Socioeconomic Inequality and Children's Cognitive & Brain Development

Kimberly Noble, MD, PhD

Teachers College,

Columbia University

HCEO Summer School on Socioeconomic Inequality

July 30, 2018

Welcome!

Overview

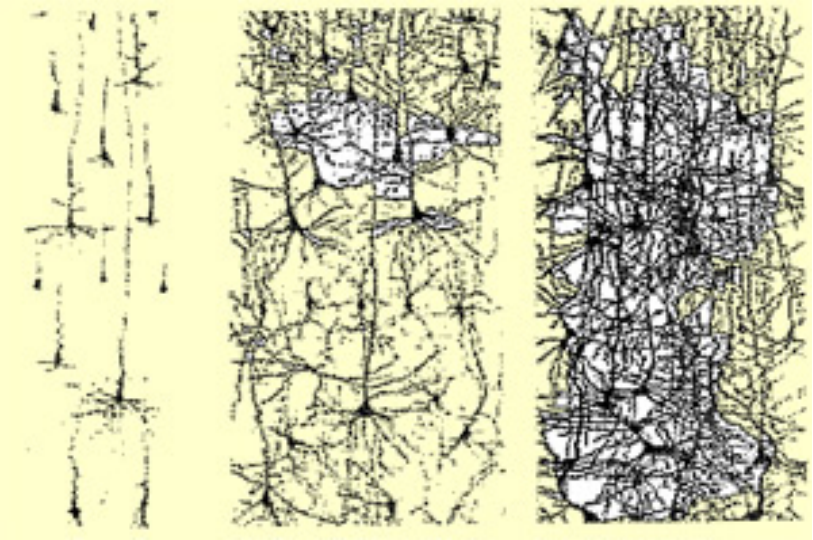
- Introduction
- Primer on neuroscience methods
- SES and the brain
  - Part 1: Behavior
  - Part 2: Brain structure
  - Part 3: Brain function
  - Part 4: Links to achievement and life outcomes

The Most Complex 3 Pounds in the Universe

- 100 billion neurons at birth
- 250,000-500,000 new neurons per minute in the first months of life

Most growth is not new neurons, but new connections

- Brain connections increasingly complex from birth to 3



birth 3 months 2 years

1000 trillion connections by age 3

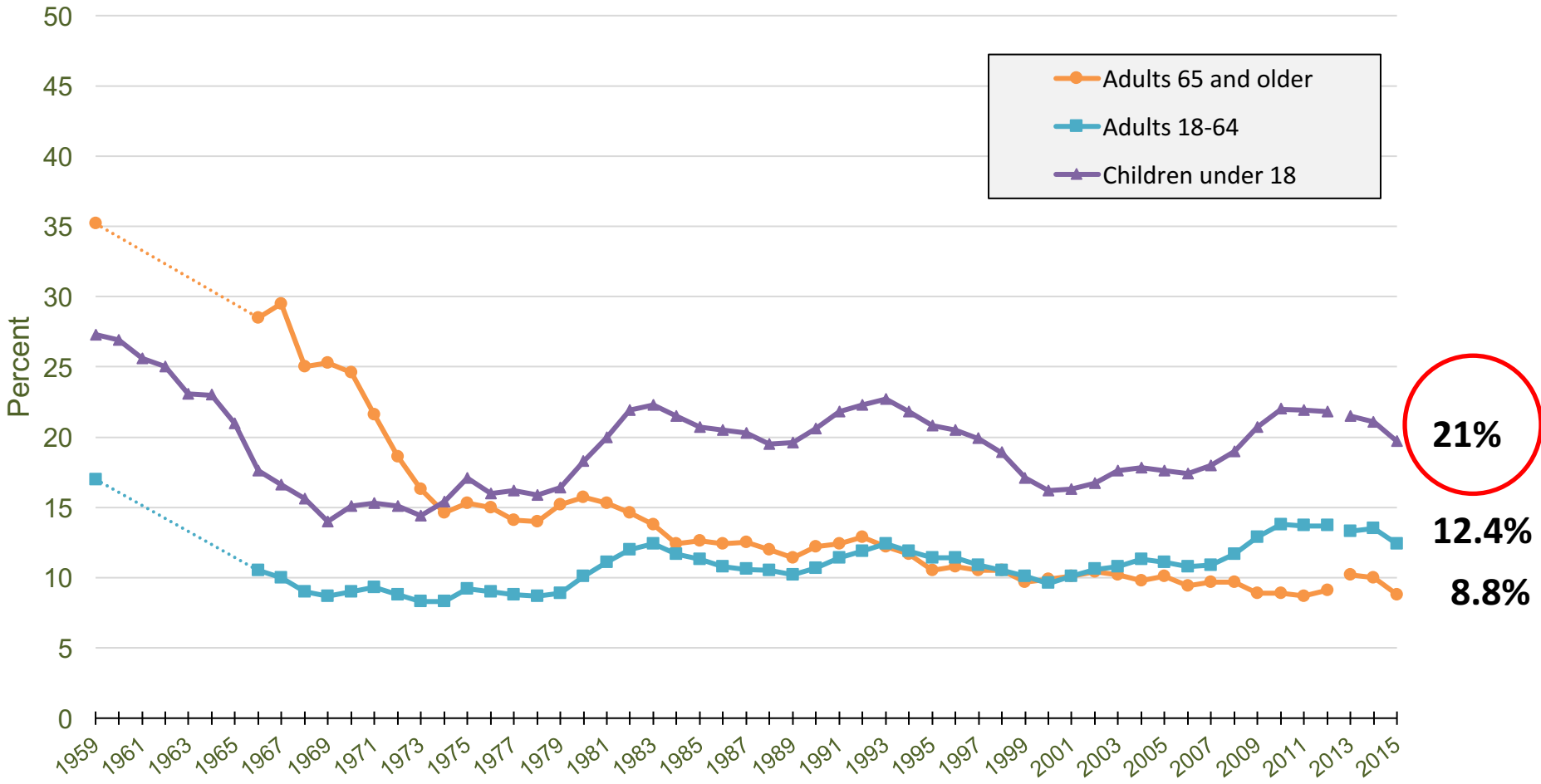
Early Experience Shapes Brain Development

- “Use it or lose it:” connections strengthen or are pruned
- The brain is most “plastic,” or able to make new connections, early in childhood
- Experience varies widely as a function of family social and economic factors

What is Poverty?

- Varies by family size and composition
- Does not vary geographically
- Family with 2 adults, 2 children
- $ 24,600
- Poverty puts children at risk for a host of negative physical health, mental health, and achievement outcomes

U.S. Poverty Rates by Age Group: 1959 to 2015



**Estimates for 2013 and beyond are not directly comparable to previous years due a re-design of the income questions.*

Slide courtesy Benard Dreyer, MD

Source: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplement

Socioeconomic status (SES) is more than just poverty

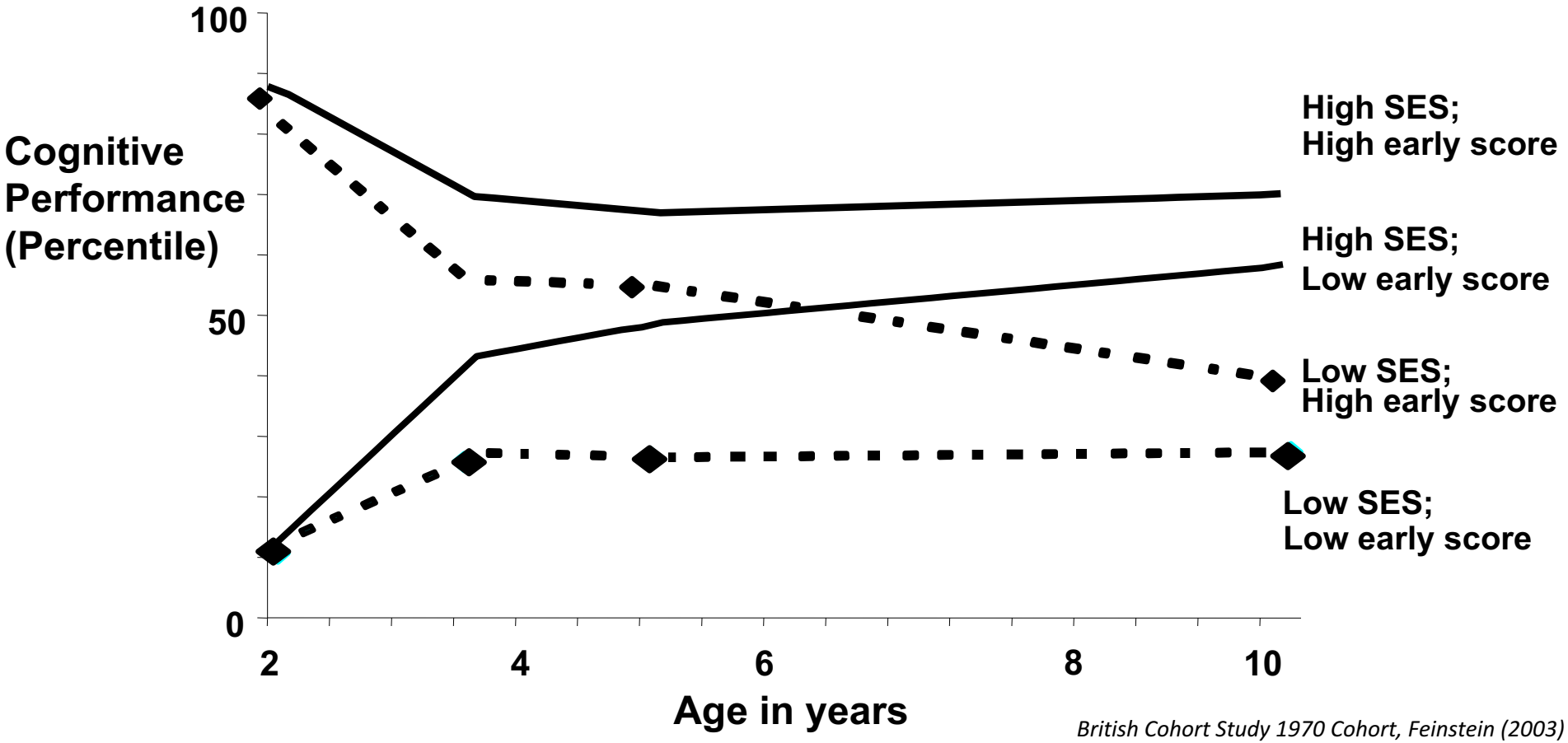
- Income
- Parent Education
- Occupation
- Subjective social status

Child SES is strongly associated with cognitive development

- Achievement test scores
- Grade retention
- Literacy
- IQ
- High school graduation

Evans (2004) *American Psychologist*

The SES gap emerges early and widens through the elementary years



British Cohort Study 1970 Cohort, Feinstein (2003)

What factors contribute to the SES gap?

Nutrition

Prenatal care

Perinatal complications

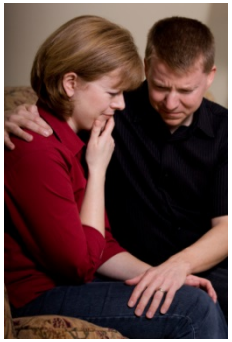
Prenatal drug exposure

Environmental toxicants

Home learning environment

Early education differences

Family Stress

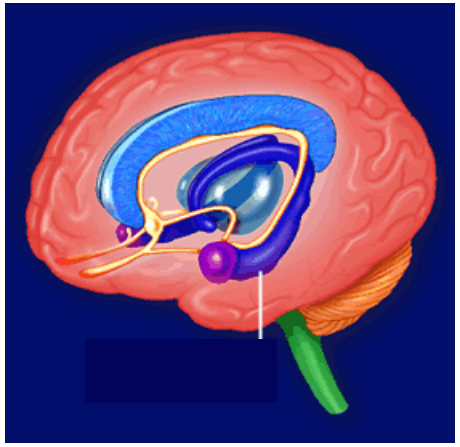


Each of these factors contributes to the link between SES and cognitive skill

“Cognitive skill” is too broad

- Traditional achievement measures not specific in terms of brain function
- Which particular cognitive skills, and corresponding brain circuits, are most strongly associated with SES?

Executive function



Visuospatial skills

Memory

Language

Which core cognitive systems are most highly associated with SES?

