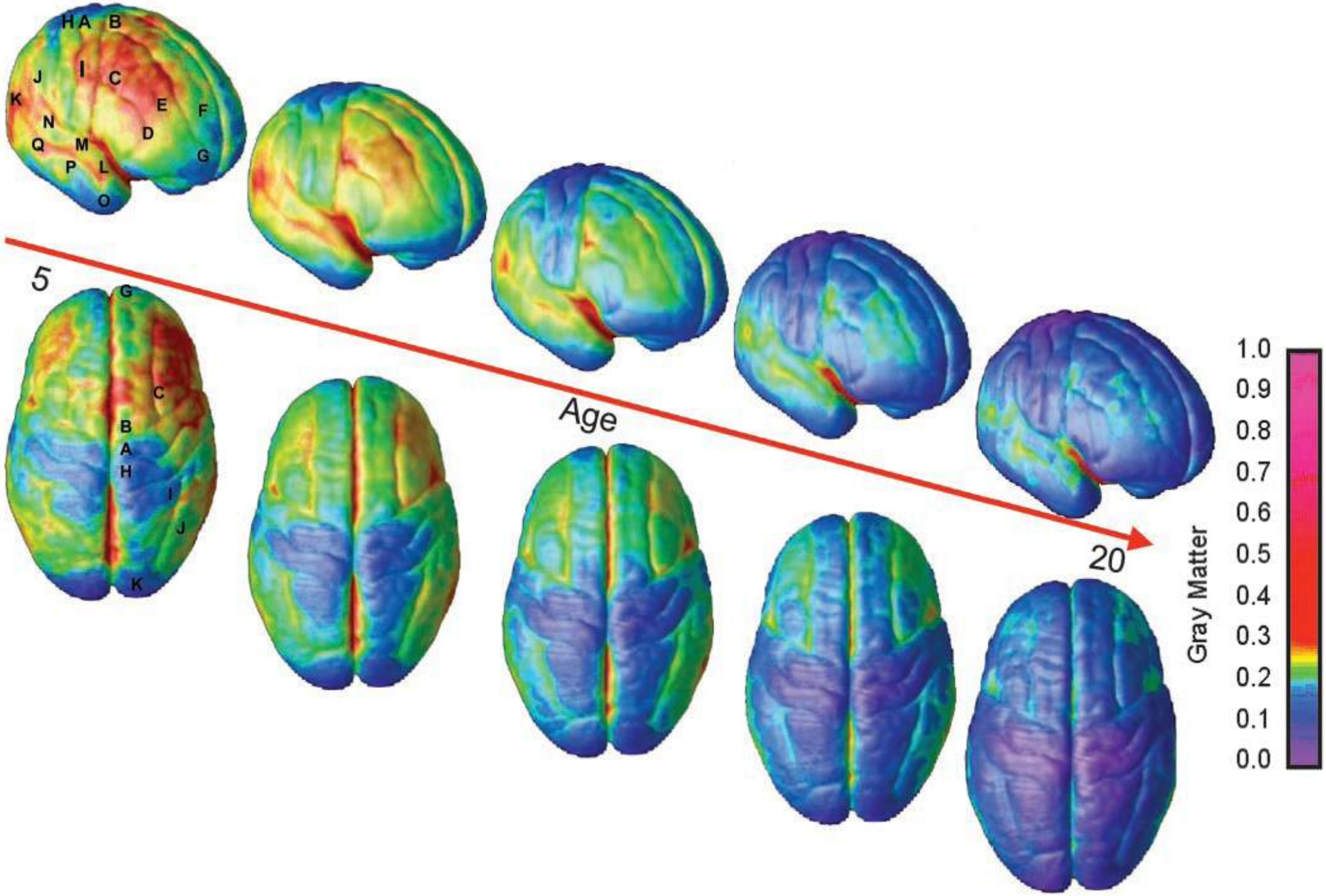
Similar Patterns of Relative Thickness Across the Brain in Lower (LI) and Higher (HI) SES Students



No SES Effects on Cortical Surface Area or White-Matter Volume

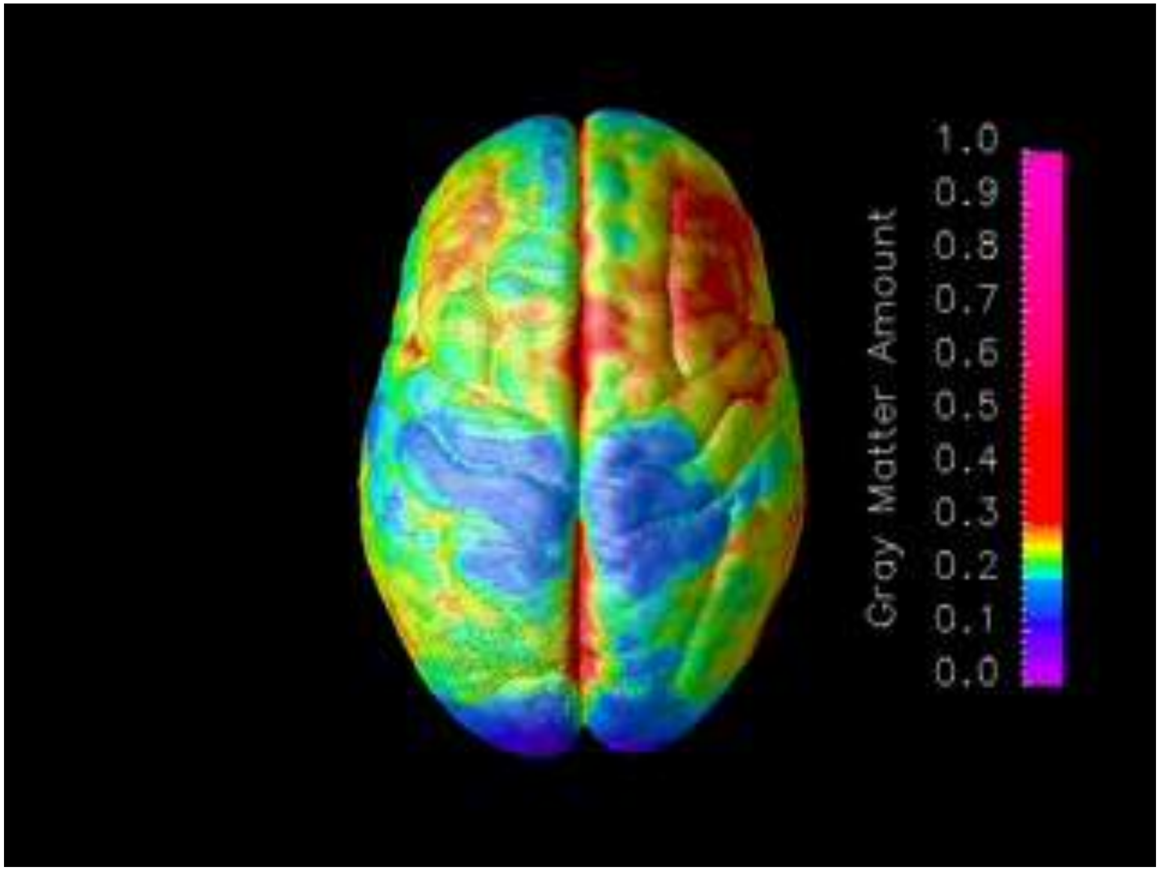


Developmental Brain Changes in Cerebral Cortex



Gogtay et al., *PNAS*, 2004

Cortical Brain Growth Thinning
Ages 4-21



Gogtay et al., *PNAS*, 2004

A Paradox

- **higher SES is most often associated with *thicker* or *greater* cortex (this study; Hanson et al., 2013; Jednoróg et al., 2012; Lawson et al., 2013; Noble et al., 2012, 2015; Hair et al., 2015; Betancourt et al., 2015)**

- **in other studies in which SES is not considered (higher SES?) *thinner* cortex associated with better neuropsychological functioning (Schnack et al., 2014; Squeglia et al., 2013)**

- **is accelerated thinning detrimental or adaptive or both?**

Executive Functions, Schools, and Academic Achievement

Executive Functions

(cognitive control, supervisory attentional system)

regulation/management of cognitive (& emotional) processes

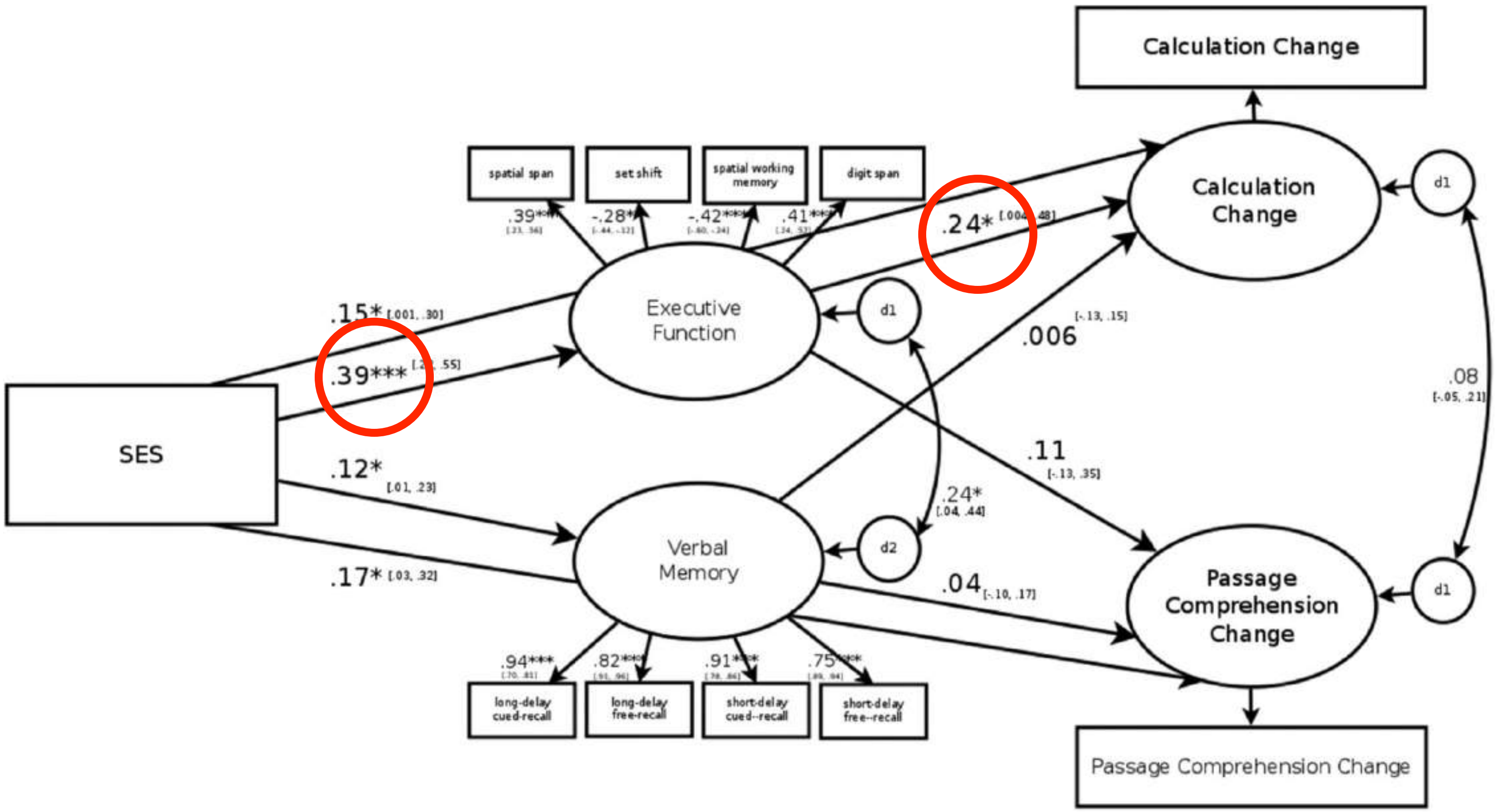
- working memory
- reasoning
- flexibility
- problem solving
- planning & execution of plan

Academic Achievement

scores on statewide standardized tests

Executive Function as a Mediator Between SES & Academic Achievement Throughout Childhood

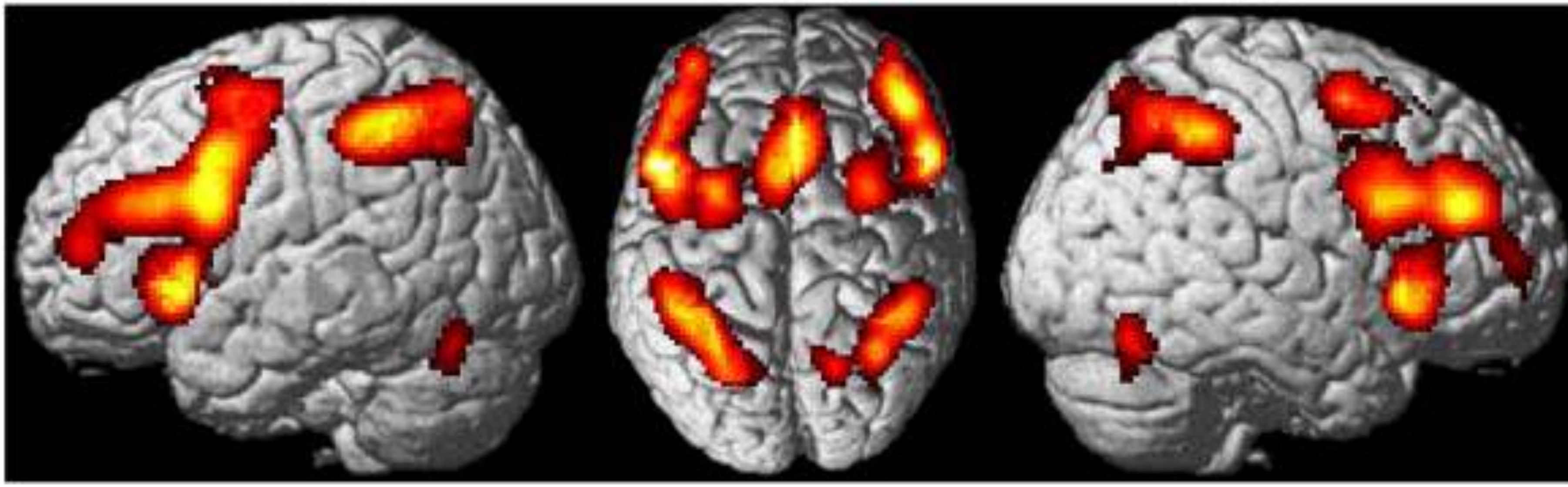
parental education and family income and changes in reading and math achievement in a sample of 336 children between the ages of 6 and 15 years from the NIH MRI Study of Normal Brain Development



Path output with standardized estimates and 95% confidence intervals for the Full Model

Gwendolyn M Lawson, and Martha J Farah International Journal of Behavioral Development 2015;0165025415603489