Neuroscience methods

- Brain function
  - Behavior
  - EEG/ERP
  - PET
  - fMRI
- Brain structure
  - MRI
  - DTI

Methodology #1: Neurocognitive behavioral measures

Executive function

Visuospatial skills

Memory

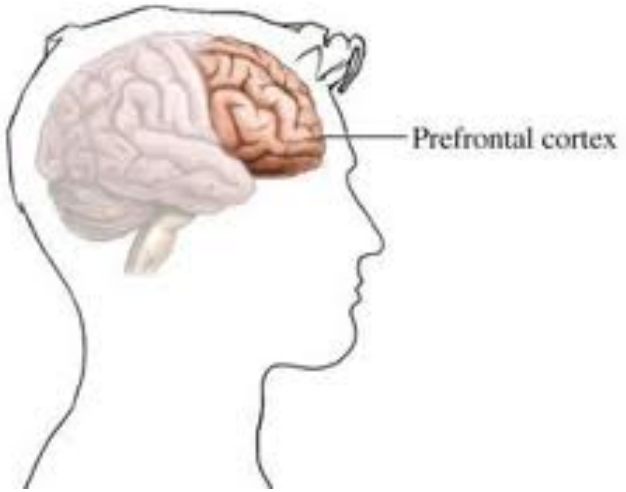
Language

Neurocognitive testing

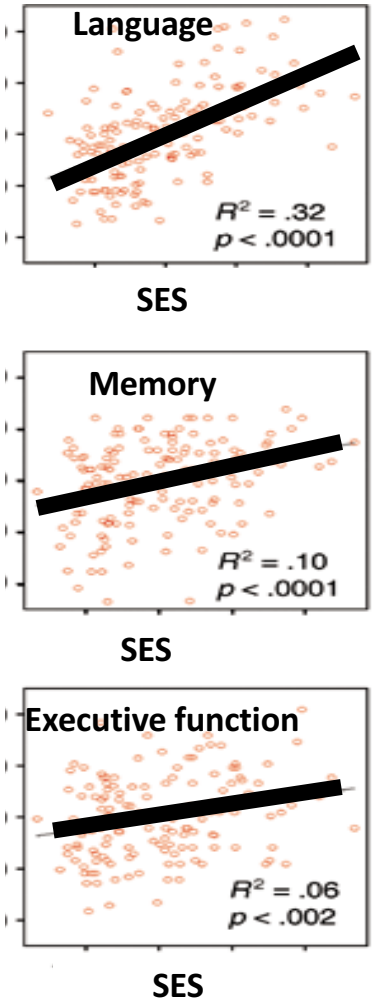
- Paper-and-pencil or computer testing
- Relatively inexpensive
- Can be similar to actual classroom activities
- No direct measurement of the brain

Example – Stroop task

PURPLE YELLOW RED
BLACK RED GREEN
RED YELLOW ORANGE
BLUE PURPLE BLACK
RED GREEN ORANGE



How does socioeconomic disadvantage relate to neurocognitive performance?



Noble et al, 2007 *Developmental Science*

But what about directly measuring the brain?

Methodology #2: Electroencephalogram (EEG)

- Can measure the electrical activity of the human brain by placing electrodes on the scalp and amplifying the signal.
- Changes in voltage can then be plotted over a period of time.

EEG signal

- EEG signal can be decomposed into oscillations occurring in different frequency bands

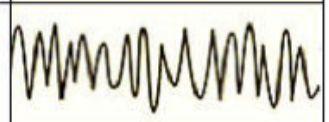
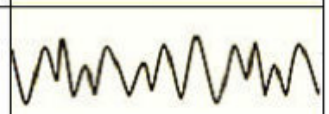
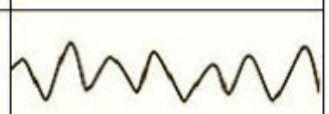
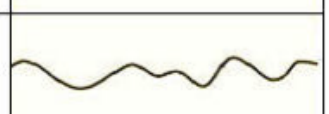
Gamma: 30-100+Hz Peak performance, flow	
Beta: 12-30Hz Awake, normal alert consciousness	
Alpha: 8-12Hz Relaxed, calm, lucid, not thinking	
Theta: 4-7Hz Deep relaxation and meditation, mental imagery	
Delta: .1-4Hz Deep, dreamless sleep	

EEG

- Relatively inexpensive and noninvasive
- Outstanding temporal resolution
- Relatively poor spatial resolution
- Just measures the brain at rest, not while doing any particular cognitive activity
- But can be correlated with performance on cognitive tests or other characteristics

For example, learning and attention disorders tend to exhibit

Deficit of high-frequency oscillations

Gamma: 30-100+Hz Peak performance, flow	
Beta: 12-30Hz Awake, normal alert consciousness	
Alpha: 8-12Hz Relaxed, calm, lucid, not thinking	
Theta: 4-7Hz Deep relaxation and meditation, mental imagery	
Delta: .1-4Hz Deep, dreamless sleep	

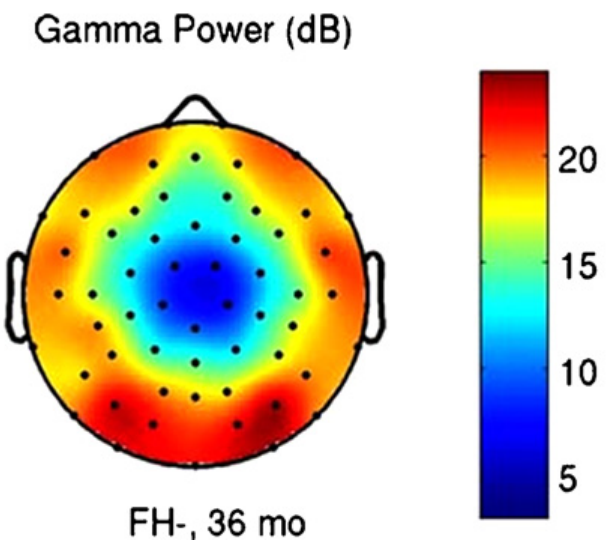
Excess low-frequency oscillations

EEG

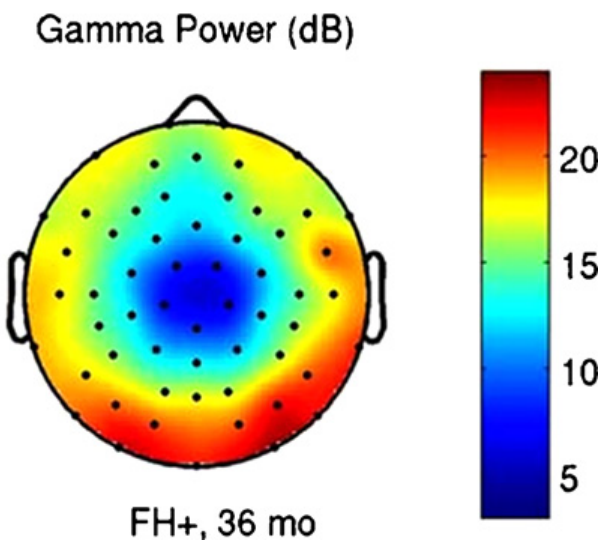
- Can choose a particular frequency band and “map” it across the scalp
- Can compare differences in frequency bands between groups

Children with family history of language impairment have less high-frequency activity at the front and sides of the brain

Children WITHOUT family history of language impairment



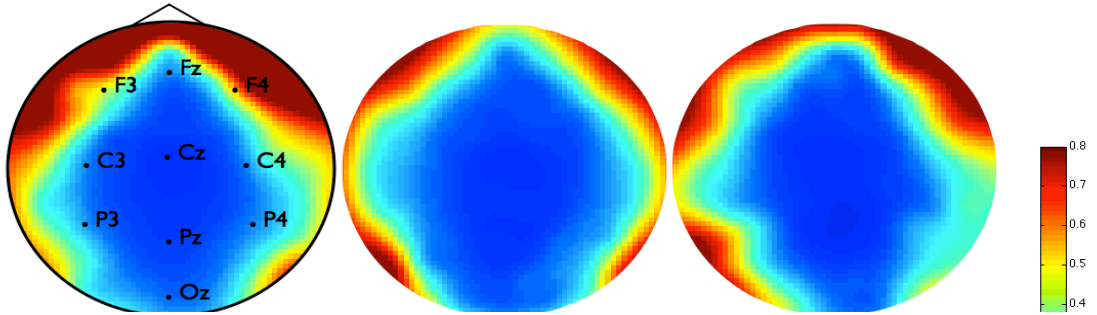
Children WITH family history of language impairment



Can "map" each frequency band to show which scalp areas have the highest power in that frequency band

Benasich et al, 2008

Children whose parents have higher-prestige occupations have more high-frequency EEG power toward the front of the brain



Managerial/ Professional positions

Intermediate

Unemployed

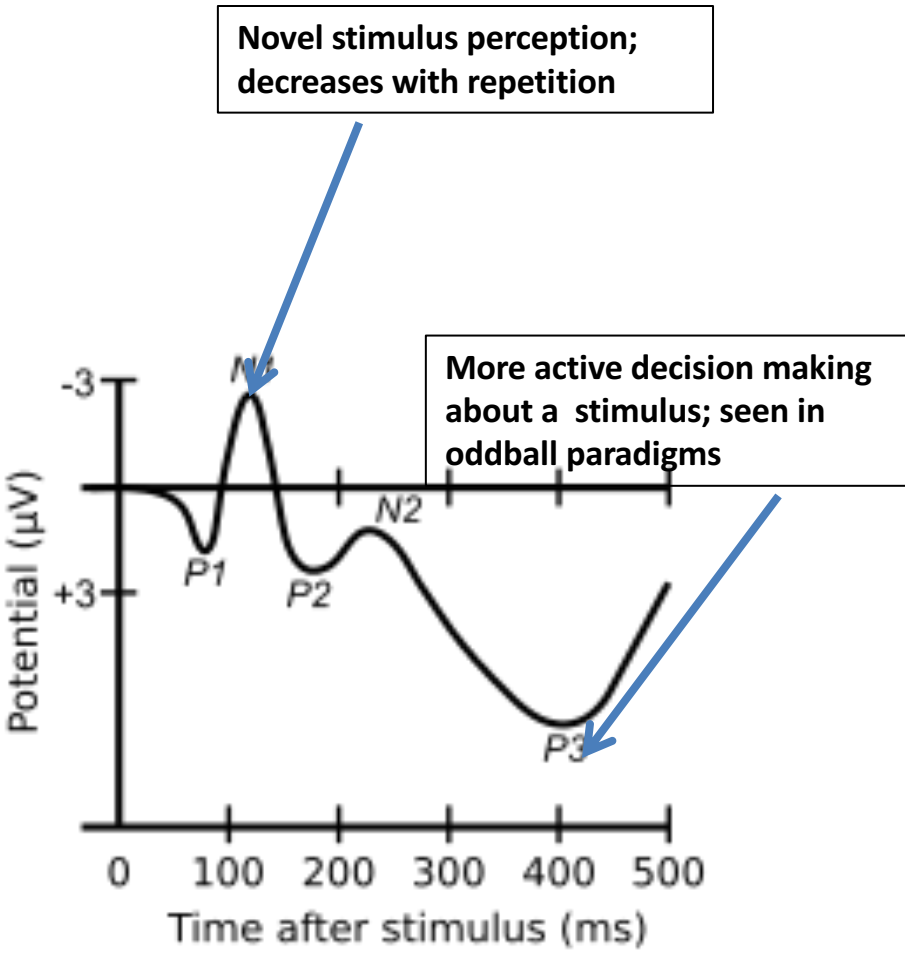
Tomalski et al, 2013

EEG is measured while the child is “at rest”

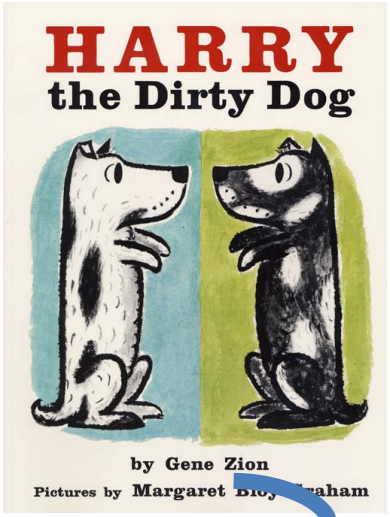
- But what about measuring the brain when the child is engaged in a cognitive task?