Meta-Analysis of 189 Neuroimaging Studies of Working Memory

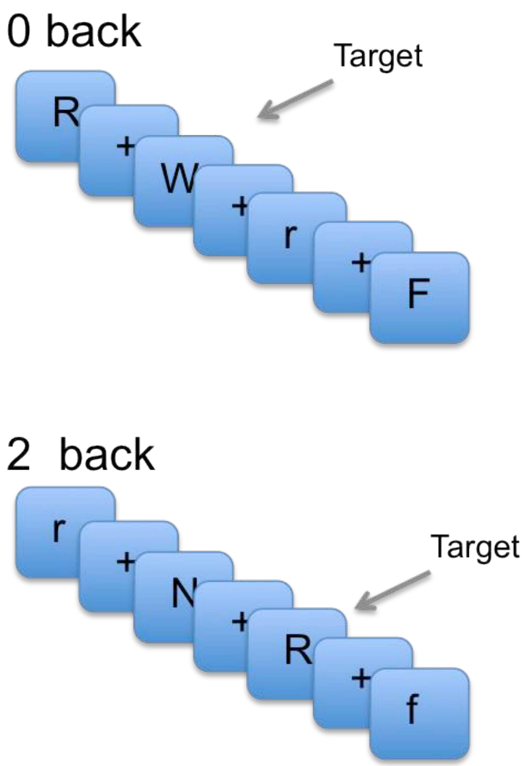


Rottschy et al., *NeuroImage,* 2012

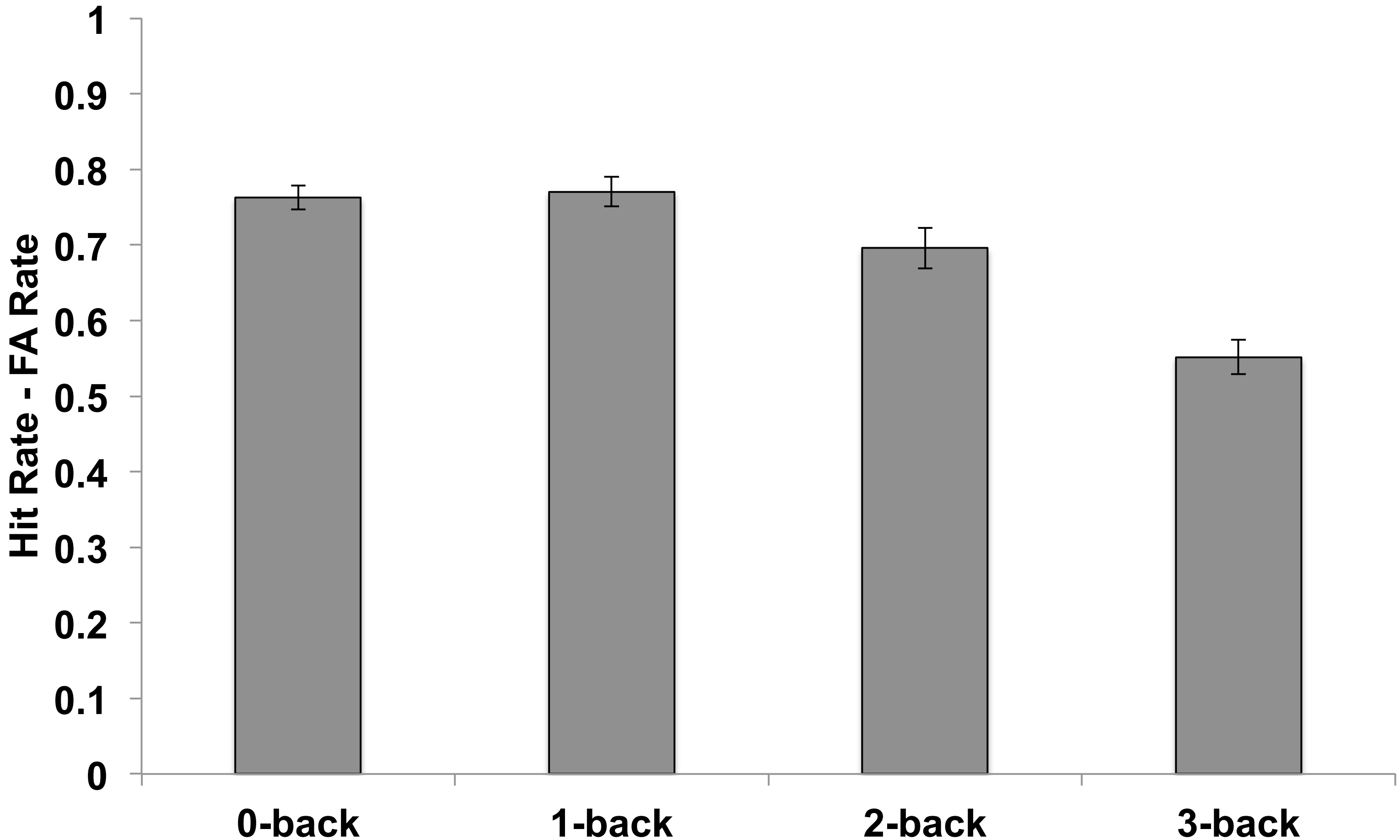
*activation for fluid reasoning (*Prabhakaran et al.*, Cognitive Psychology,* 1997)

Working Memory, Brain, & MCAS

- **diverse sample of 53 8th graders**
- **N-Back test of working memory capacity**

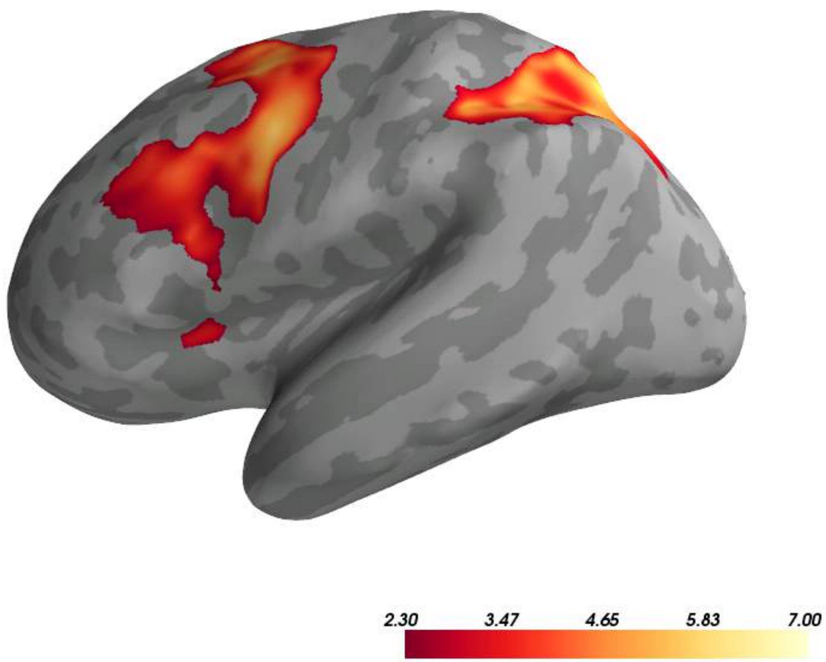


N-Back Performance

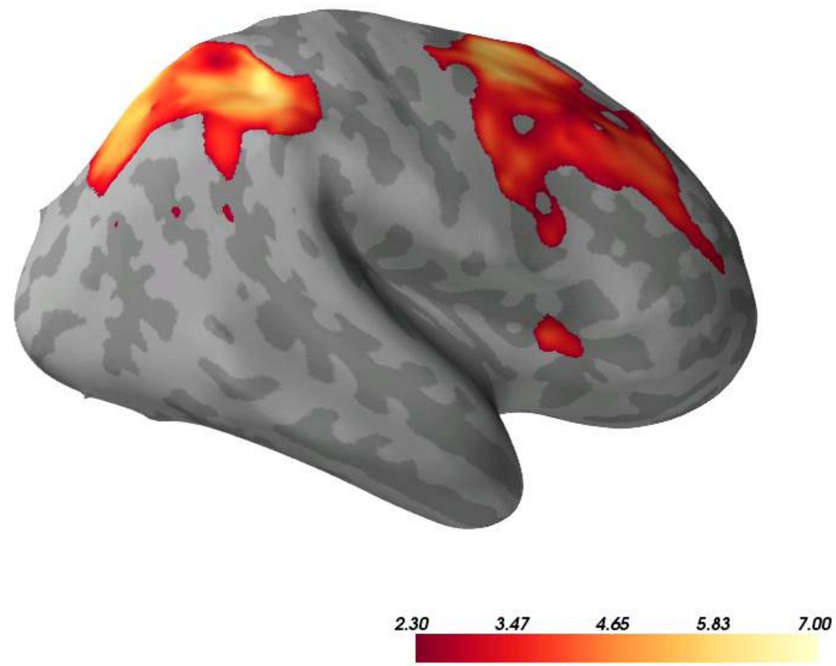


Finn et al., *Developmental Science*, 2016

Greater Activation in Prefrontal & Parietal Neocortices with Greater Working Memory Demand



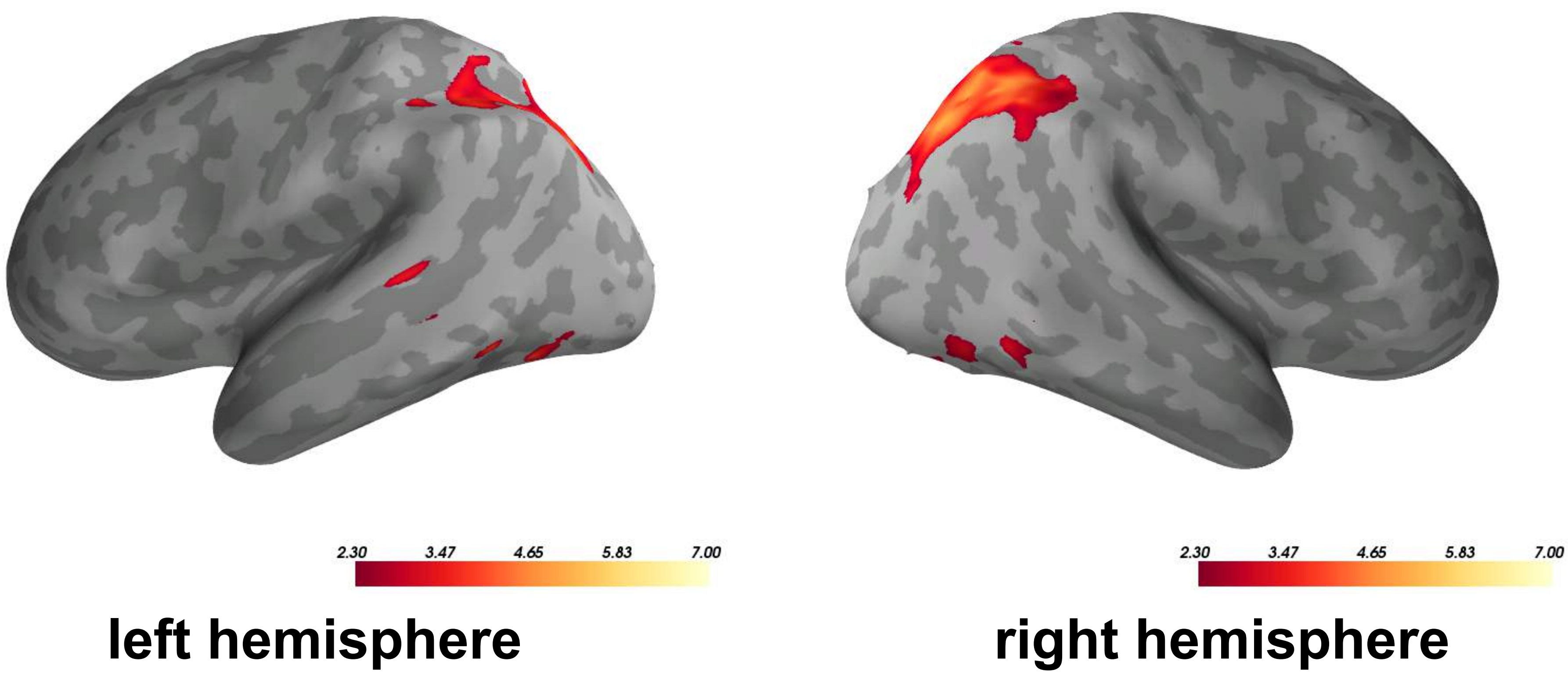
left hemisphere



right hemisphere

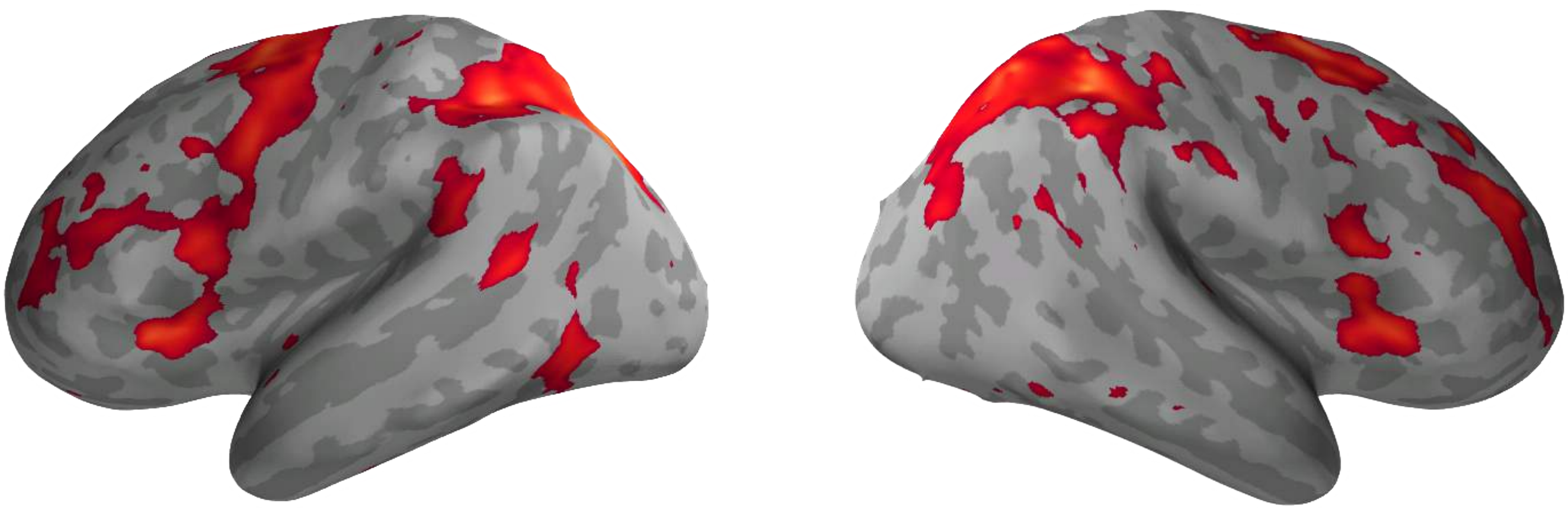
Finn et al., *Developmental Science*, 2016

Greater Working Memory Activation Associated With Higher MCAS Math Test Scores

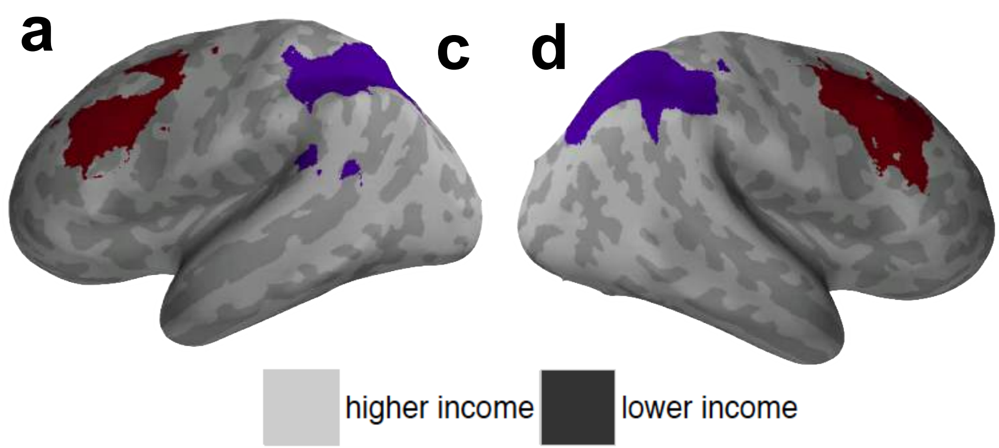


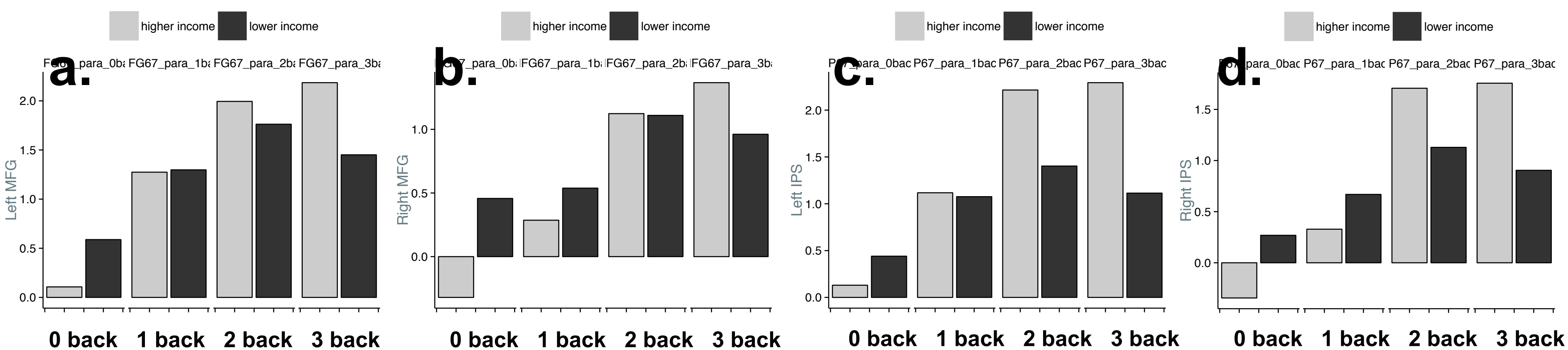
Finn et al., *Developmental Science*, 2016

Greater Activation in High- Than Low-Income Students in Response to Increasing WM Demands



Finn et al., *Developmental Science*, 2016





Finn et al., *Developmental Science*, 2016

Executive Functions, Schools, and Academic Achievement

- ***1,367 8th graders in 32 middle school in Boston Public Schools***
  - 47% male, 77% free-lunch eligible
  - 41% African- American, 36% Hispanic, 12% White
- **MCAS scores (Math & ELA) from 4th and 8th grades**
- **three measures of executive function**
  - fluid reasoning
  - working memory capacity
  - processing speed

Finn et al., *Psychological Science*, 2014

Processing Speed

1	3	4	2	1	3	1	2	3	1	4	2	6	3

1	2	5	1	3	1	5	4	2	7	4	6	9	2	5	8	4	7	6	1	8

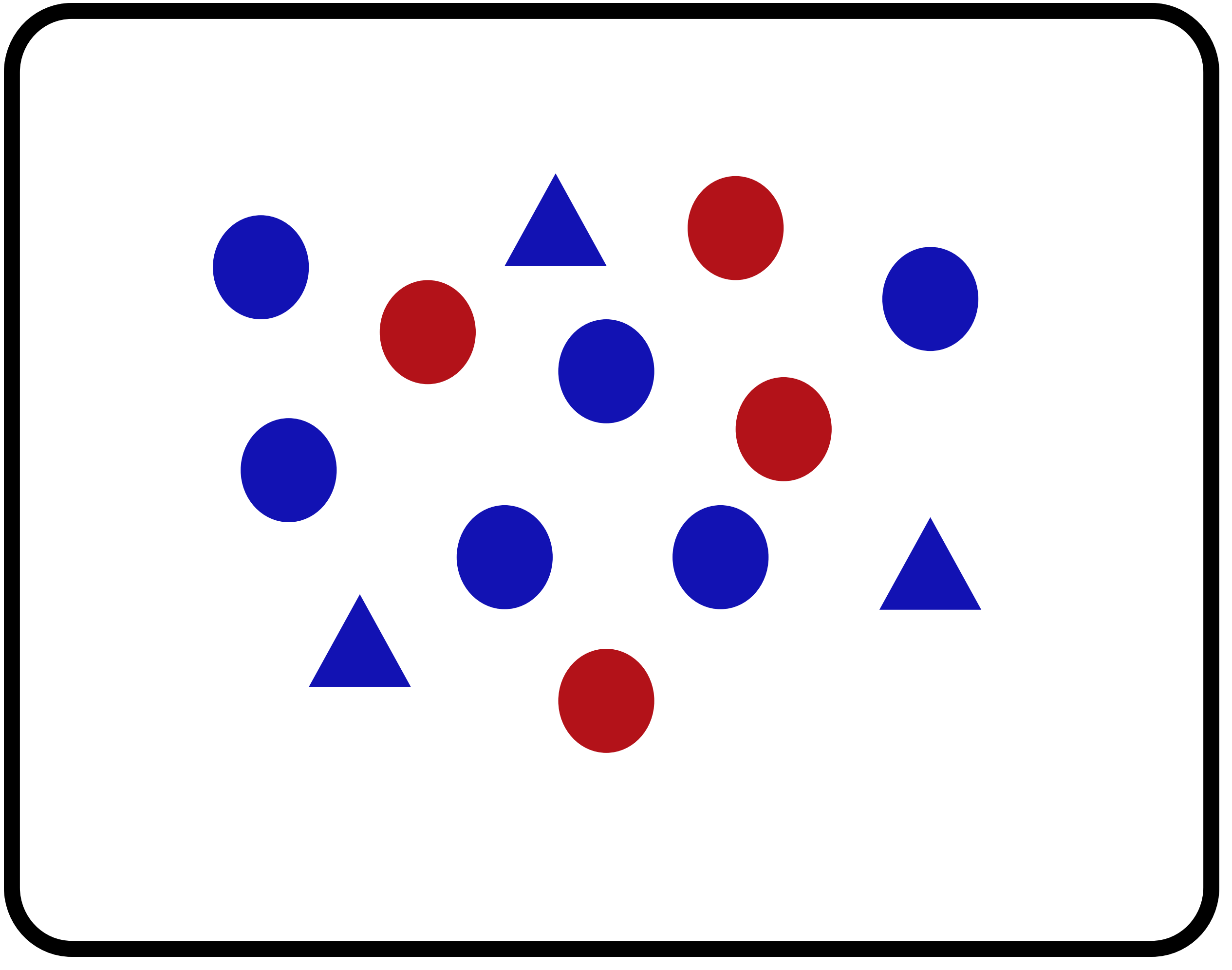
7	5	4	8	6	9	4	3	1	8	2	9	7	6	2	5	8	7	3	6	4

5	9	4	1	6	8	9	3	7	5	1	4	9	1	5	8	7	6	9	7	8

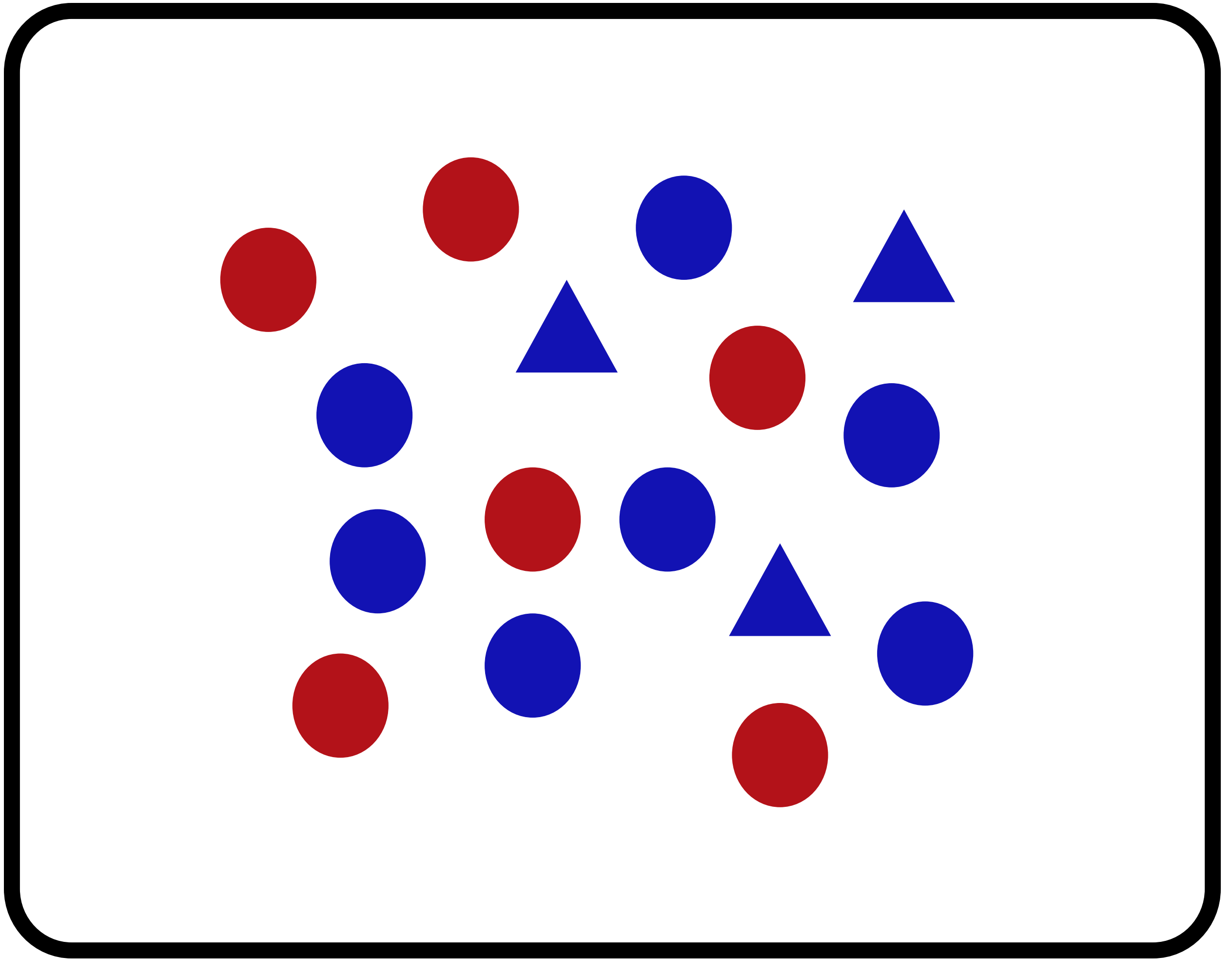
2	4	8	3	5	6	7	1	9	4	3	6	2	7	9	3	5	6	7	4	5

2	7	8	1	3	9	2	6	8	4	1	3	2	6	4	9	3	8	5	1	8

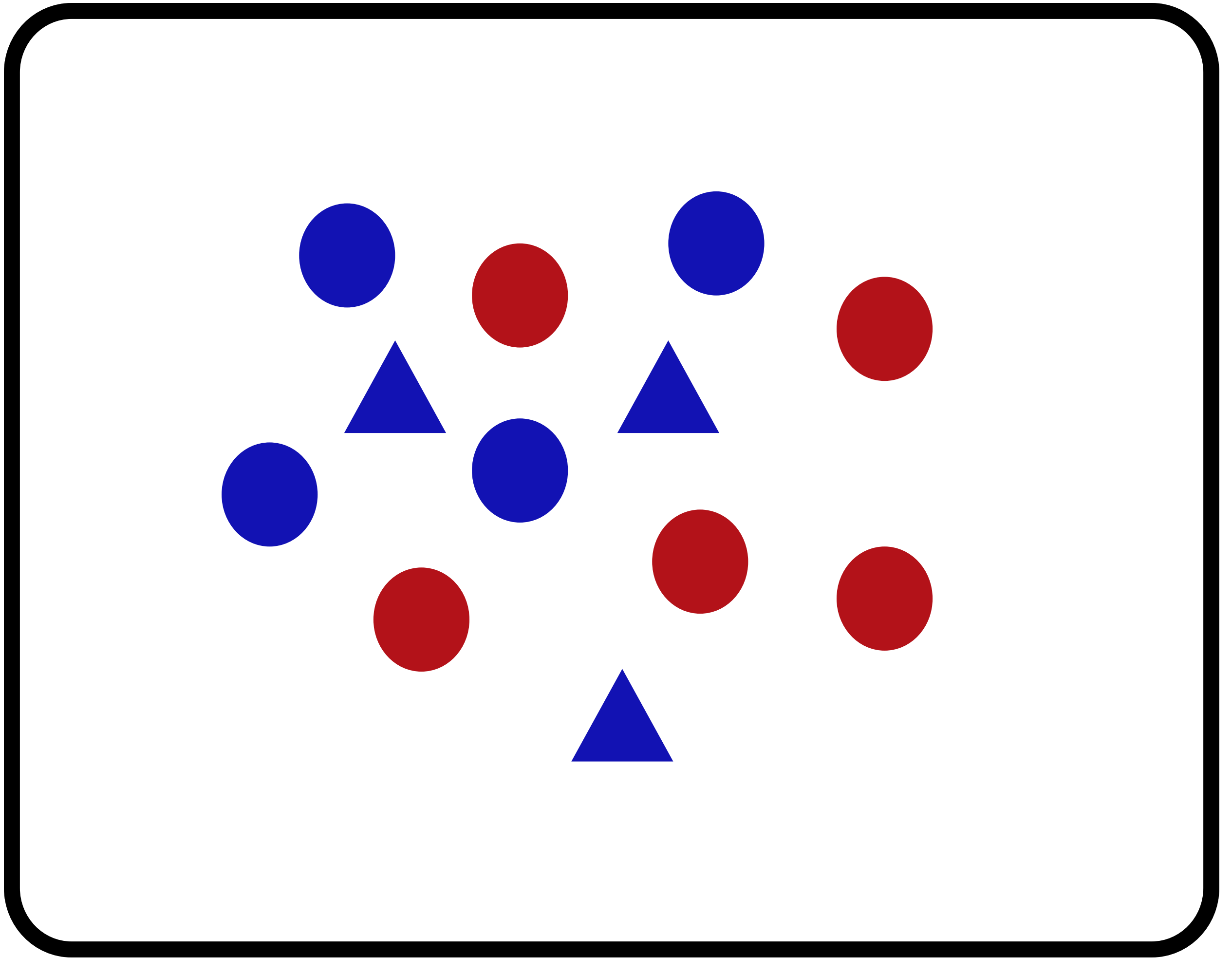
Working Memory



Working Memory



Working Memory



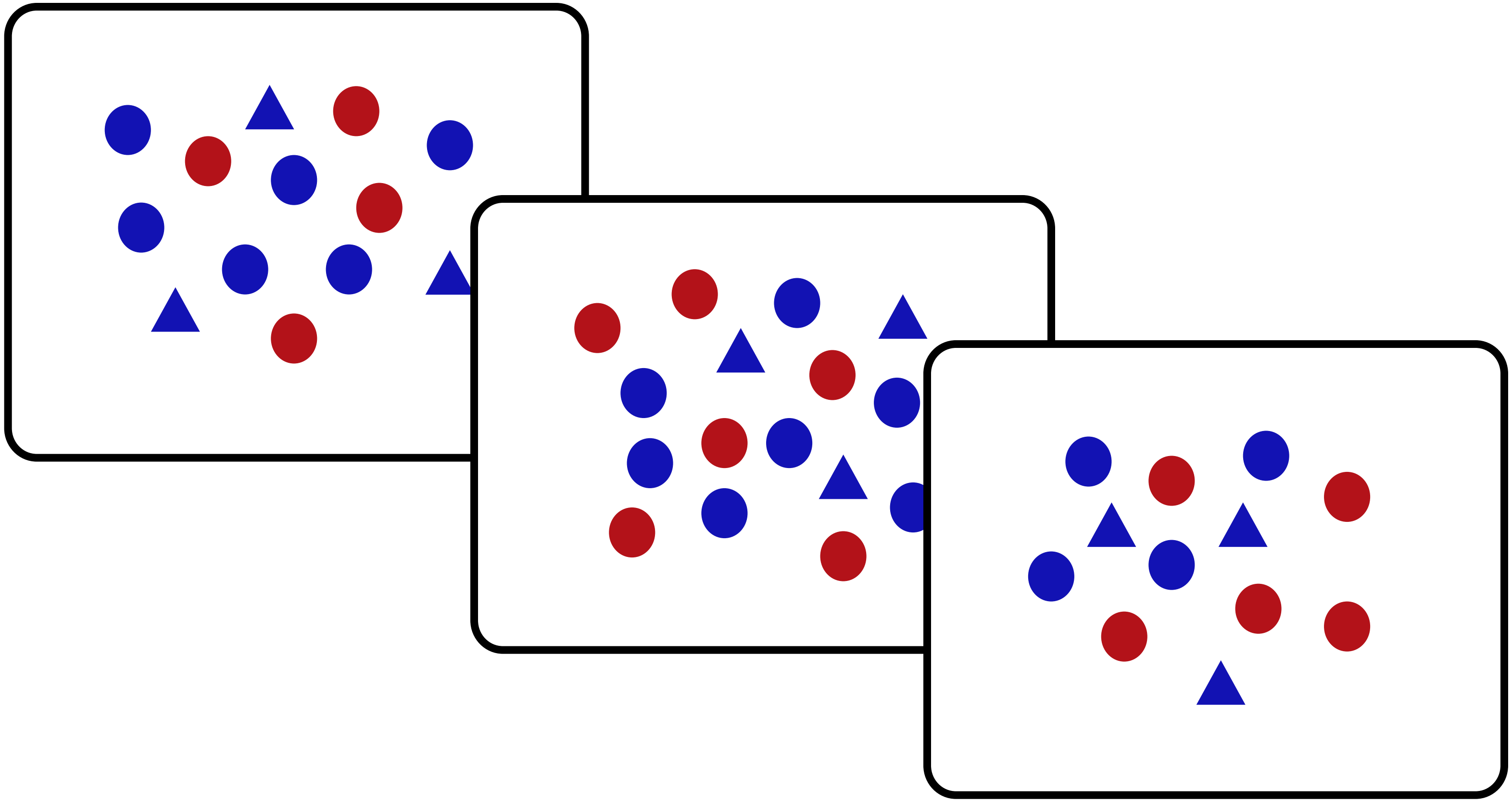
Working Memory

Answer?