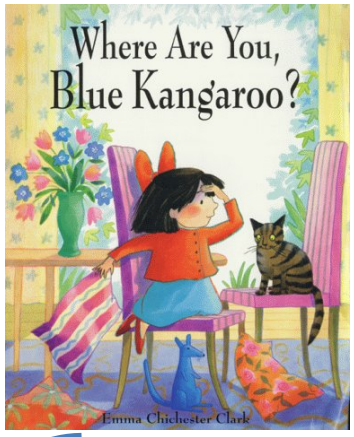
Methodology #3: Event-Related Potentials (ERP)

- ERP measures neural response to a particular set of stimuli, such as words or pictures
- Multiple trials of a type of stimulus are presented and then averaged over trials
- Reduces noise from unrelated variation in brain electrical activity
- Plotted with negative voltages upward
- Certain components of the waveform have classic associations with function



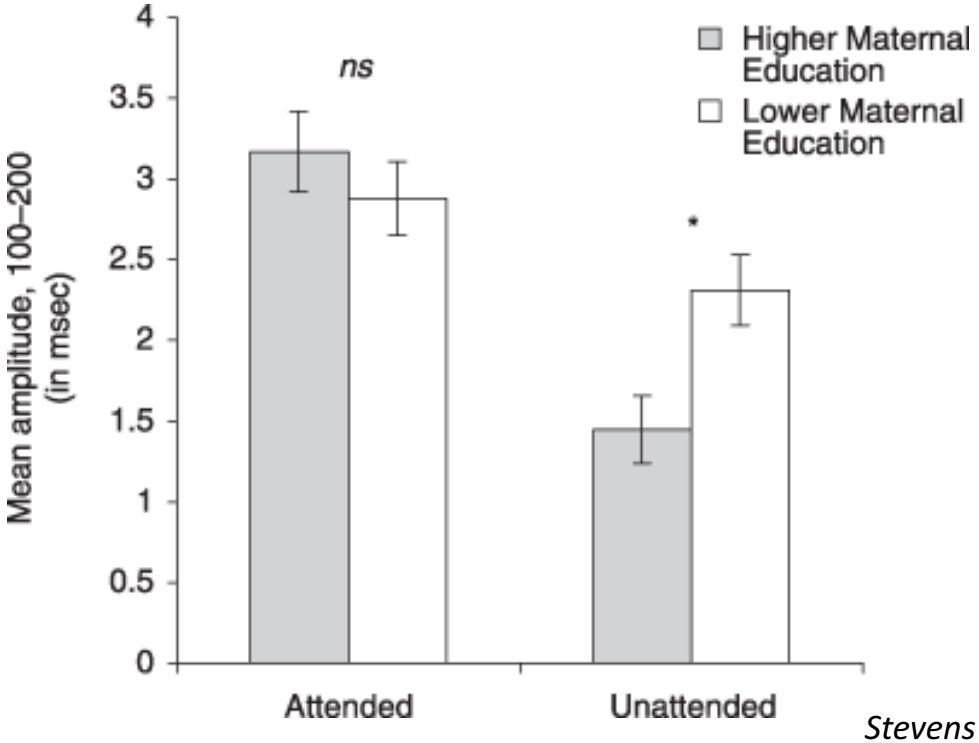
Dichotic listening paradigm





Stevens et al., 2009, Developmental Science

Children of higher educated mothers better able to suppress distracting stimuli

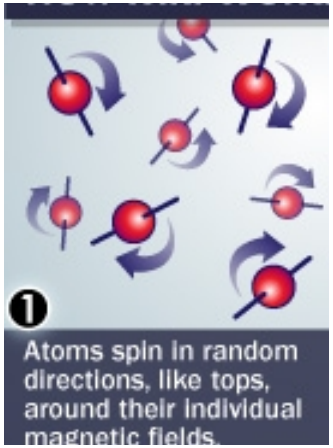


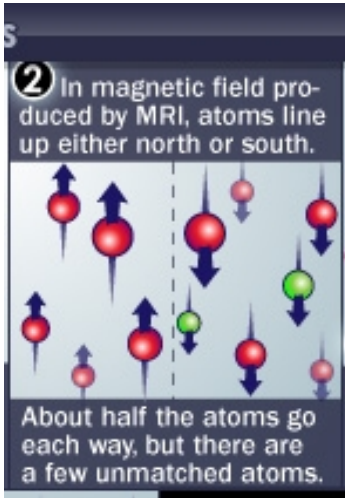
Stevens et al., 2009, Developmental Science

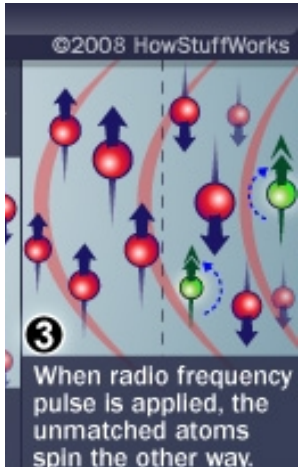
But these squiggly lines don’t look like brains at all!

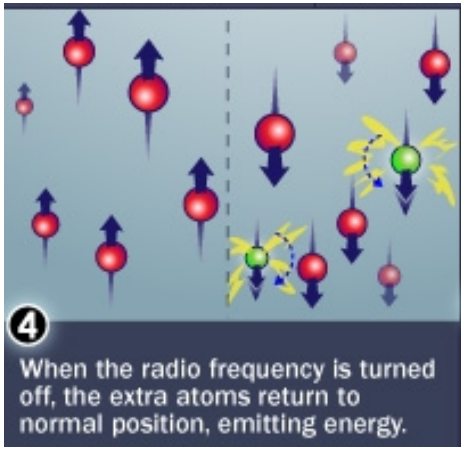
Methodology #4: Structural MRI

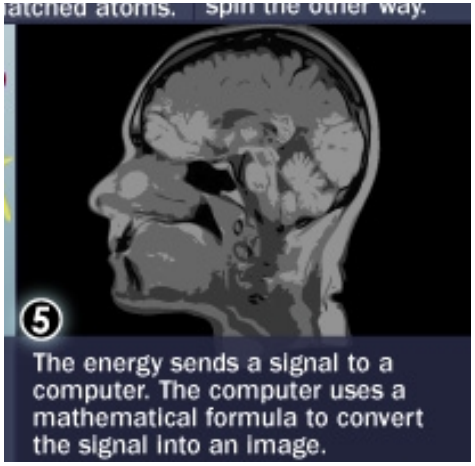
How MRI works







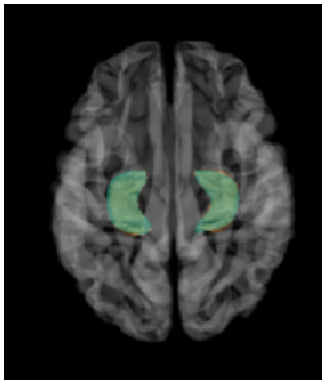


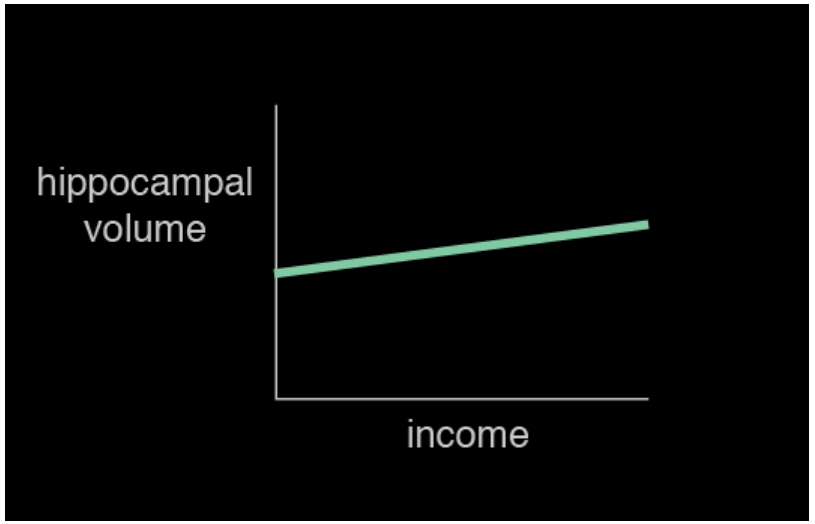


MRI

- Very strong magnet, about 10K times the strength of the Earth's magnetic field
- Excellent spatial resolution (millimeters)
- Non-invasive
  - No radiation
  - But loud, may be uncomfortable
- Can correlate anatomical measurements with cognitive performance or other characteristics

Higher family income is associated with greater hippocampal volume

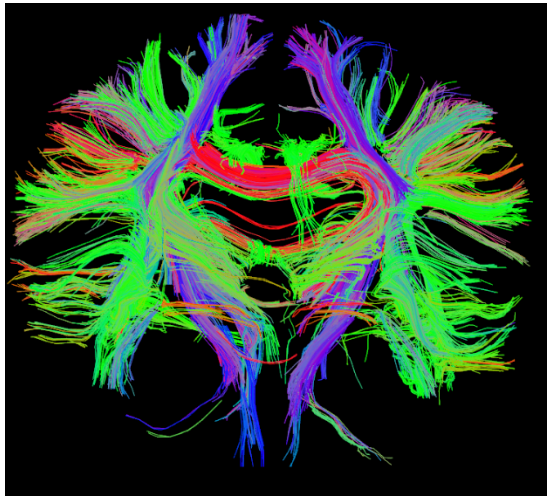




Noble et al, 2012, Developmental Science

Diffusion tensor imaging

- MRI-based neuroimaging technique
- Measures the location, orientation, and "fractional anisotropy," or integrity, of white matter tracts



Diffusion tensor imaging

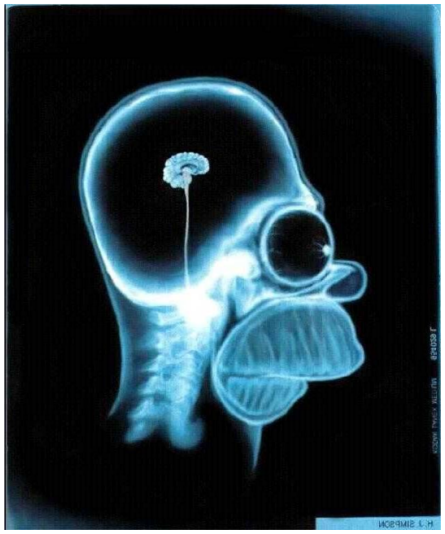
- Children who experienced early extreme neglect (institutionalization) show differences in the integrity of numerous white matter tracts
- This is partially ameliorated among children who were placed in early foster care

Bick et al., 2015, JAMA Pediatrics

Can we have pretty pictures of the brain that tell us about what the brain is *doing*?

Structural MRI vs. *Functional* MRI

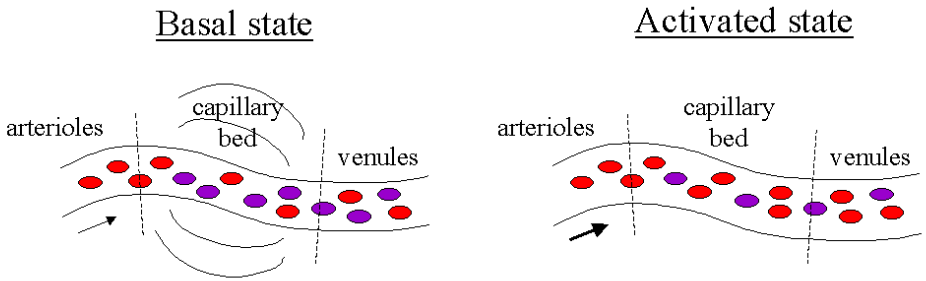
***Structural* MRI reveals brain anatomy.**



***Functional* MRI (fMRI) reveals brain function.**

Methodology #5: Functional MRI (fMRI)

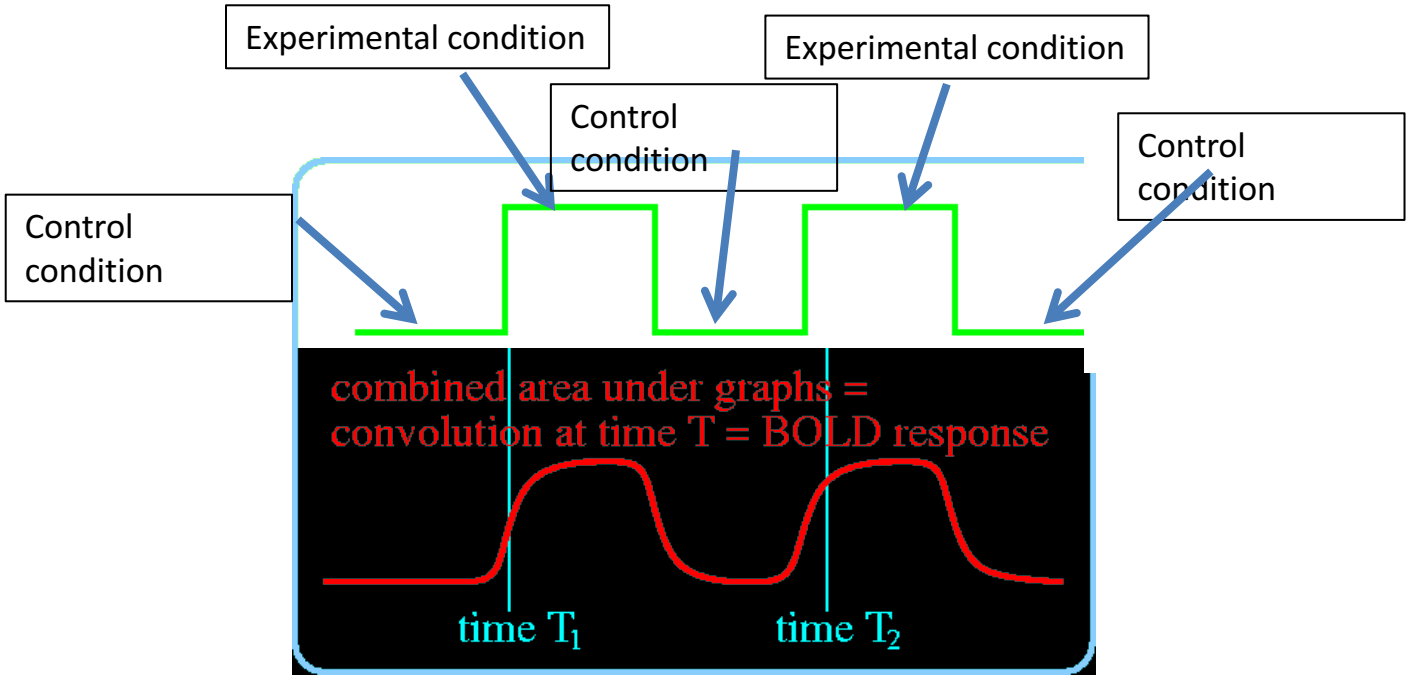
- In response to an increase in neuronal activity, local oxygenation increases → more intense MR signal