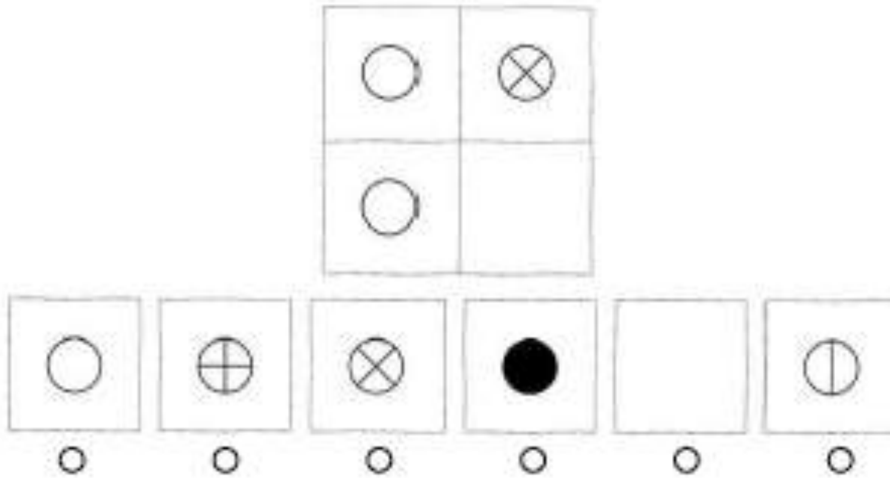
Working Memory

Answer?

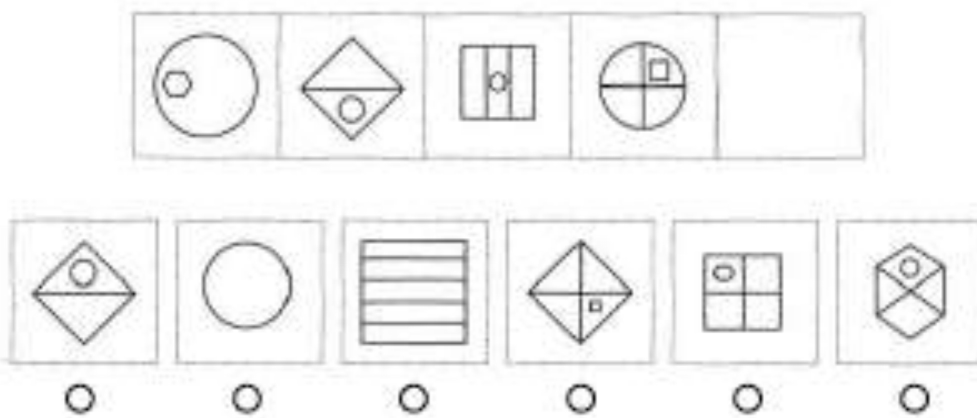
6 **7** **4**



Fluid Reasoning



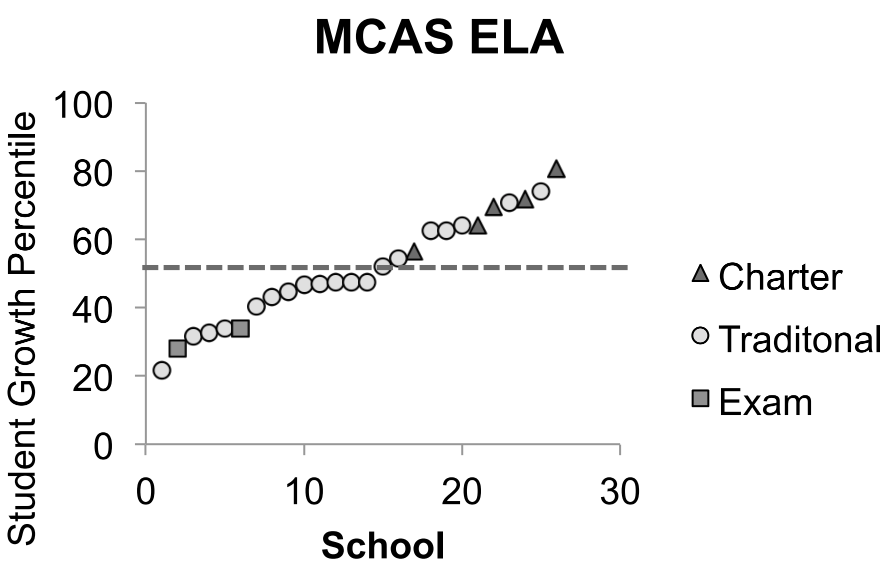
1 2 3 4 5 6

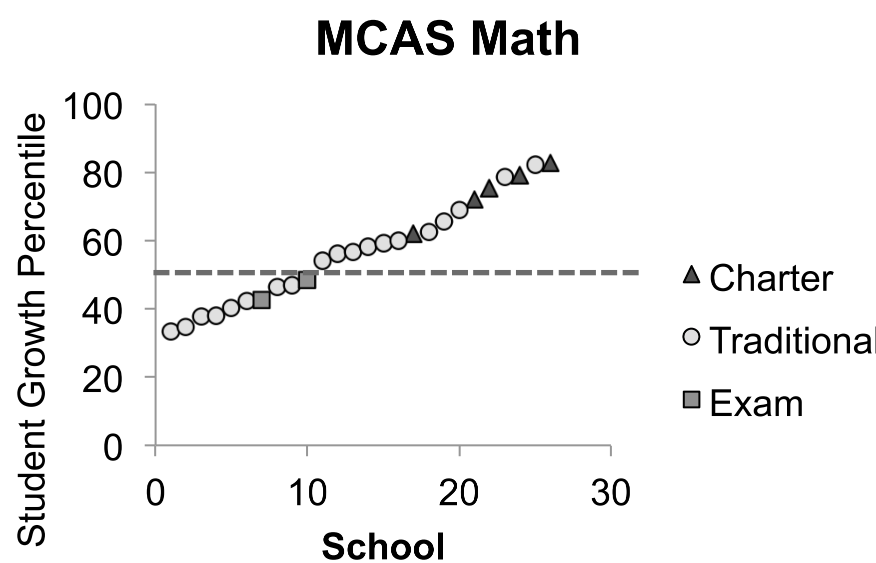


1 2 3 4 5 6

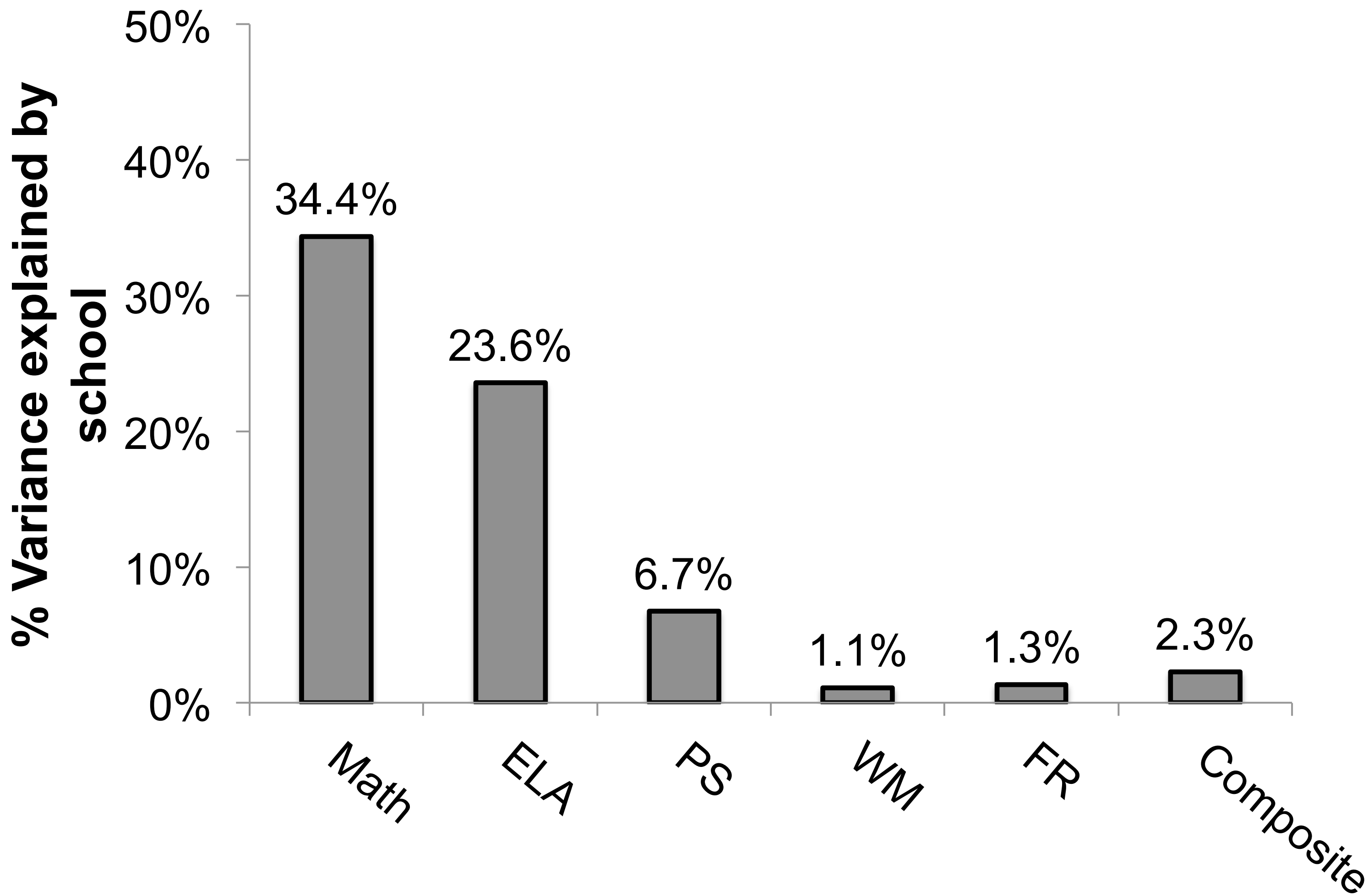
Schools Vary In Raising Test Scores

- **student growth percentile**





Schools Influence Test Gains, But Not Executive Functions



Finn et al., *Psychological Science*, 2014

Education, Cognition, & Brain

- **Brain differences associated with academic achievement or SES can reflect genetics, environment, and gene x environment interactions**
- **Brain differences do NOT indicate fixed biological or cognitive differences**
- **Brain is plastic**

Early Language Experience

SES is strongly correlated with children's language exposure = "30 million word gap"

(Hart & Risley 1995)

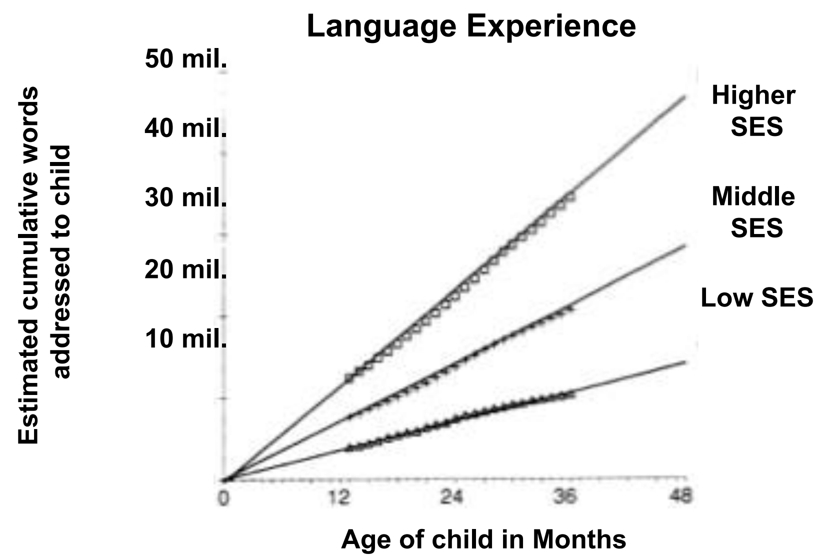
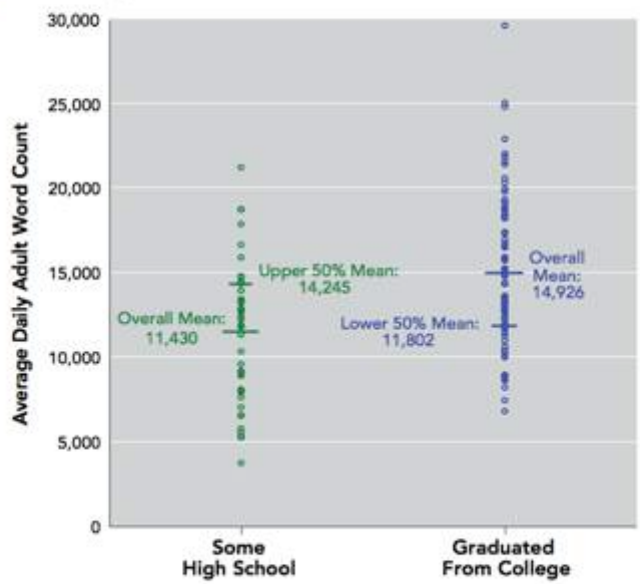


Figure 14. Daily Adult Word Count Varies Within Education Groups



Great variability in language exposure even within SES groups

(LENA Natural Language Study, 2006)

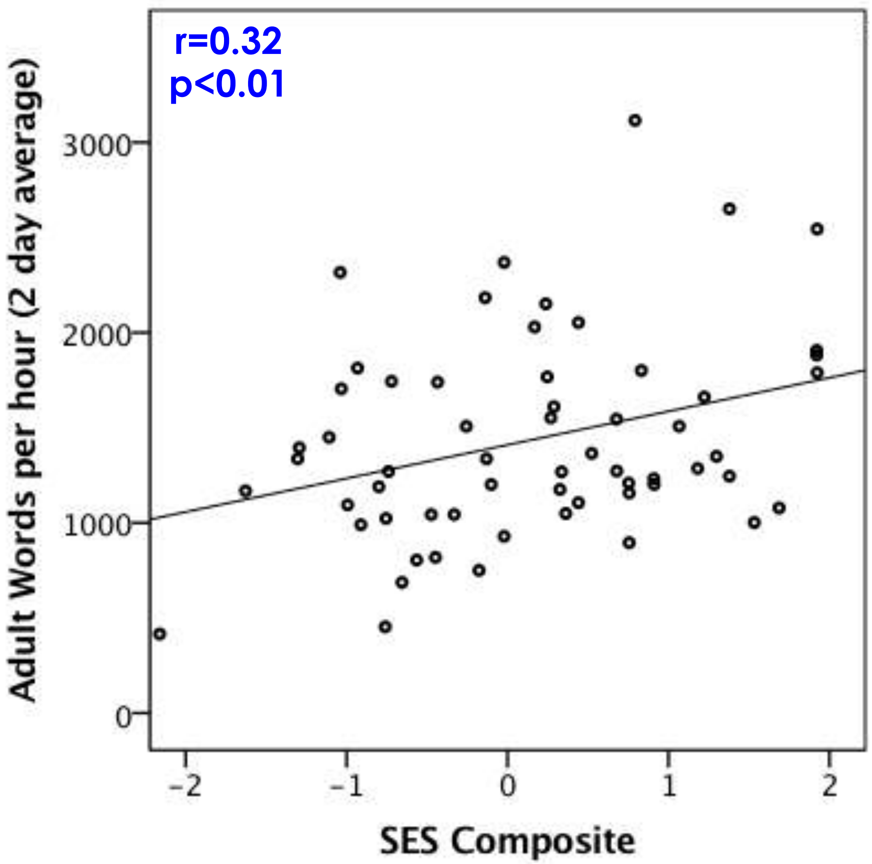
LENA = Language ENvironment Analysis

- Small, child-worn recorder than can hold a whole day's worth of audio (≥16 hours)
- Software automatically analyzes recordings and determines:
  - How many "adult words" the child heard
  - How many "child vocalizations" the child said
  - How many "conversational turns" occurred between the child and any adult

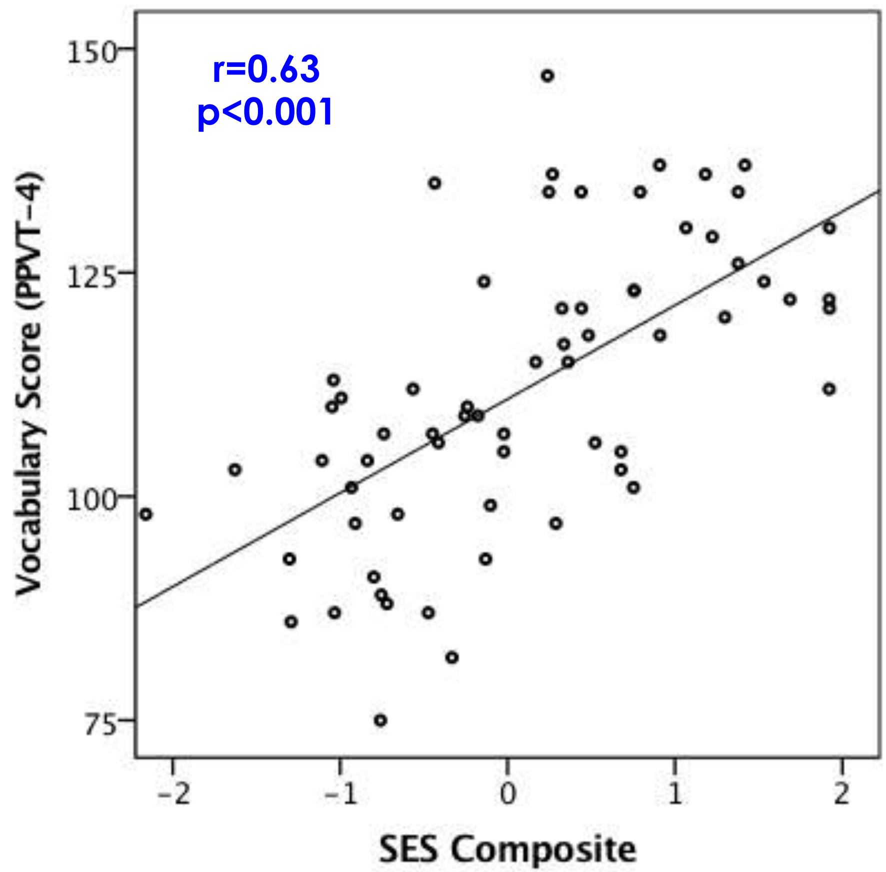
SES "gaps" in Vocabulary & Words Heard

n = 60 children ages 4-6 years

Word Gap



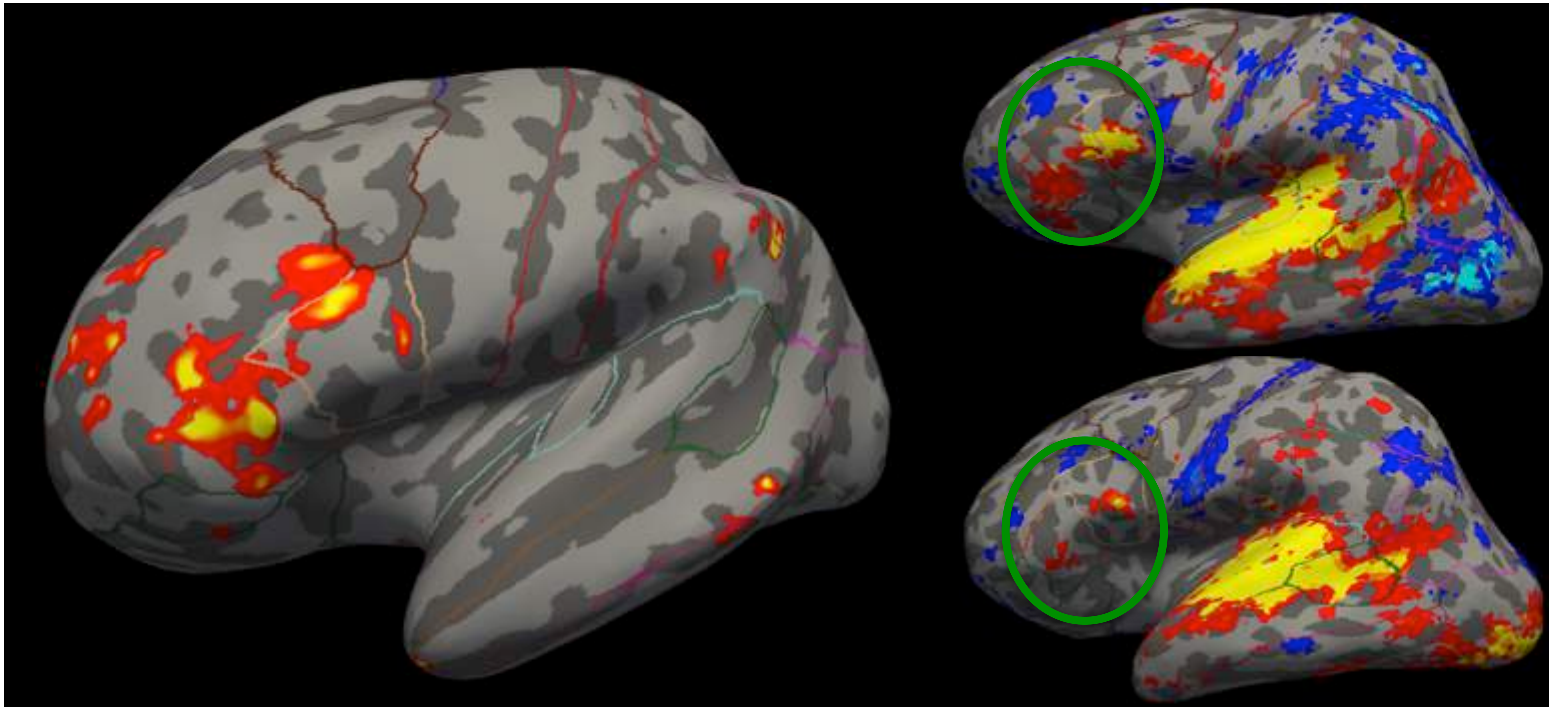
Vocabulary Gap



Romeo et al., SfN 2016

Language Exposure and the Brain

- fMRI: heard simple stories; forward > backwards speech
- correlation with conversational turns independent of SES



Region of
significant correlation
(pars triangularis + pars opercularis)

Two girls, same age & SES
Top hears >1000 CTs per day
Bottom hears < 500 CTs per day

Romeo et al., SfN 2016

Neuroeducation

- Basic neurocognitive research about learning
- Neurocognitive research about educational outcomes
- When brain measures outperform conventional behavioral measures

DEVELOPMENTAL DYSLEXIA

- **unexplained difficulty in reading in 5 to 10% of children**

Natural Development of Spoken & Heard Language

Learning to Read: Formal, Explicit Instruction

UNITS OF WRITTEN & SPOKEN LANGUAGE

Item	Examples						
Pictures							
Words	Book			Scarf			
Graphemes	B	OO	K	S	C	AR	F
Phonemes	/b/	/oo/	/k/	/s/	/k/	/ahr/	/f/

Phonemes - smallest linguistic units of sound
Graphemes - letter or letters
45 phonemes in English
Learning to read is learning to map phonemes onto graphemes via *phonological awareness*

Paracchini et al., Annu. Rev. Geonmics Hum. Genet., 2007

DYSLEXIA: CAUSES

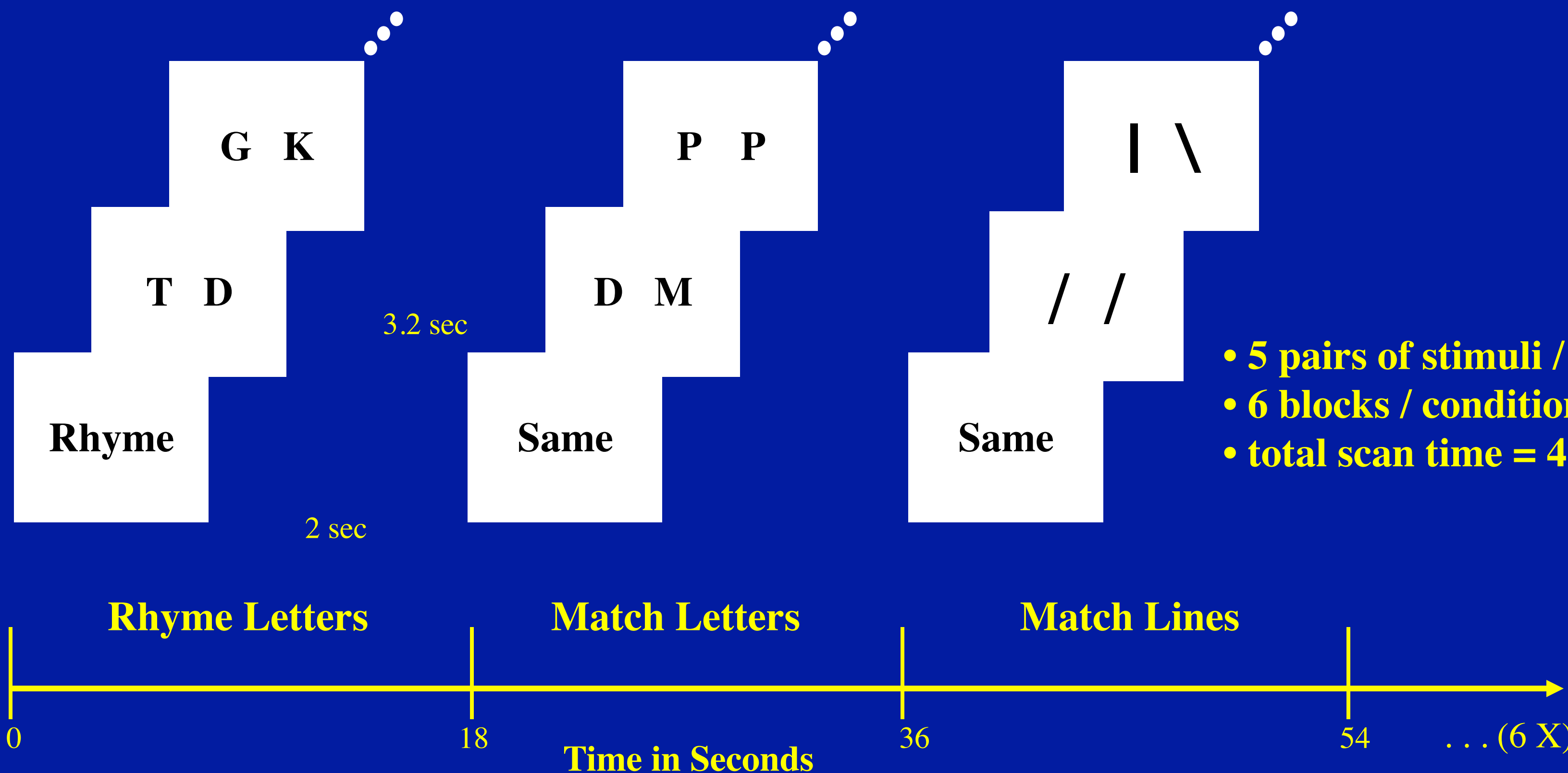
- Phonological Hypothesis
  - deficit in processing of speech sounds
  - poor grapheme-phoneme mapping
- Fluency
- Lower-level perceptual processes (?)

PARTICIPANTS

	Normal Reading Children	Dyslexic Reading Children	
Sample	N=23	N=22	
Age	10.5 (1.9)	10.8 (0.9)	ns
Non-Verbal IQ	13.4	11.3	p=0.04
Word Reading Decoding Comprehension	108.7 110.3 110.8	78.9 86.2 85.6	p<0.0001 p<0.0001 p<0.0001