- Can measure the blood-oxygen level dependent (BOLD) signal at thousands of points in the brain

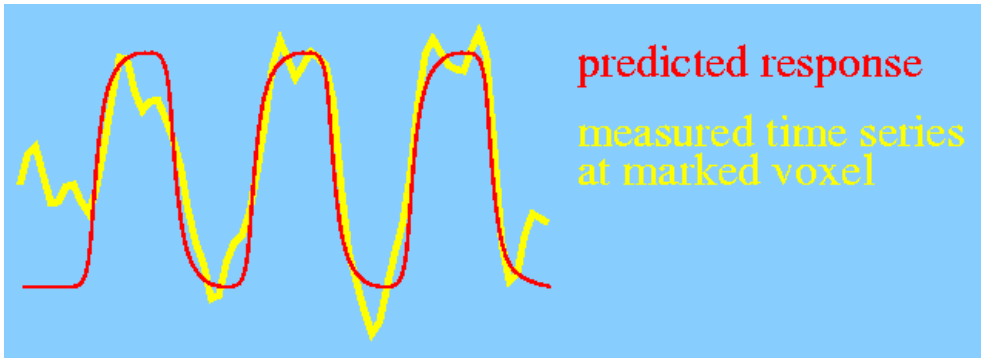
www.functionalmri.org

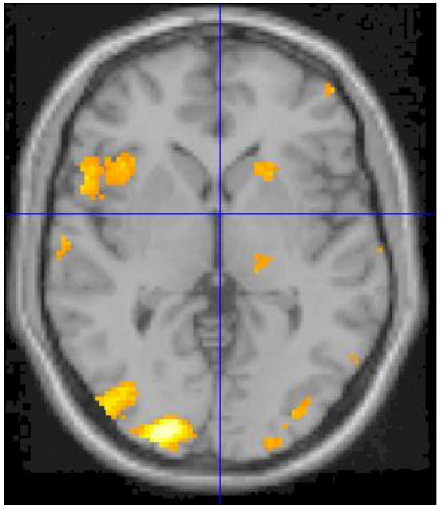
Functional MRI (fMRI)



Functional MRI (fMRI)

- Can map which areas respond according to the predicted model

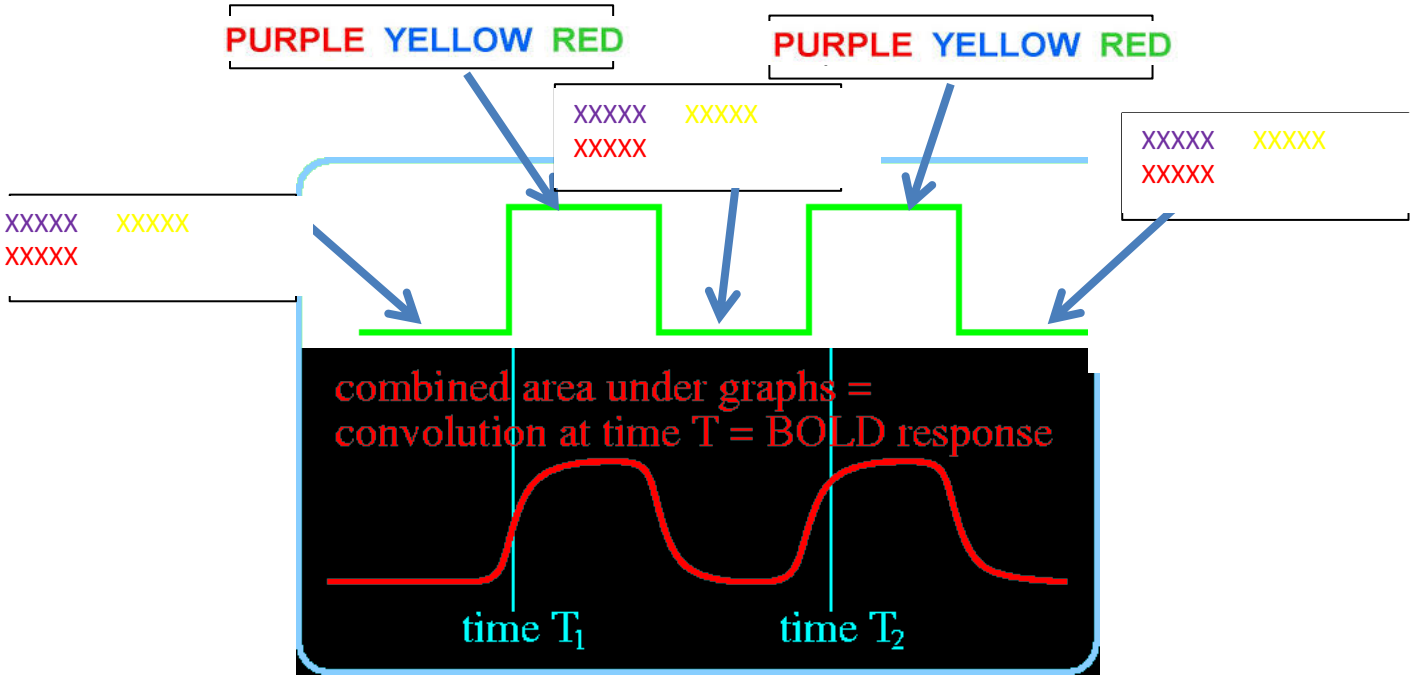




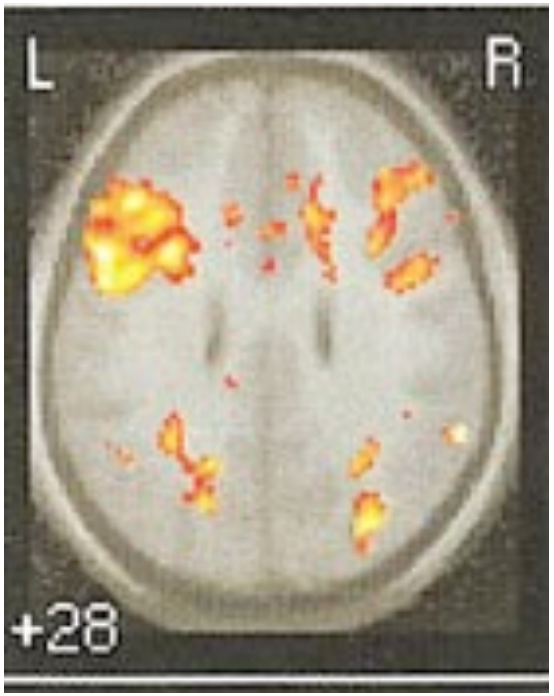
Functional magnetic resonance imaging (fMRI)

- Excellent spatial resolution
- Moderate temporal resolution (seconds)
- Non-invasive
  - No radiation
  - But loud, may be uncomfortable
- Directly measures brain function
- However, experience of doing a task in the scanner may be very different from doing a task in real life

An example: Stroop task

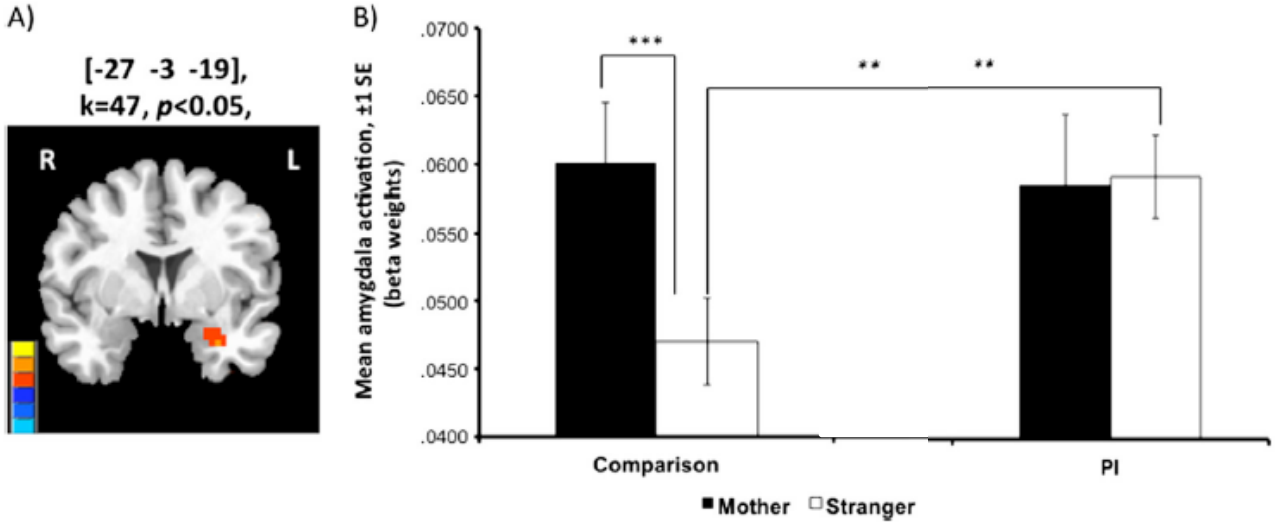


Stroop task:
Prefrontal cortex activation greater in inhibition vs. control condition



Adelman et al 2002 *Neuroimage*

Typically developing children show a stronger amygdala response to their mother's face than a stranger's face

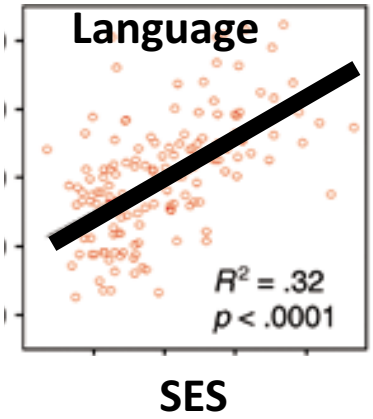


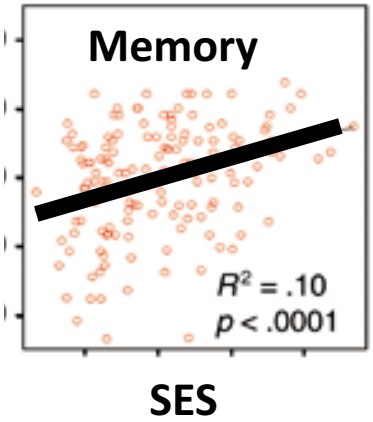
But children who experienced severe early neglect did not, even once adopted into new homes

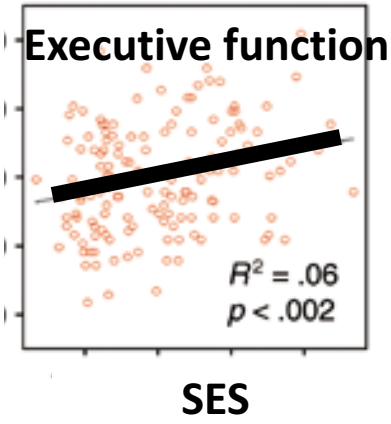
SES and the Brain
Part 1: Behavior

From kindergarten through adolescence:

Greatest disparities in language, memory, and certain forms of executive function