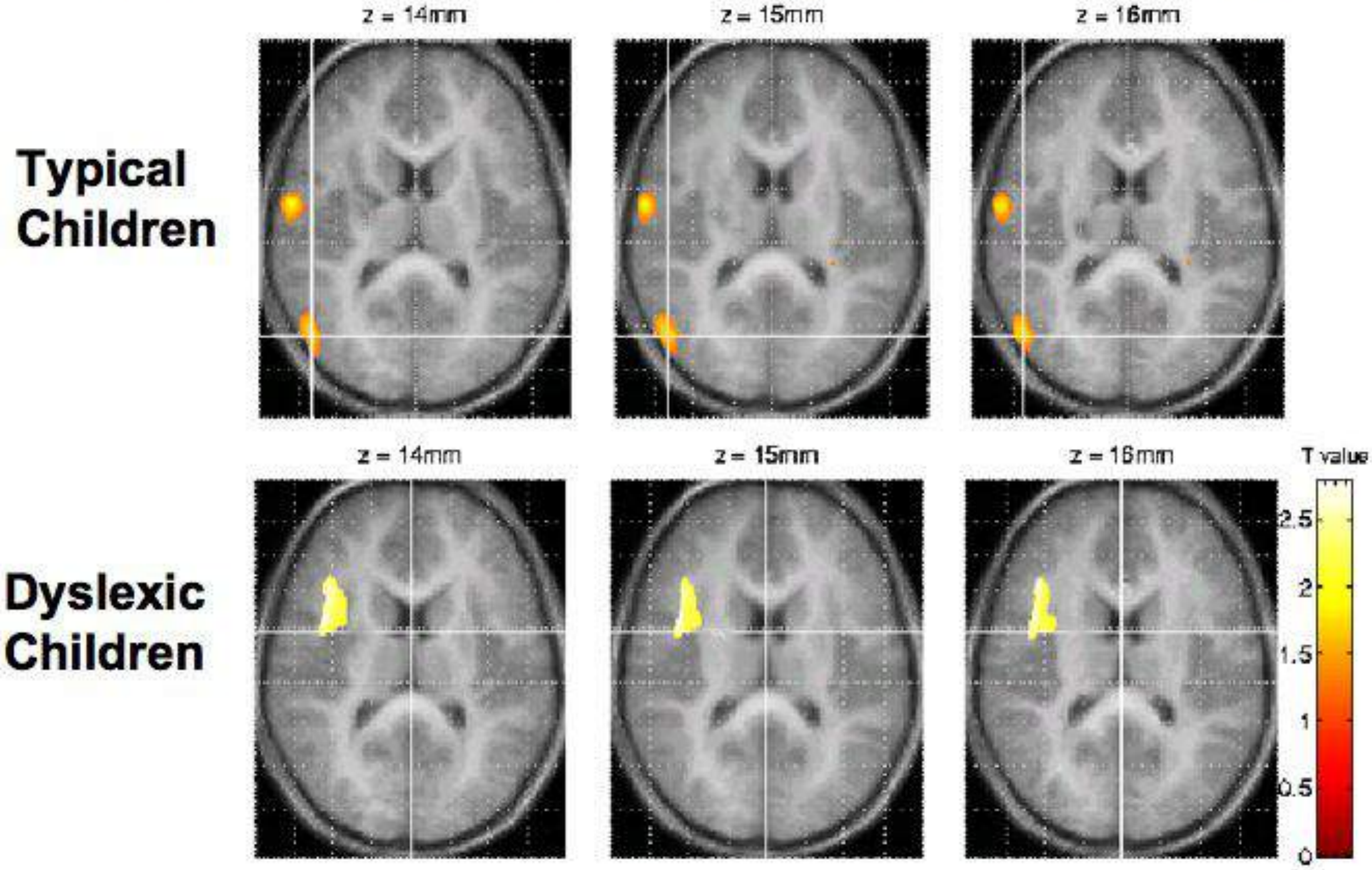
Temple et al., *PNAS*, 2003

Phonological Processing Task



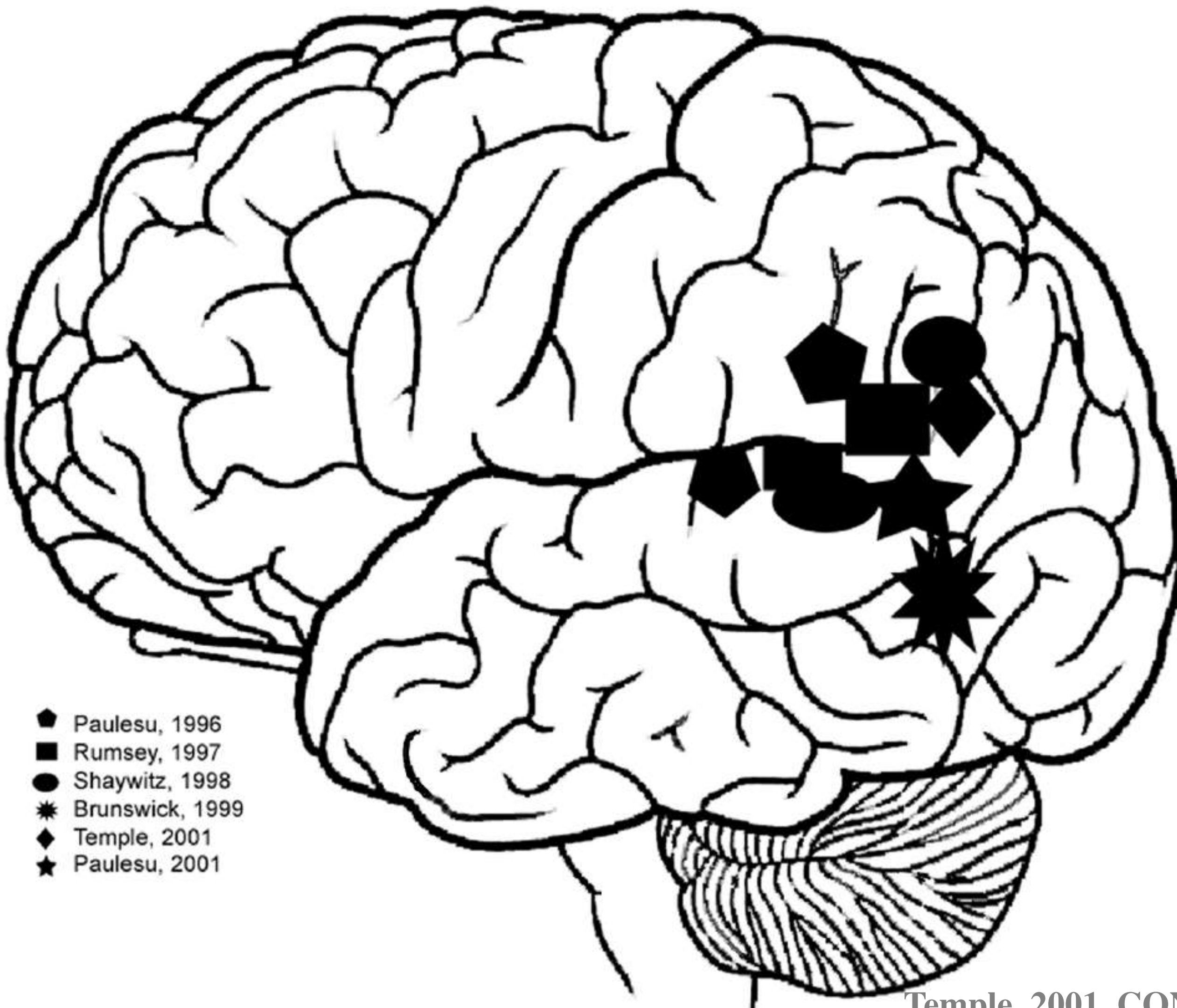
- 5 pairs of stimuli / block
- 6 blocks / condition
- total scan time = 4.5 m.

PHONOLOGICAL PROCESSING



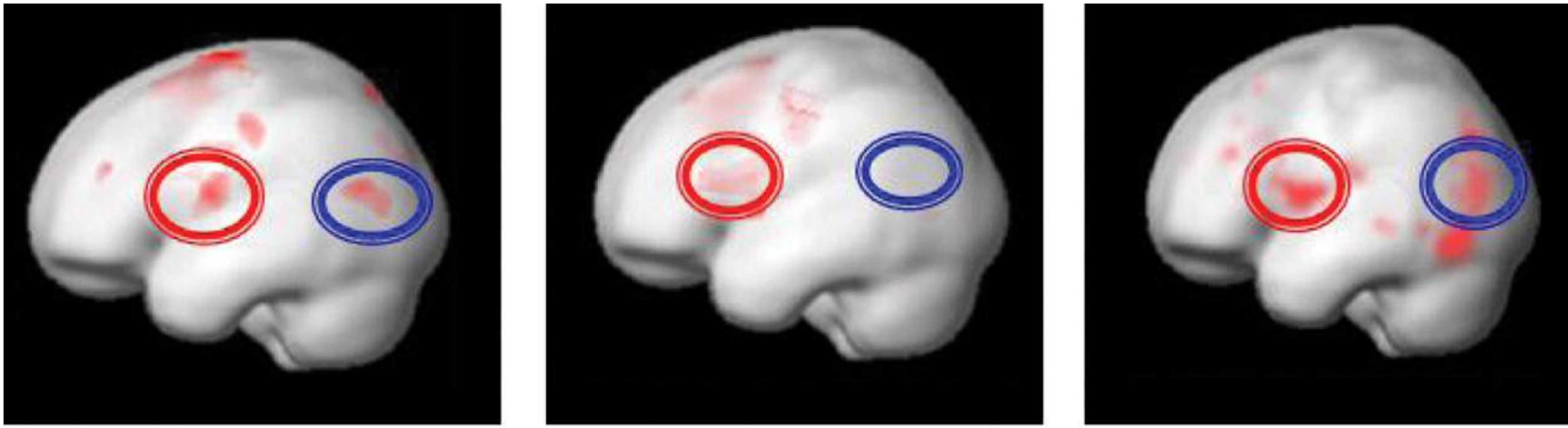
Temple et al., *PNAS*, 2003

Reduced Response for Phonological Analysis of Print In Dyslexia



Temple, 2001, CONB

Brain Plasticity Associated With Effective Remediation In Children with Dyslexia

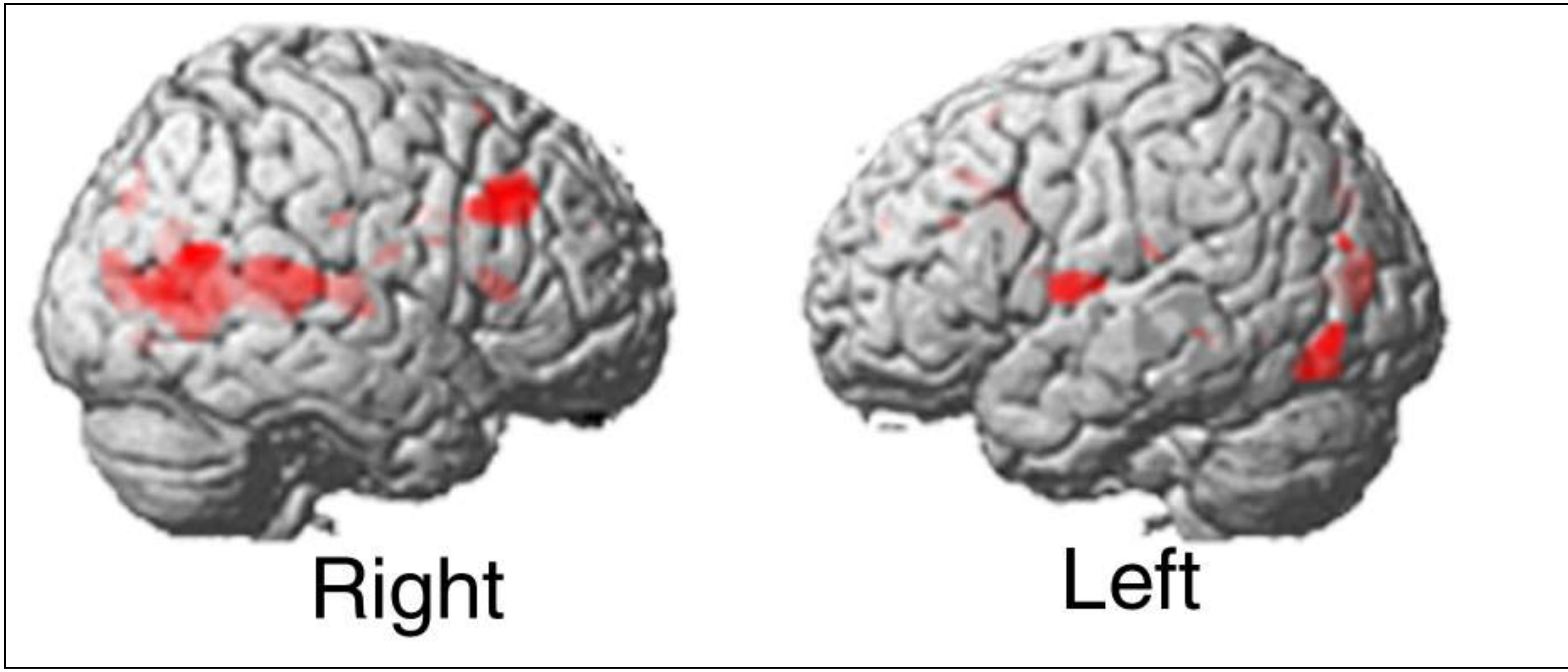


Typically reading children | Children with dyslexia before remediation | Children with dyslexia after remediation

computer-based training for poor readers

Temple at al., *PNAS*, 2003; PNAS; Gabrieli, *Science*, 2009

Brain Effects of Training: Phonological Processing



Compensation & Normalization

Prediction vs. Correlation

- ***Correlations*** **are usually “overly optimistic”**
  - weak relation from one sample to another
- ***Predictions*** **aim to generalize across samples and to yield single-subject values (e.g., leave-one-out cross validation in which each subject’s prediction is based on model from other subjects, independent samples)**

Neuroprediction

- **most group comparisons are based on group *homogeneity;* neuroprediction based on *heterogeneity (diversity)***
- **brain mechanisms for prediction reflect *brain's capacity to respond to education*, may or may not reflect pathophysiology or plasticity in response to treatment**

Predicting Compensation in Dyslexia

- some children compensate, some children do not compensate
- what is the brain basis of compensation?

    more like typical development?

    an alternative brain pathway?
- who compensates? who does not compensate?

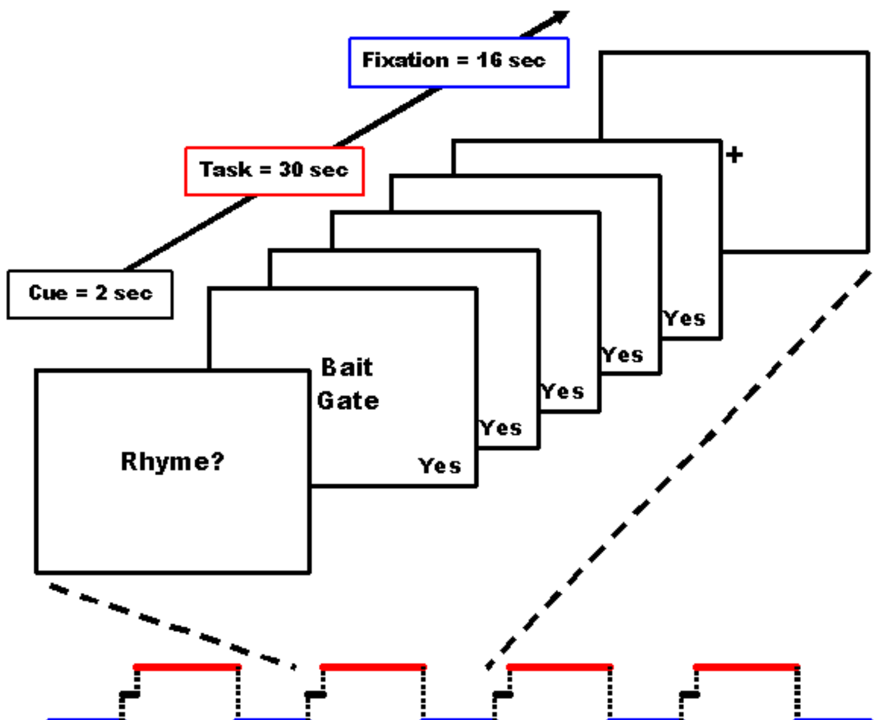
Hoeft et al., PNAS, 2011

Phonological Awareness for Print

Do the two words rhyme?