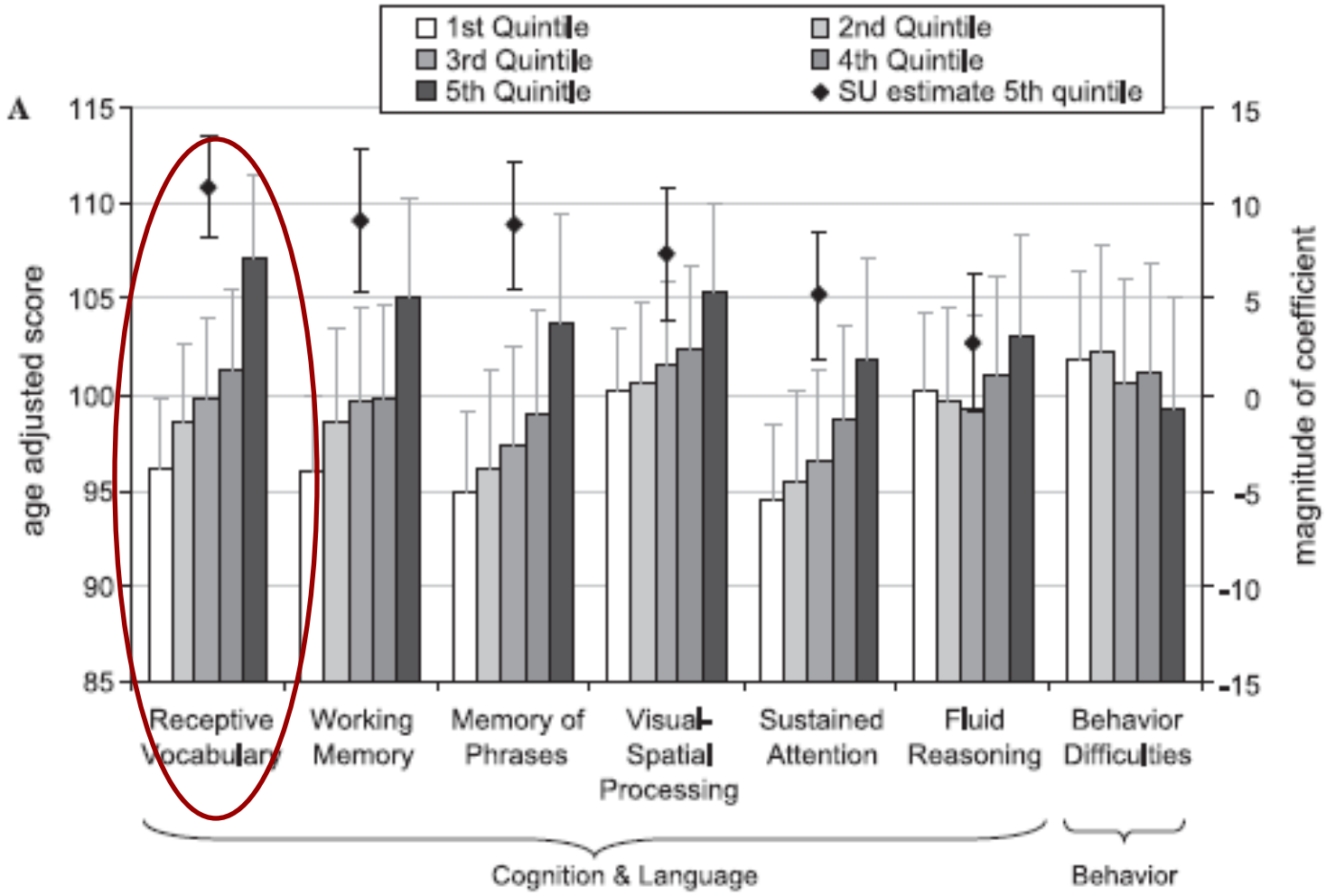
Noble et al, 2007 *Developmental Science*

Do socioeconomic gradients exist in developing countries?

- Madagascar
  - 68% of the country below the international poverty line
  - Gross national income per capita $340
- 1232 children age 3-6
  - Nationally representative sample of rural and urban communities

Fernald et al, 2011

Socioeconomic gradients in child development in a very low income population

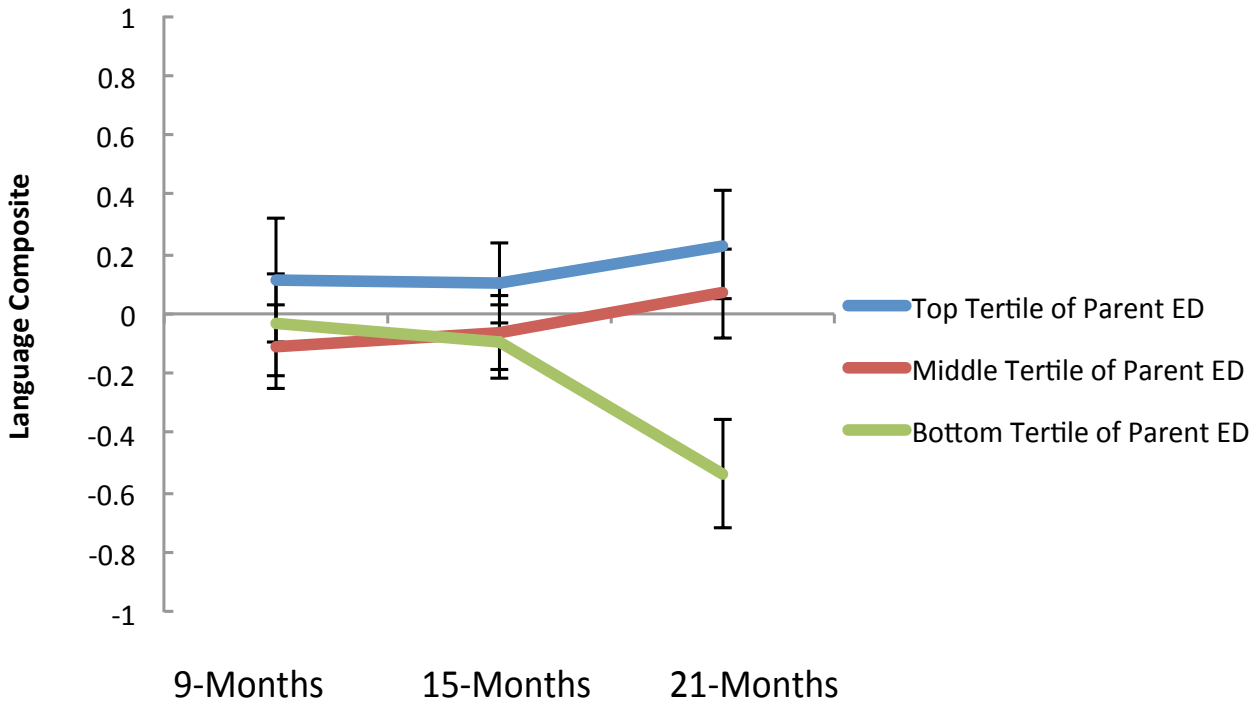


L.C.H. Fernald et al, 2011

How early are effects detectable?

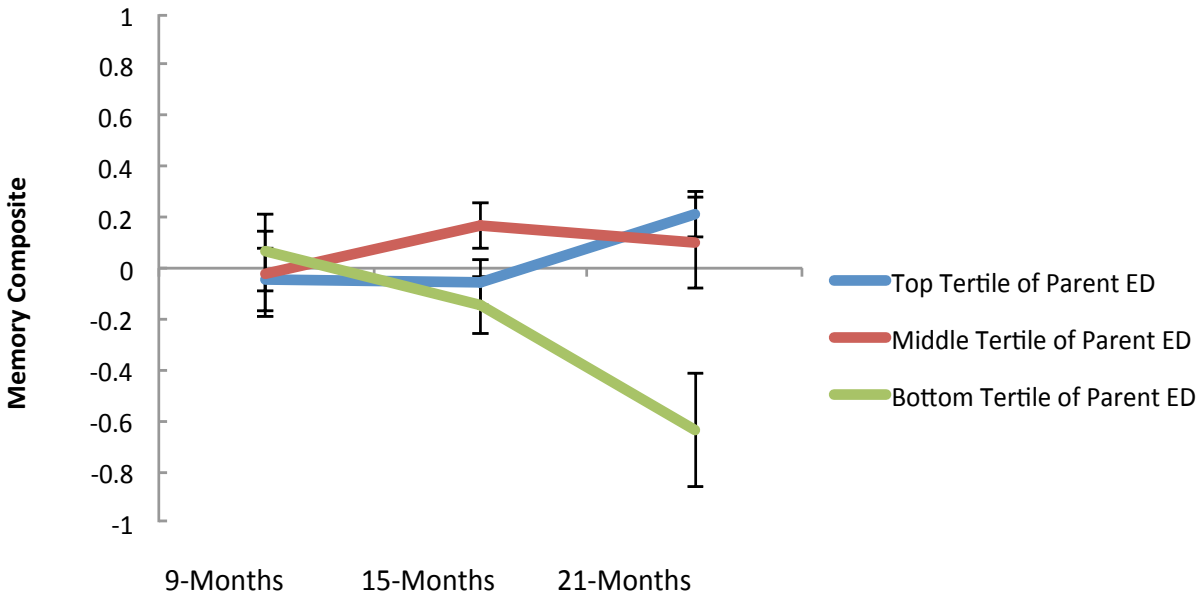
- 179 infants from socioeconomically diverse families
  - 9, 15, 21 months
  - Administered commonly used tests of infant language and memory development

Children of more highly educated parents have better language skills by 21 months



Noble et al, 2015,
Developmental Psychobiology

Children of more highly educated parents have better memory skills by 21 months



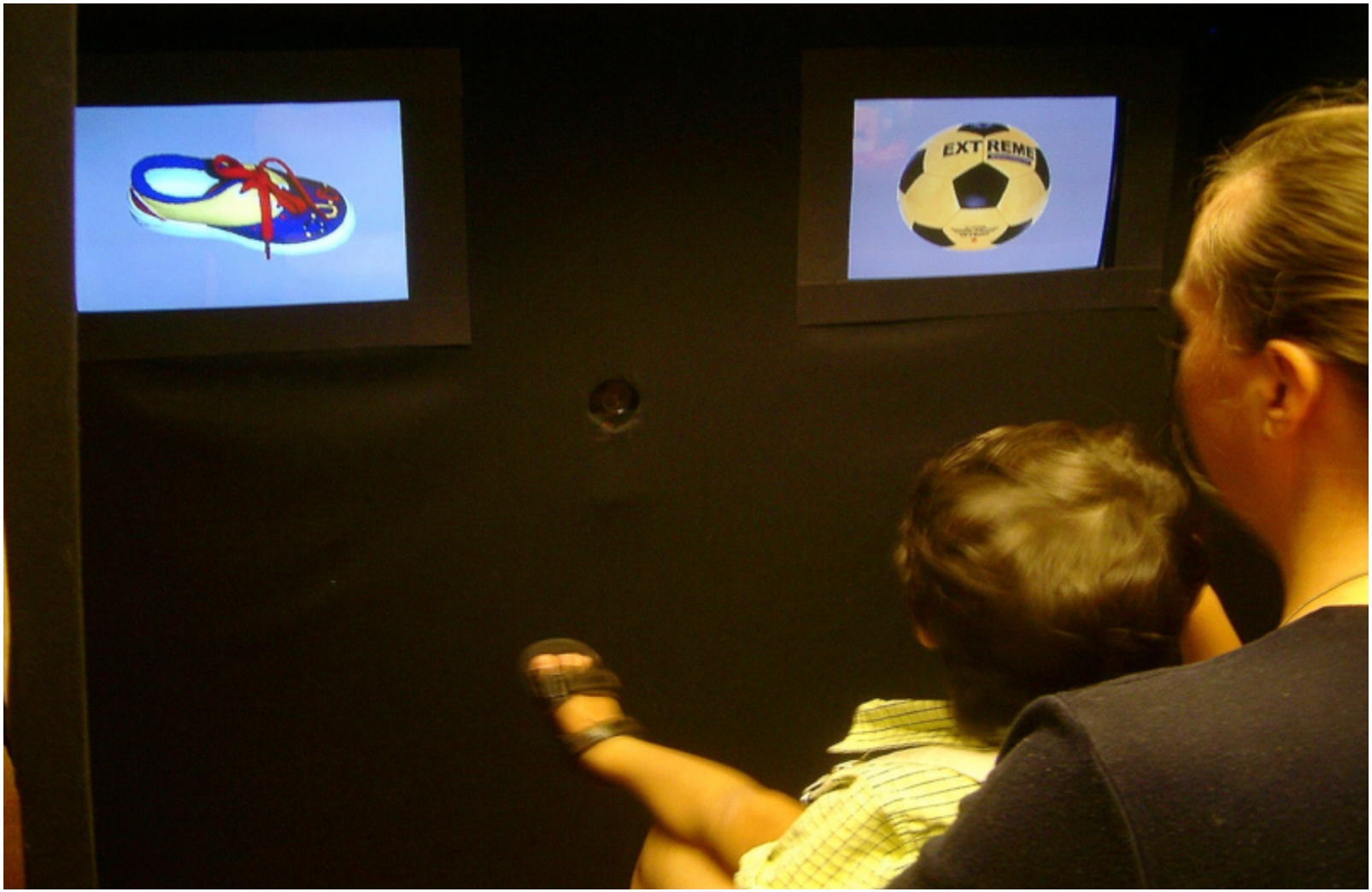
Noble et al, 2015,
Developmental Psychobiology

Socioeconomic disparities in toddler language development

- 48 English learning infants followed longitudinally from 18 to 24 months
- Two SES groups
  - Lower SES: average maternal ed 13.2
  - Higher SES: average maternal ed 16.7
- Language measures at 18 & 24 months:
  - Macarthur-Bates Communicative Development Inventory
  - Looking-while-listening paradigm

Fernald, Marchman & Weisleder, 2013, *Developmental Science*

Looking while listening

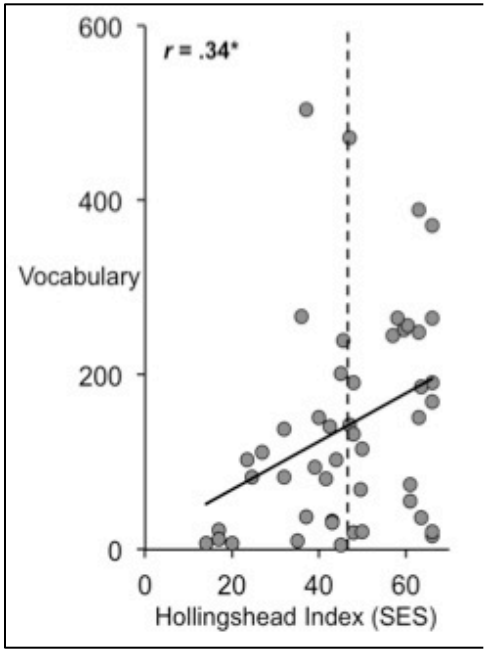


At 18 months, higher SES associated with…

Higher vocabulary

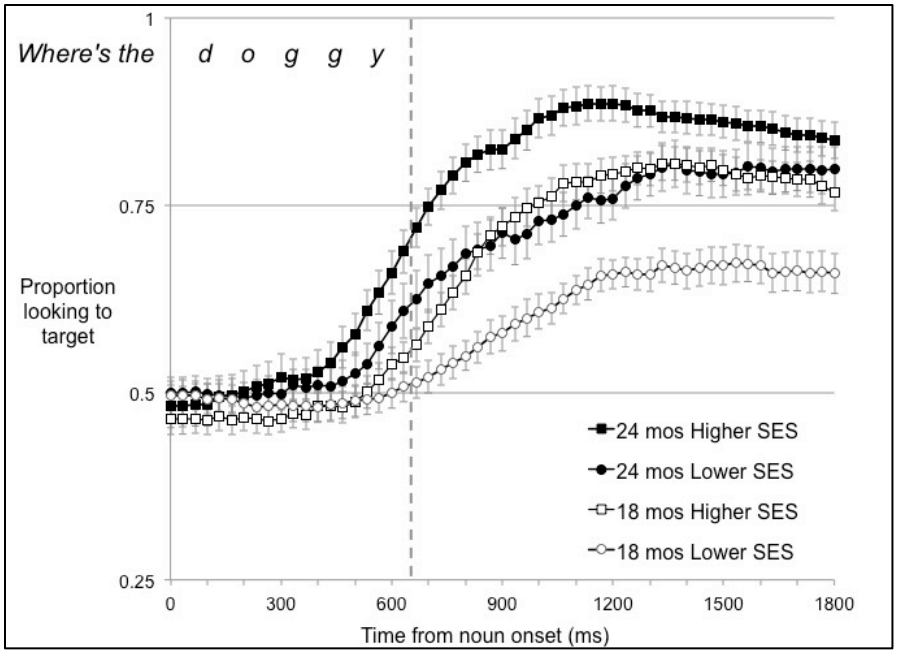
Higher accuracy

Faster speed



Fernald, Marchman & Weisleder, 2013, *Developmental Science*

Children from lower SES homes are 6 months behind by 24 months of age



- Both speed and reaction time are associated with vocabulary

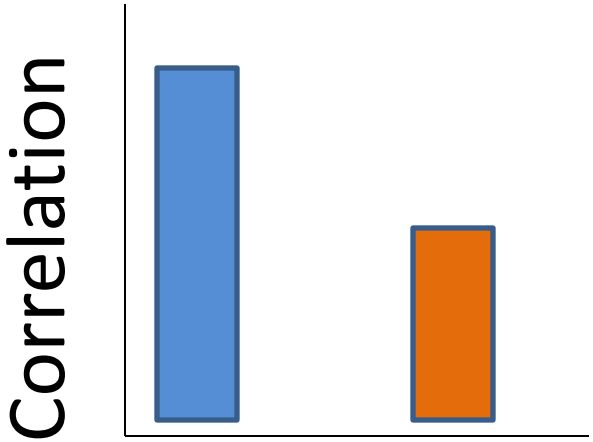
Fernald, Marchman & Weisleder, 2013, *Developmental Science*

Are these SES differences the result of differences in experience?

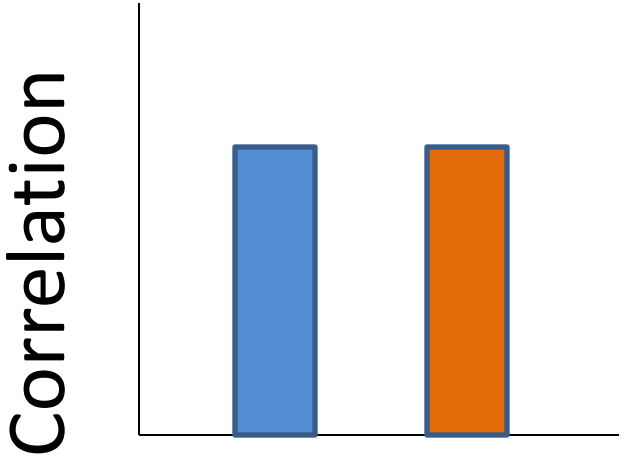
- Adopted children
- Timing: early childhood poverty is worse than later childhood poverty
- Responsiveness to intervention suggests experience-based resilience

Are these SES differences the result of differences in experience?

- Monozygotic twins: share all genes
- Dizygotic twins: share half genes



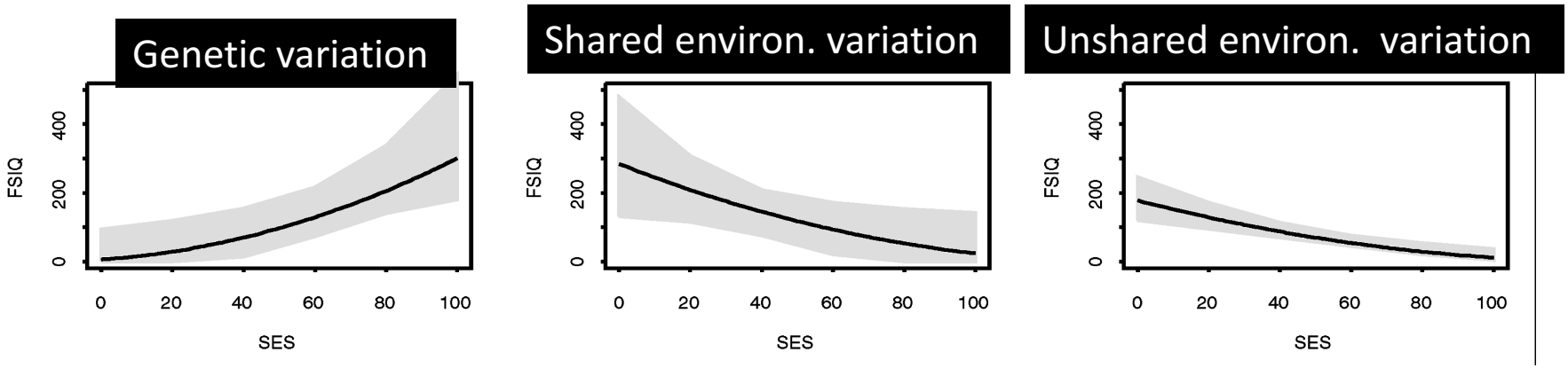
Trait is 100% genetic



Trait is 100% environmetal

Twin Studies

- IQ in twins
  - Higher SES: Genetic factors account for more variation
  - Lower SES: Environmental factors account for more variation

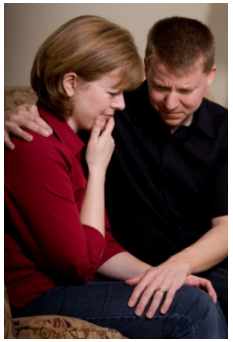


Turkheimer et al 2003

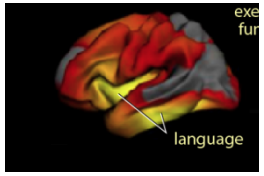
What experiences might explain these differences?

Possible causes

- Nutrition
- Prenatal care
- Prenatal drug exposure
- Perinatal complications
- Environmental toxicants
- Early education differences
- Home language environment
- Family Stress



Theoretical Model



SES

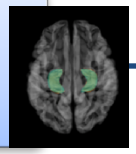
Home language environment

Left hemisphere language cortex

Language

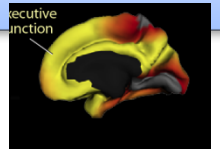
Family Stress

Hippocampus

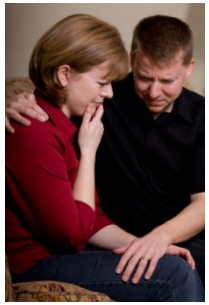


Memory

Prefrontal/Limbic circuitry



Cognitive and Emotional Regulation



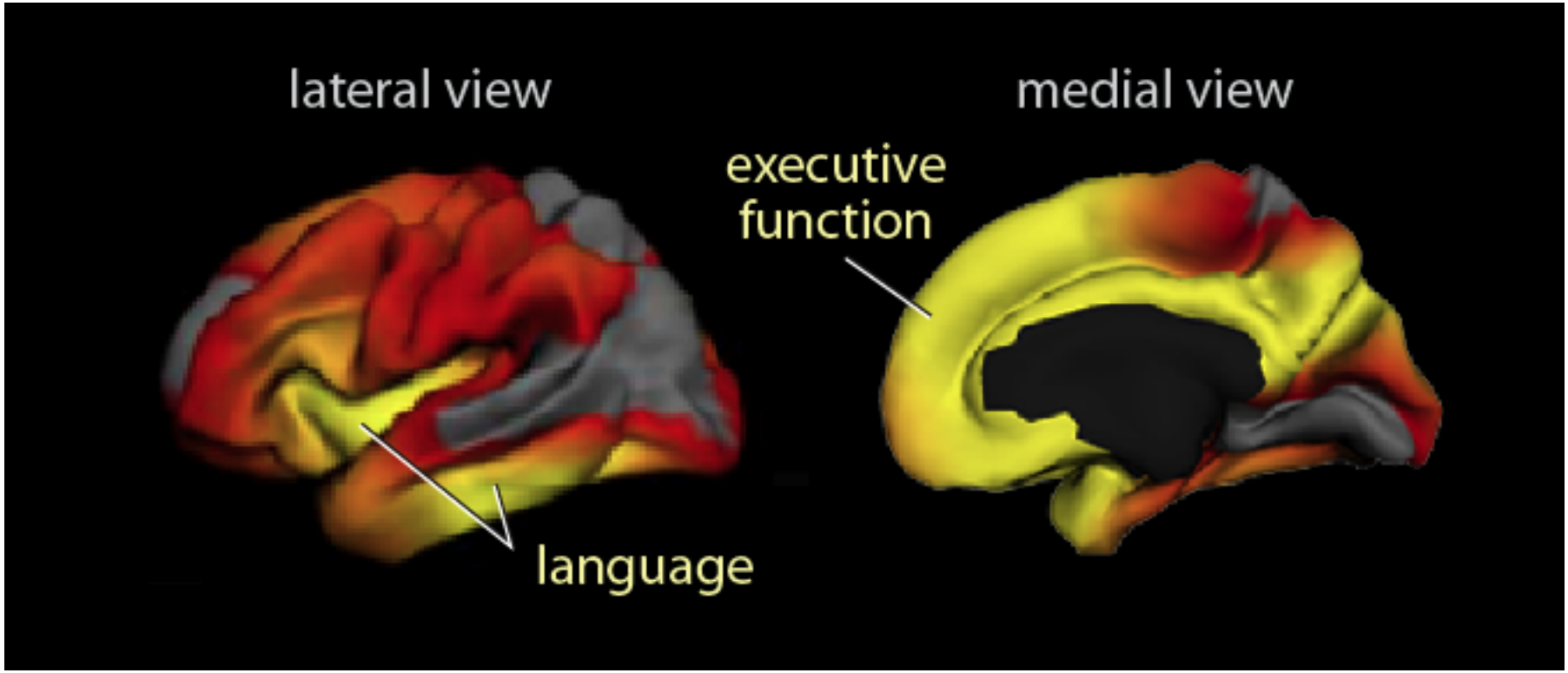
SES and the brain part 2: Brain structure