light & bite -> YES, RHYME

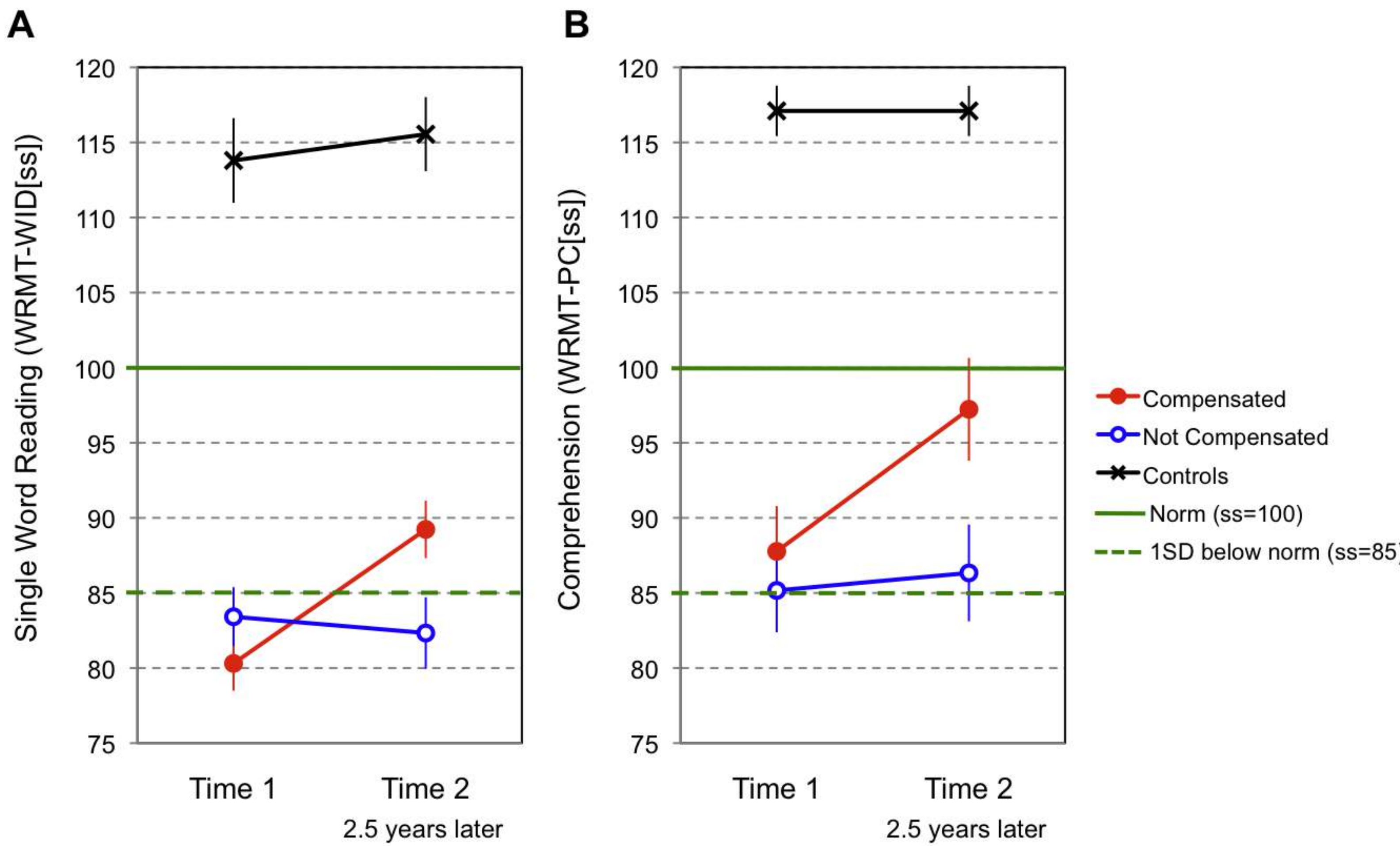
roof & soft -> NO, DON'T RHYME



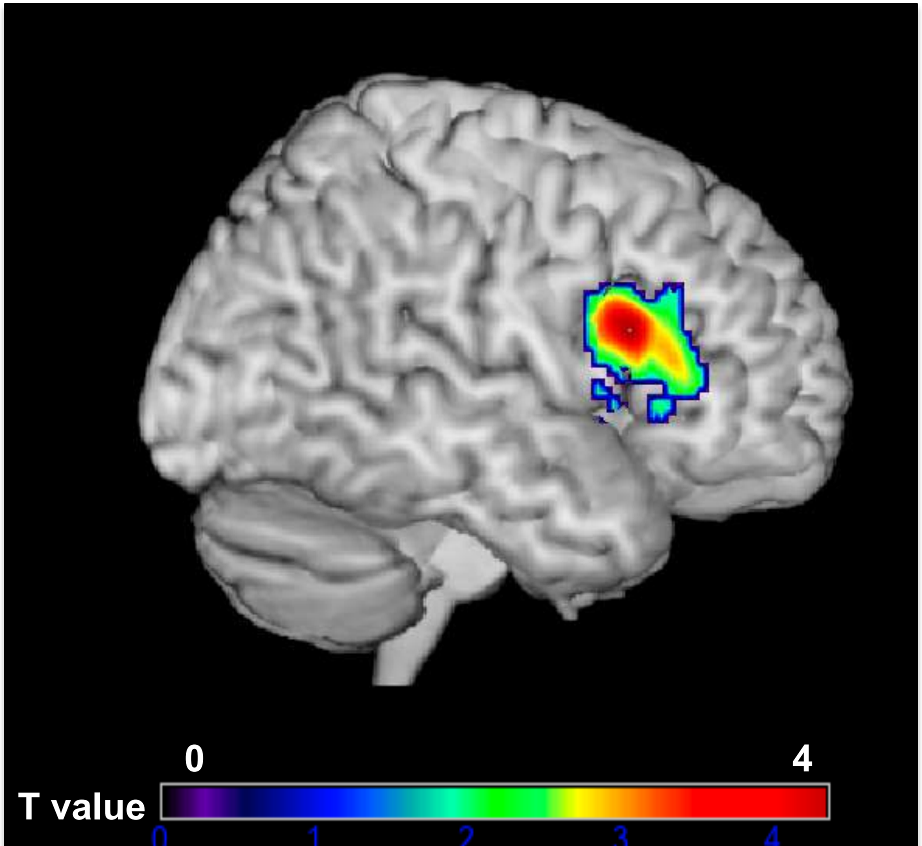
Predicting Compensation in Dyslexia

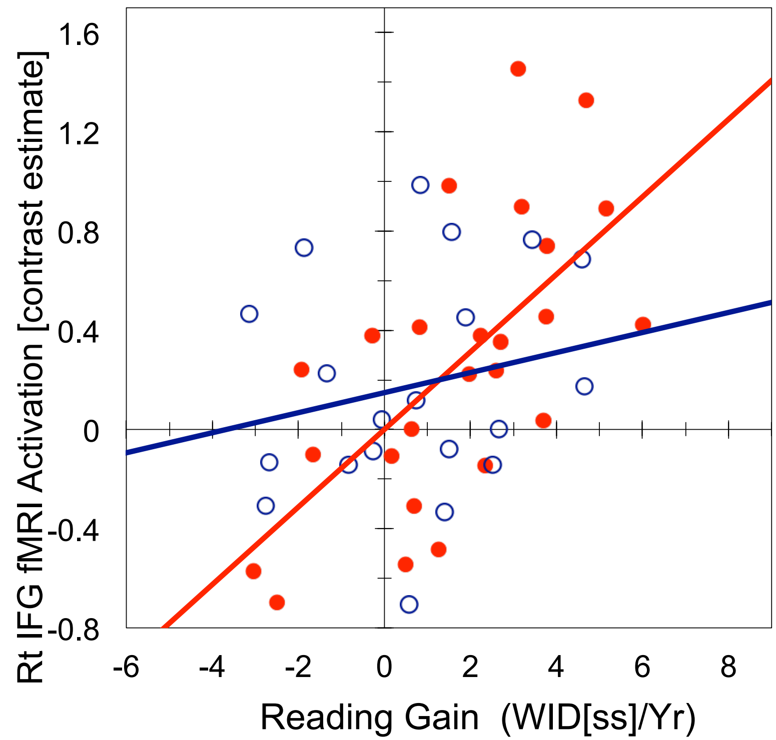
- 25 children with dyslexia, 20 typically reading children
- Time 1 – fMRI on visual rhyme task of phonological ability, DTI, 17 behavioral measures (language, reading, IQ, others)
- 2.5 years
- Time 2 – reading scores

Compensation in Dyslexia Over 2.5 Years



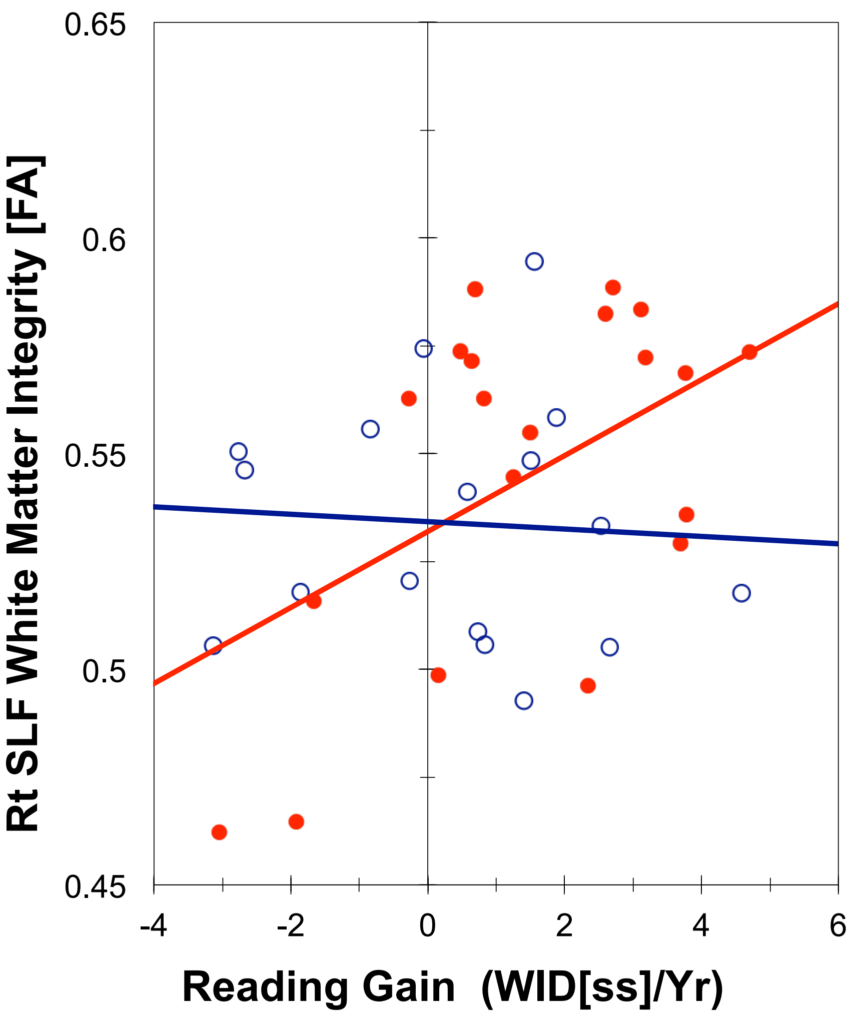
Activation in Right Frontal Cortex Predicts Compensation

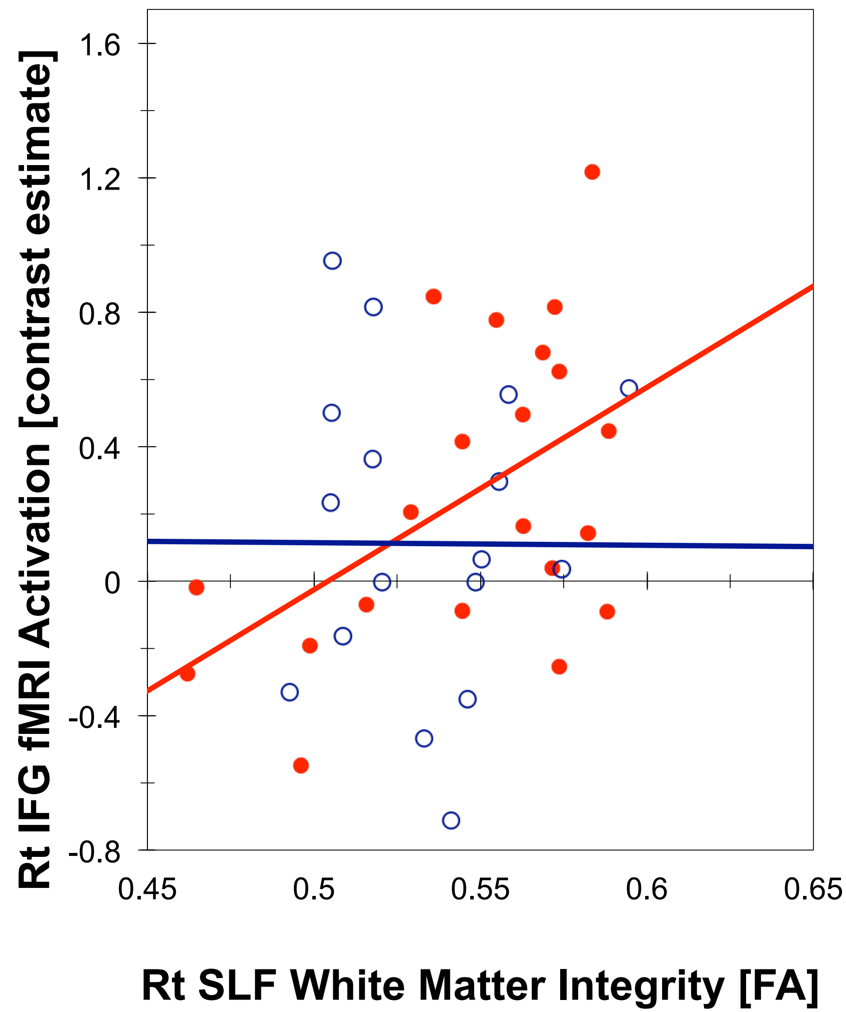




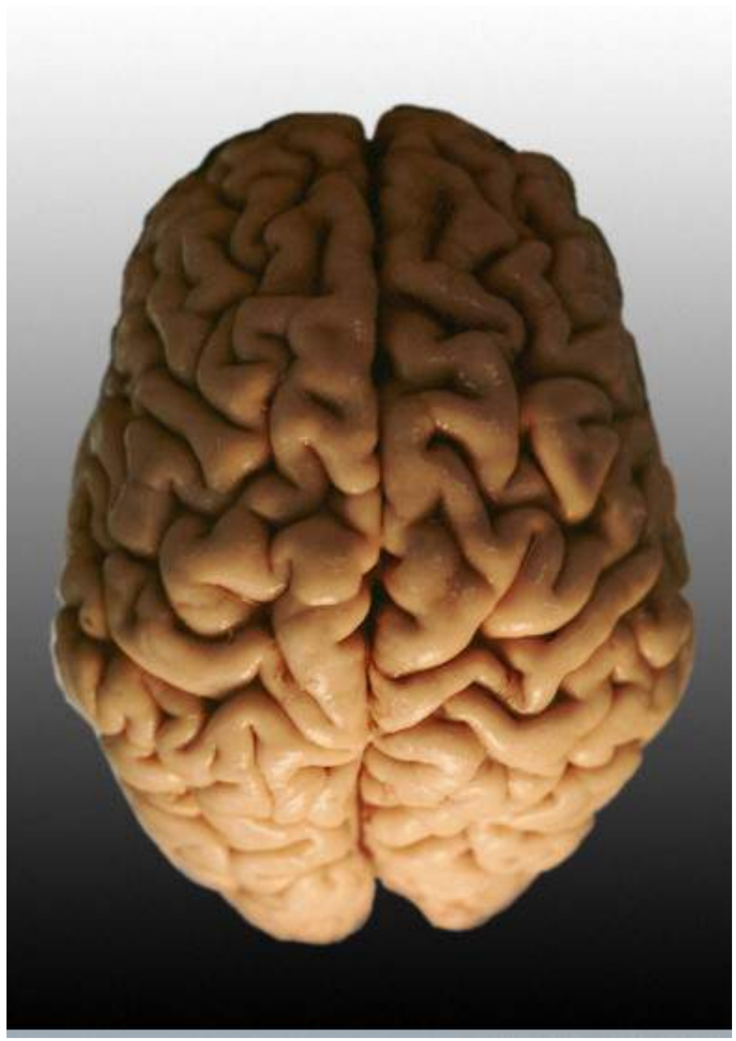
Hoeft et al., PNAS, 2011

Predictors of Future Reading Ability: Diffusion Tensor Imaging (DTI) Measure of Superior Longitudinal Fasciculus Organization





Typical Maturation of Reading Network for Phonological Awareness for Print



Typical Maturation of Reading Network for Phonological Awareness for Print

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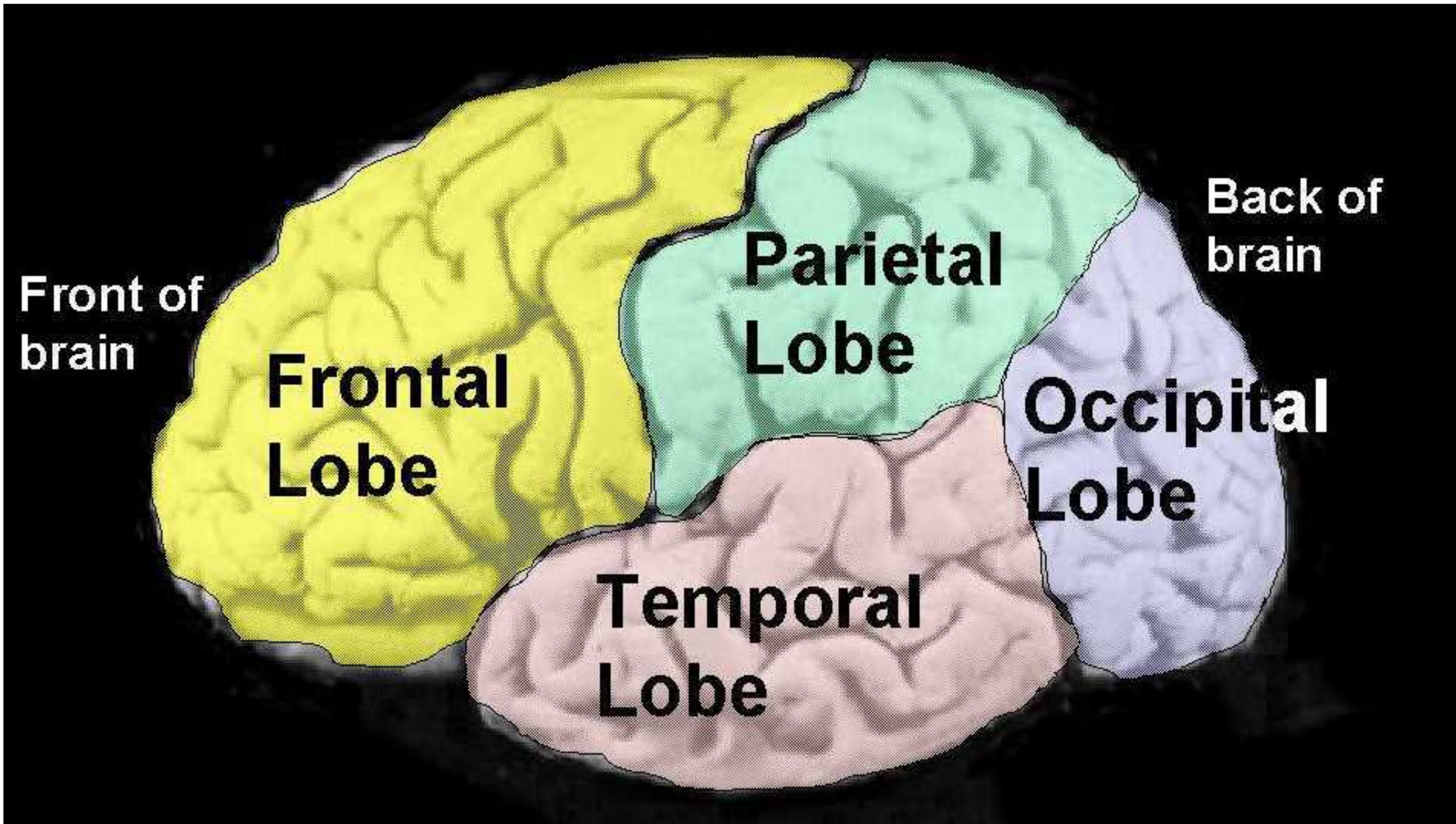