PING Study

- 1099 children and adolescents
- Ages 3-21 (mean 11.9)
- Diverse sample from 10 sites across the US
  - Average parent education some college (<7 – >16)
  - Mean household income ~$98k (<$5k - >$300k)
- Examined various aspects of brain structure
- Controlled for genetically-defined race

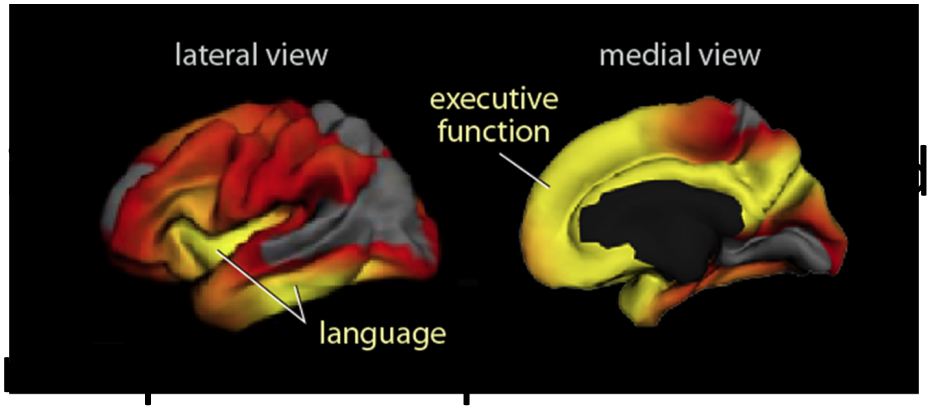
Noble et al, 2015,
Nature Neuroscience

Higher family income is associated with larger cortical surface area



Noble et al, 2015,
Nature Neuroscience

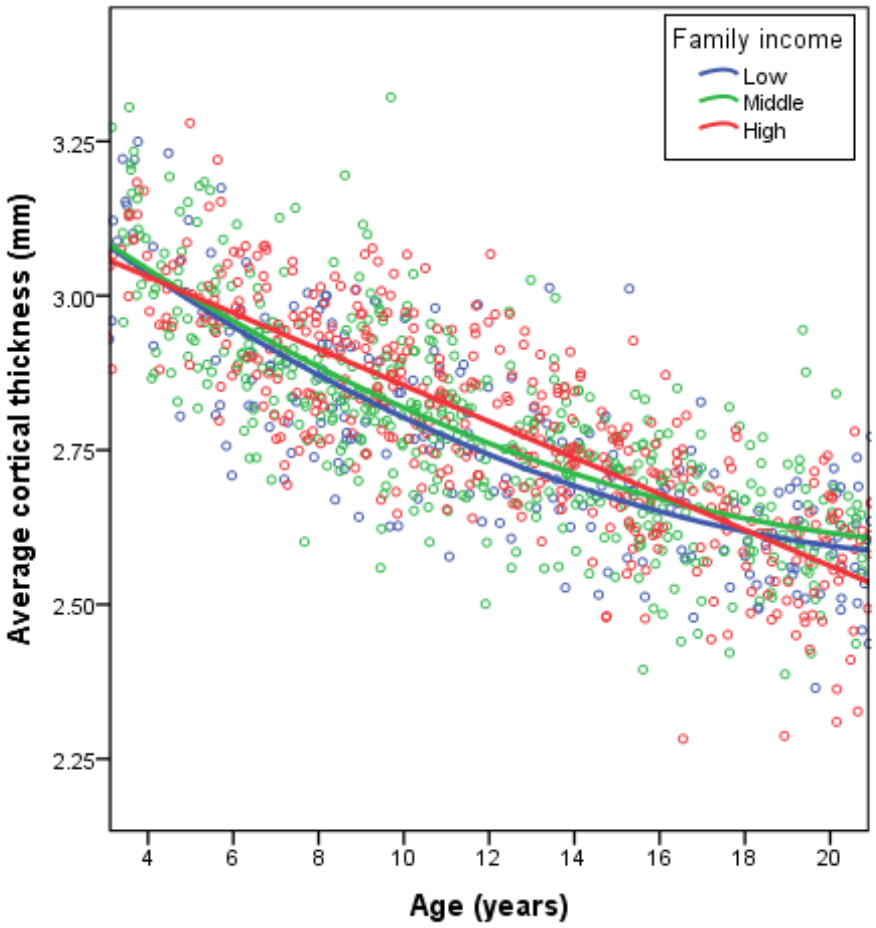
Higher family income is associated with larger cortical surface area



- Relationsh dvantaged children
- Variation f

Noble et al, 2015,
Nature Neuroscience

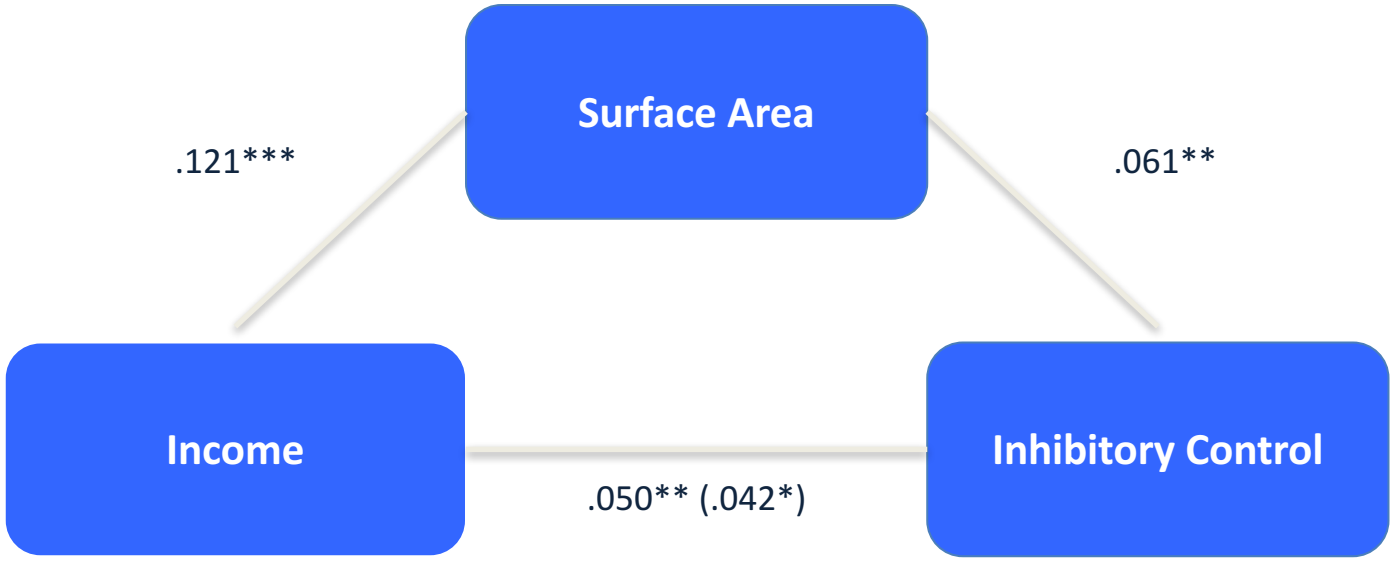
Income moderates age-related difference in cortical thickness



Piccolo, Merz et al, 2016, *PLOS One*

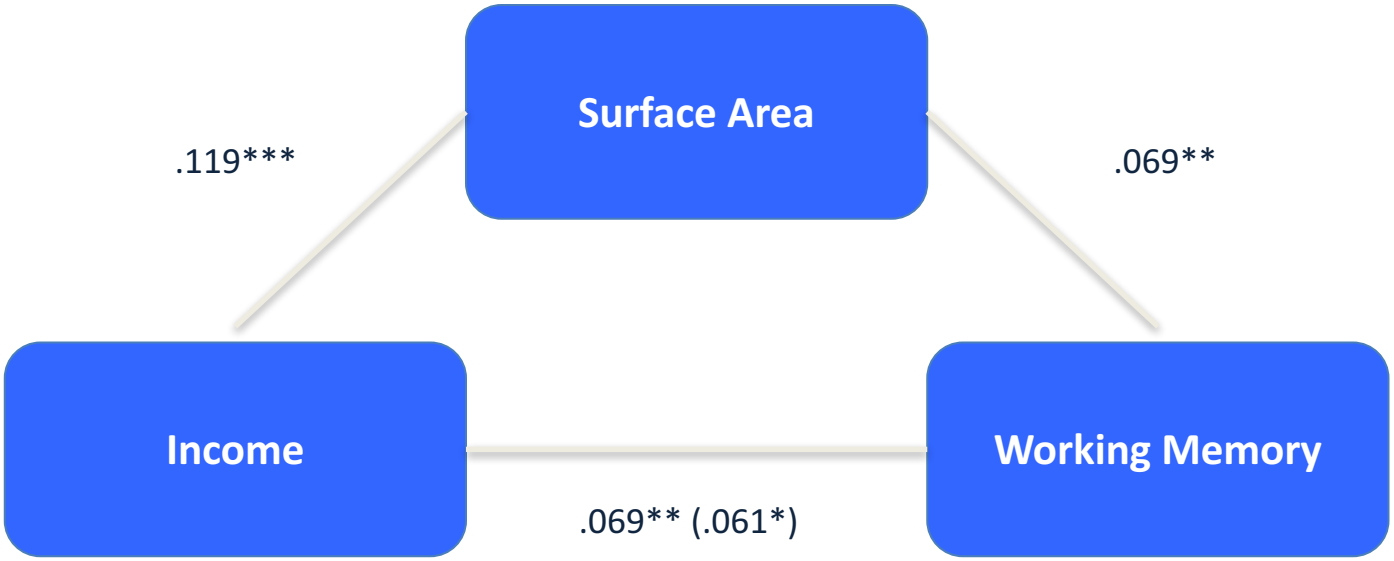
Does it matter?