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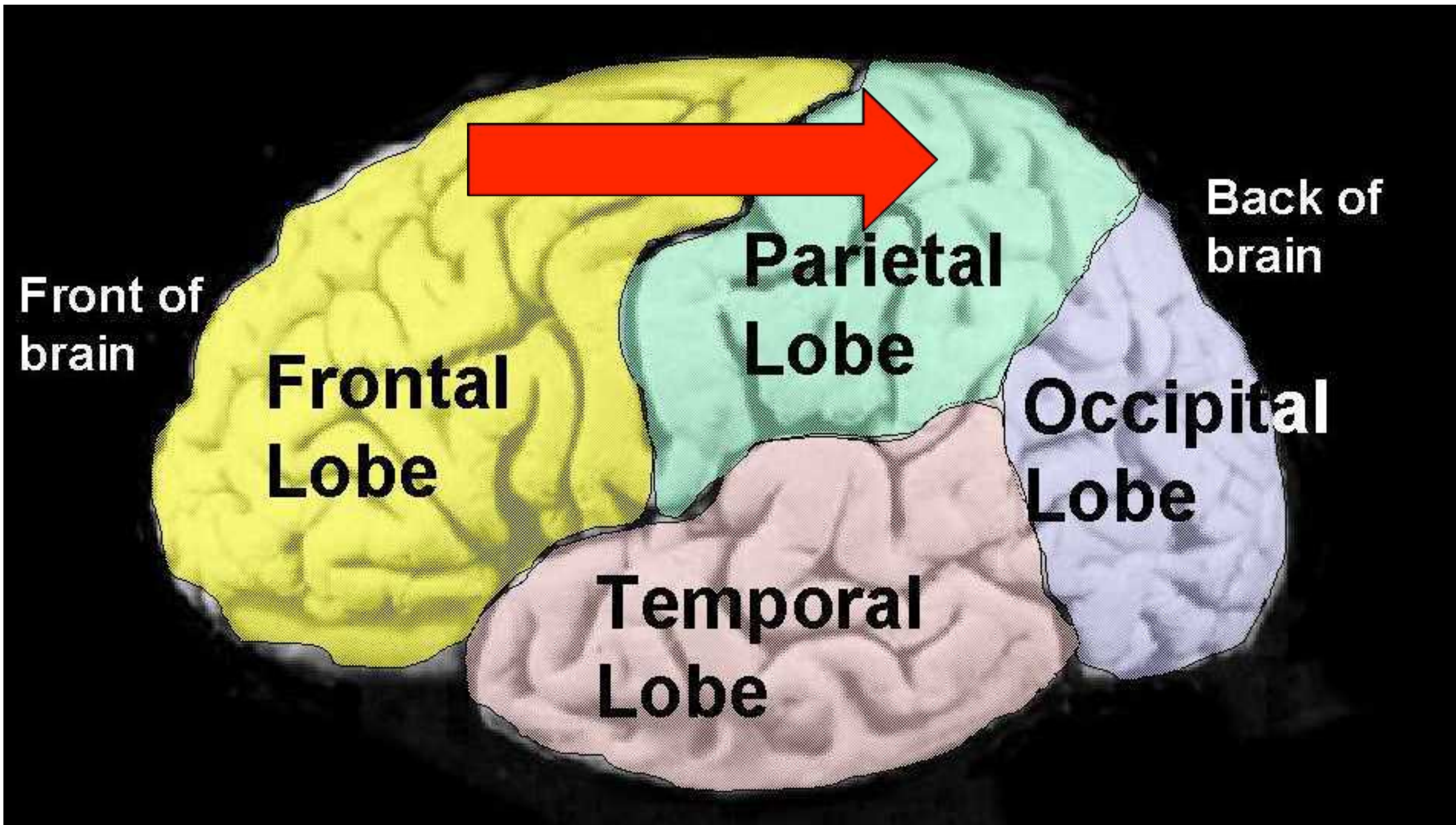

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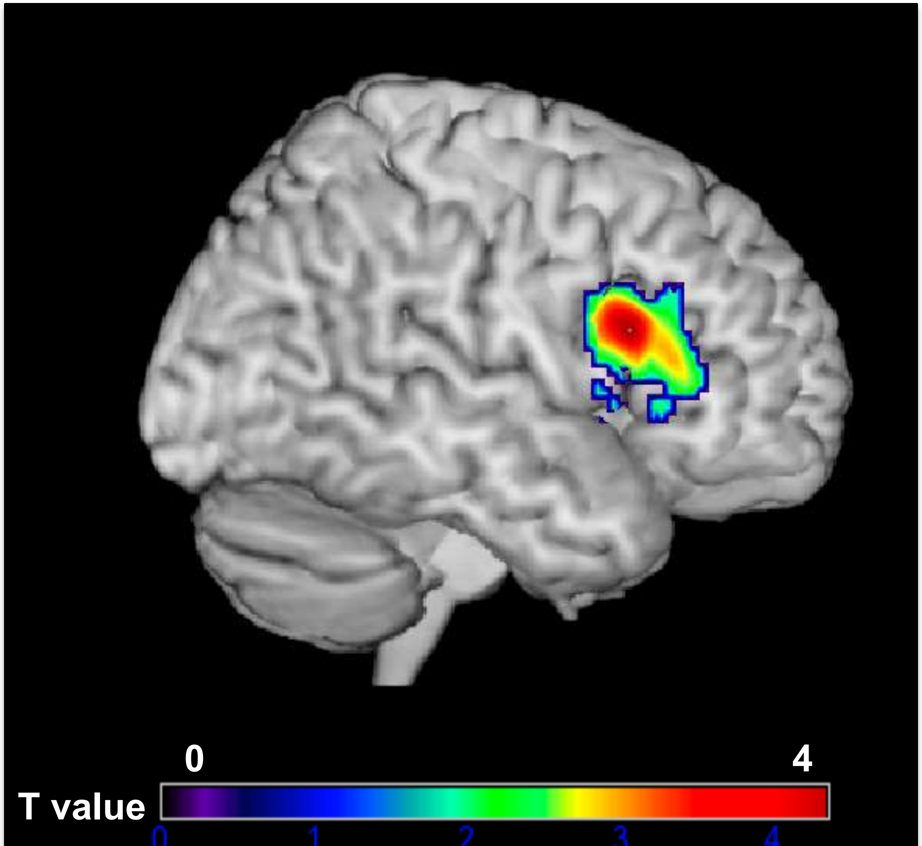
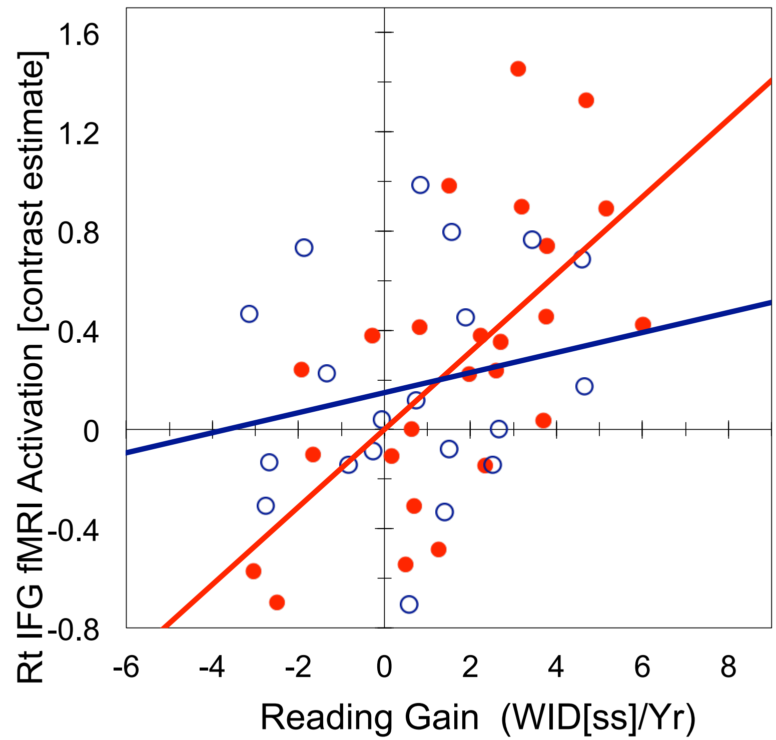
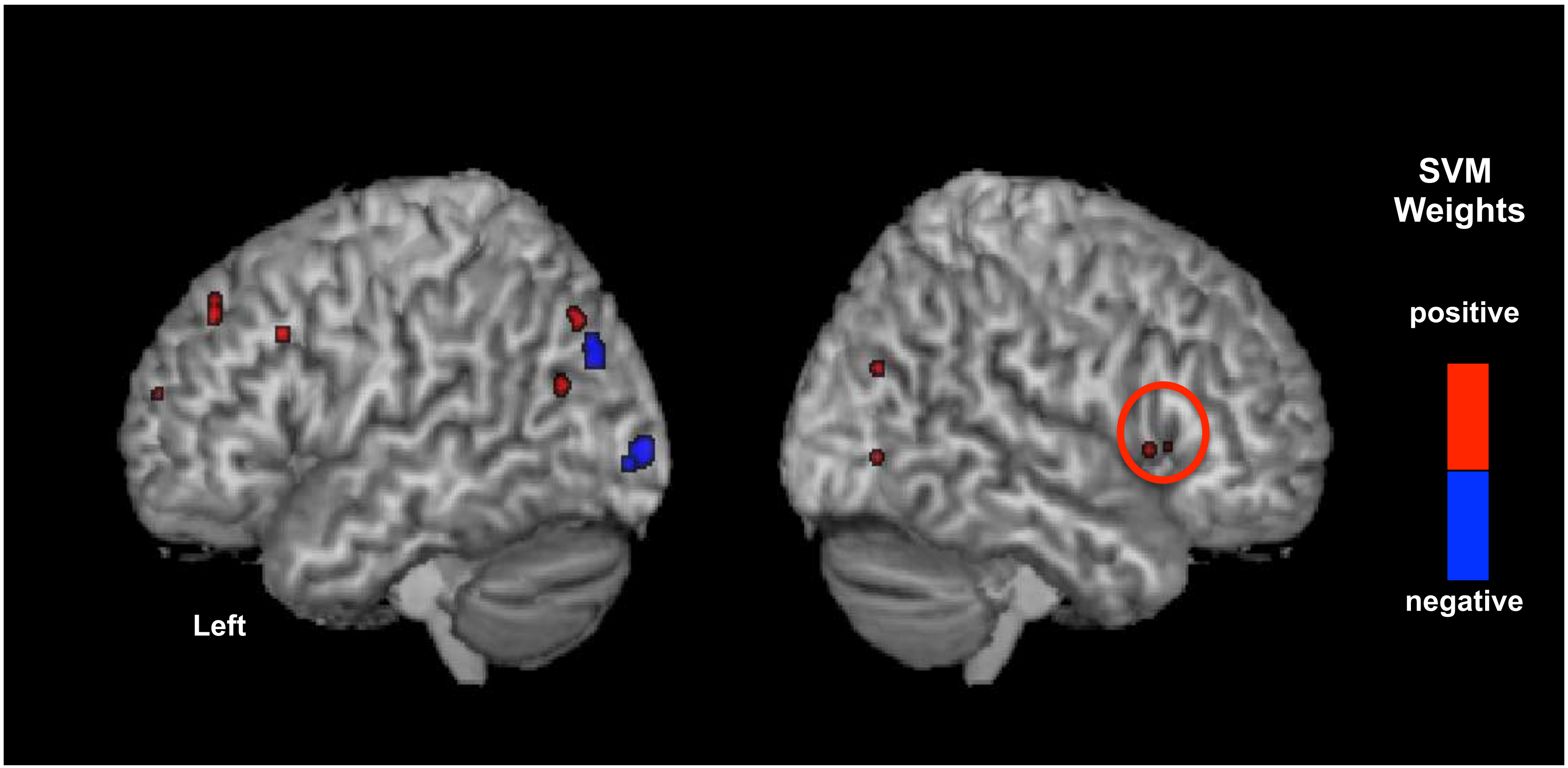




Hoeft et al., *PNAS*, 2011

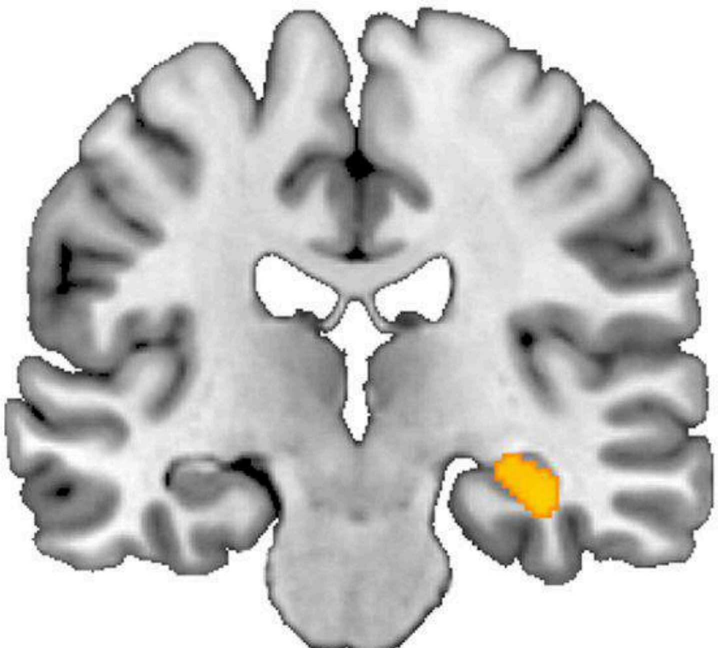
Multivoxel Pattern Analysis (Support Vector Machine)



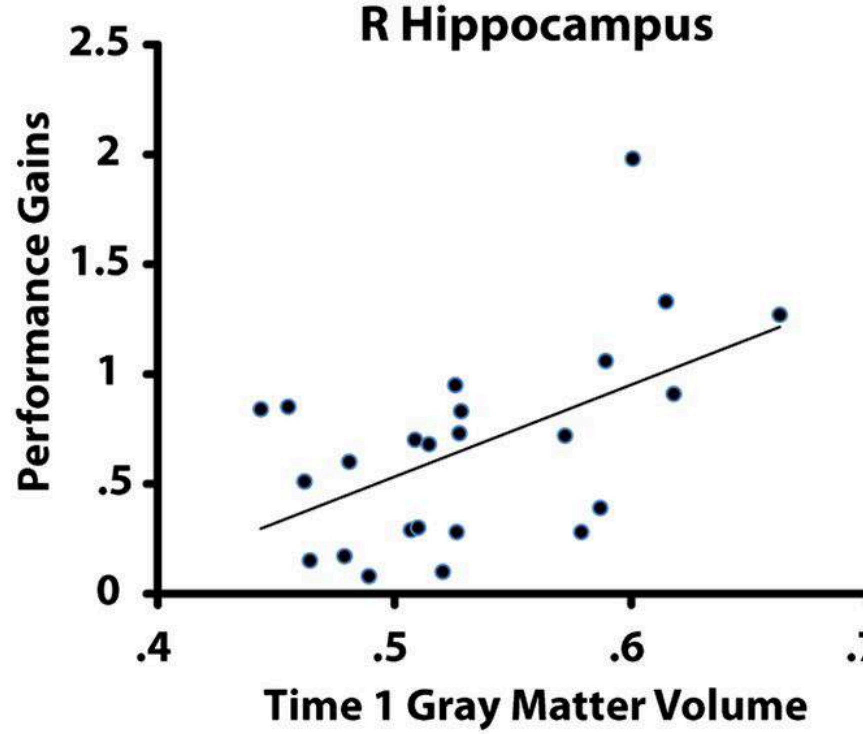
Predicting Compensation in Dyslexia

- none of 17 behavioral measures predicts reading gains 2.5 years later, alone or in combination
- greater activation in right frontal cortex predicts compensation & greater white matter integrity in right superior longitudinal fasciculus - 72%
- multivoxel pattern analysis - 92%

Neural Predictors of Individual Differences in Response to Math Tutoring in Primary-Grade School Children



y = -21



24 children in grade 3
progress not correlated with baseline behavioral measurea including IQ, working memory, math ability

Supekar et al., *PNAS*, 2013

Neuroeducation

- Basic neurocognitive research about learning
- Neurocognitive research about educational outcomes
- When brain measures outperform conventional behavioral measures

Individuated education; prediction (prevention not failure); most relevant for learning difficulties?

Collaborators & Support

- *Income-Achievement Gap*

  Amy Finn
  Chris Gabrieli
  Martin West
  Mathew Kraft
  Allyson Mackey
  Julia Leonard
  Rachel Romeo

- *Dyslexia*

  Elise Temple
  Russ Poldrack
  Fumiko Hoeft

Bill & Melinda Gates Foundation; NIH