Surface Area Partially Mediates Links between SES and Executive Function



Noble et al, 2015,
Nature Neuroscience

Surface Area Partially Mediates Links between SES and Executive Function

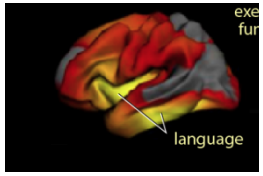


Noble et al, 2015,
Nature Neuroscience

Brain structure is associated with achievement in adolescence

Differences in brain structure account for 15-44% of the income-achievement gap

Mackey et al, 2015, *Psychological Science*
Hair et al, 2015, *JAMA Pediatrics*



SES

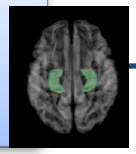
Home language environment

Left hemisphere language cortex

Language

Family Stress

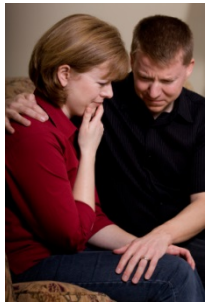
Hippocampus

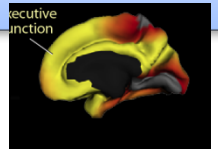


Memory

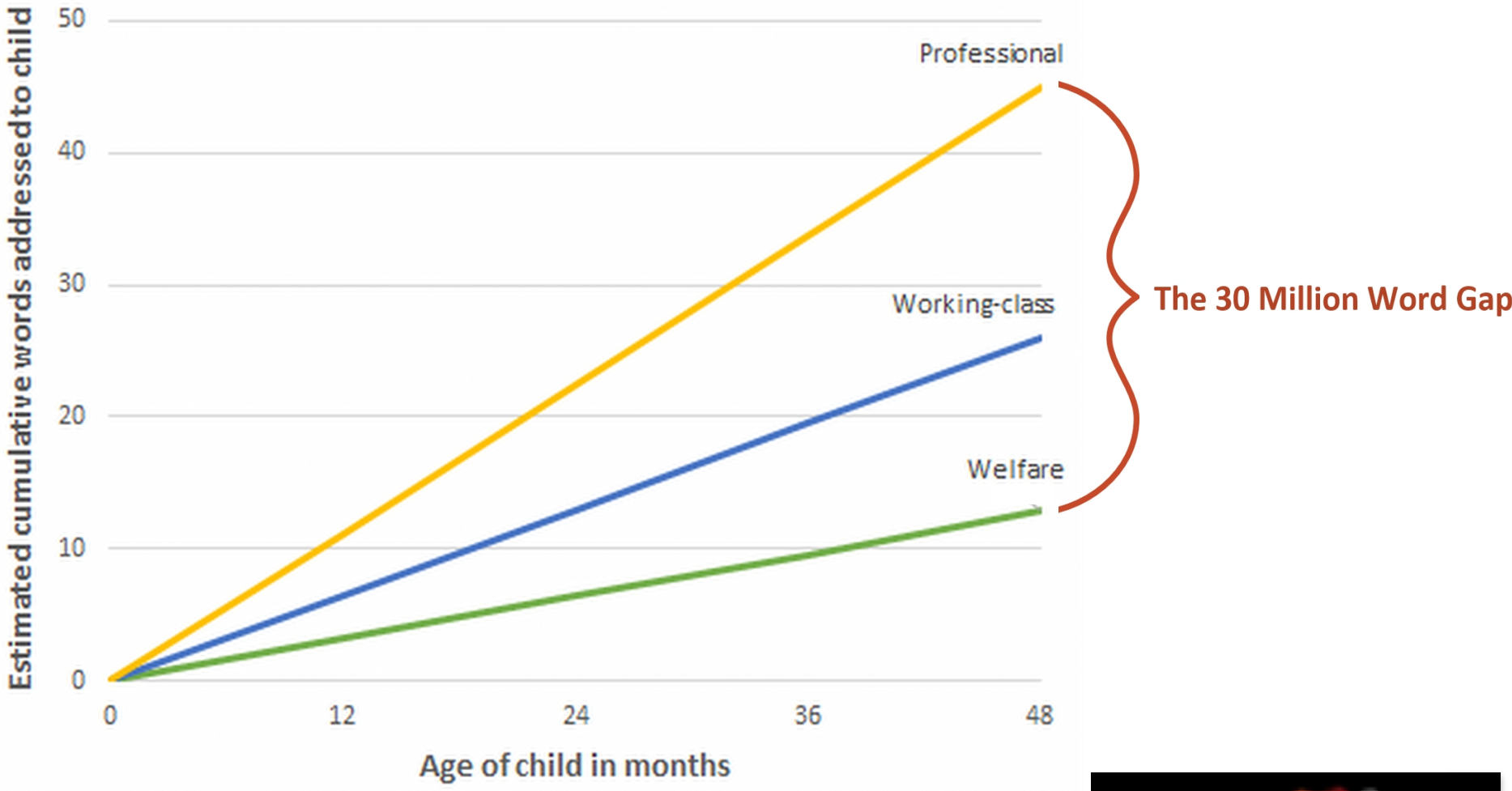
Prefrontal/Limbic circuitry

Cognitive and Emotional Regulation

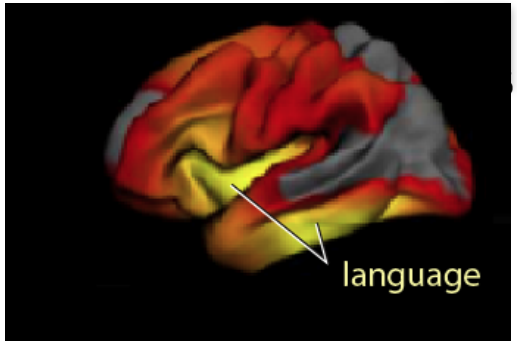




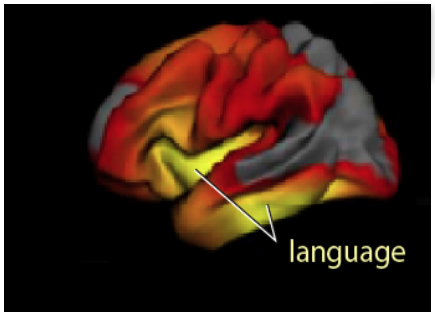
Number of Words Heard by Children Differs Across Income Groups

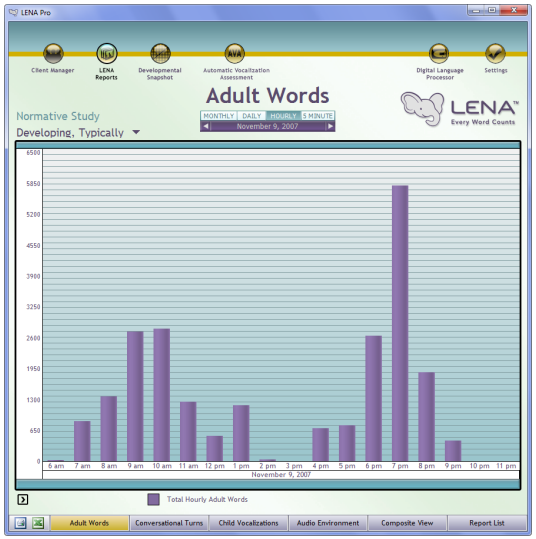


- Number, complexity and responsiveness of verbal interactions
- Number of words heard is directly related to child vocabulary size



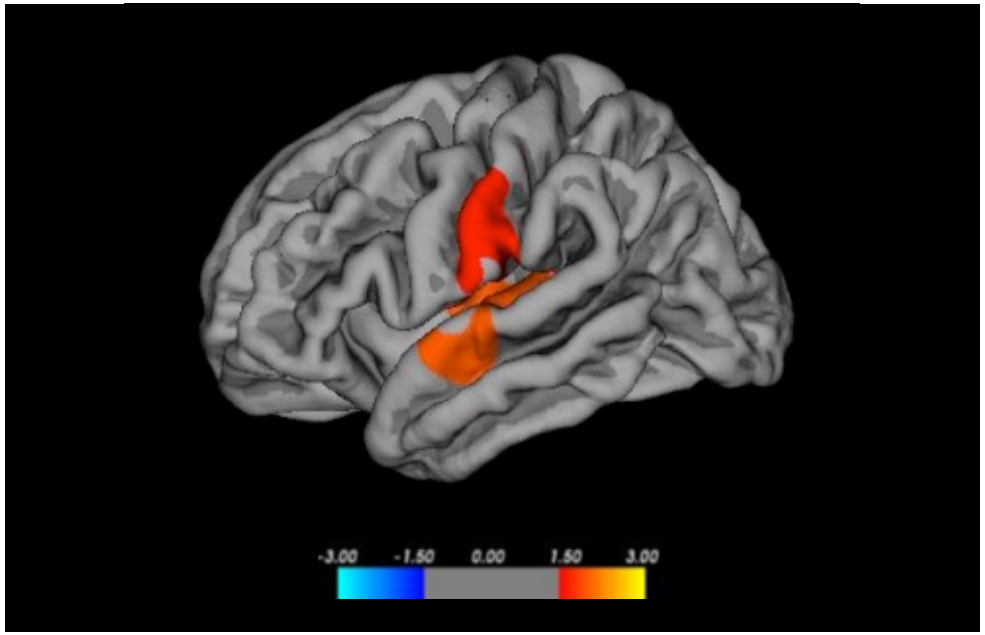
Does the language environment explain SES differences in the brain?



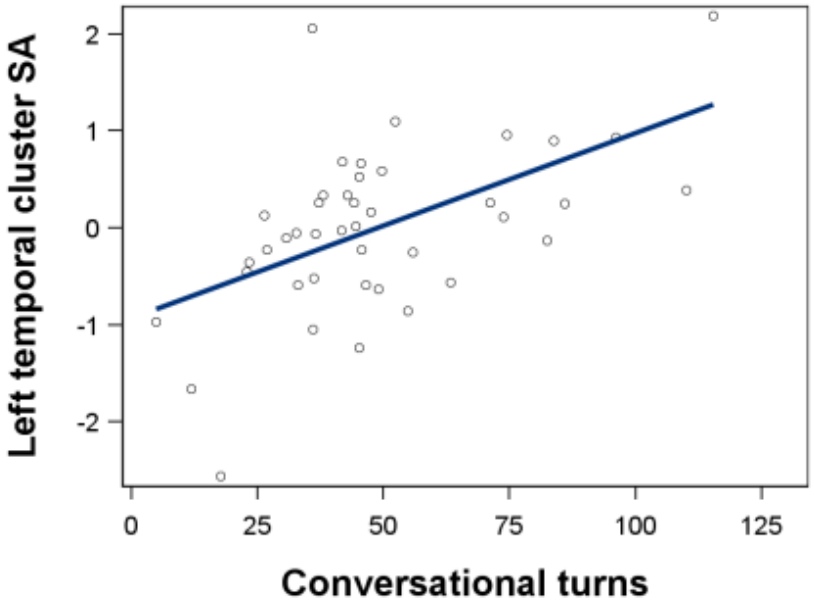


More conversational turn associated with greater surface area in left language cortex

a

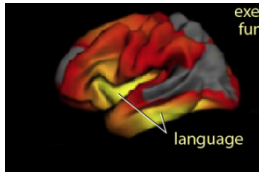


b



- Partially mediates socioeconomic disparities in reading skill
- No link between brain structure and total number of adult words or child vocalizations

Merz, et al*, under review*



SES

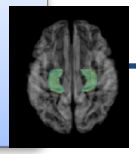
Home language environment

Left hemisphere language cortex

Language

Family Stress

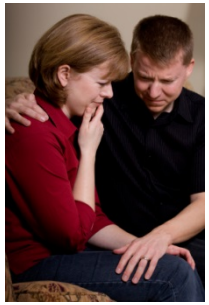
Hippocampus

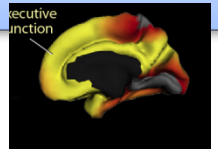


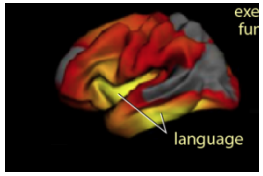
Memory

Prefrontal/Limbic circuitry

Cognitive and Emotional Regulation







SES

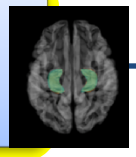
Home language environment

Left hemisphere language cortex

Language

Family Stress

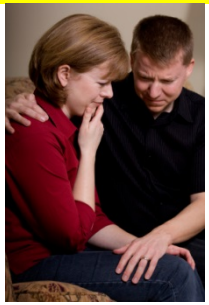
Hippocampus

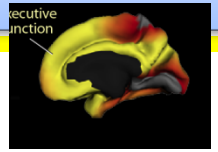


Memory

Prefrontal/Limbic circuitry

Cognitive and Emotional Regulation





What is stress?

- Novel or threatening situation that increases heart rate, blood pressure, and stress hormones (i.e., cortisol)

What is positive stress?

- Mild or moderate
- Relatively brief
- The individual has some control over the experience
- The experience is buffered by healthy relationships
- Learning to adjust to positive stress is part of healthy development
- Examples:
  - Dealing with frustration
  - Meeting new people
  - Getting a shot
  - Brief separations from parents

What is tolerable stress?

- More severe experiences that have the potential to negatively affect the developing brain
- Generally limited time periods, and therefore effects on the developing brain can be reversible
- Examples:
  - Death or illness of a loved one
  - Frightening accident
  - Divorce
  - Other negative events in the context of ongoing, supportive relationships with adults

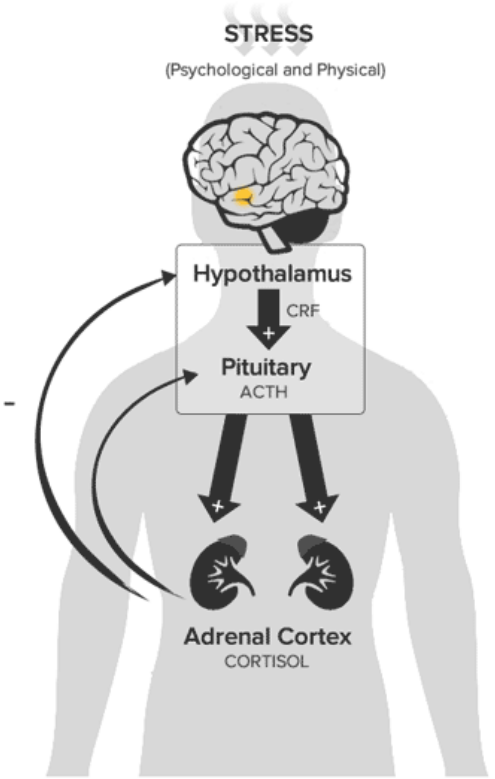
What is harmful or “toxic” stress?

- Extreme
- Long-lasting
- Frequent
- Buffering relationships are unavailable
- Such “toxic stress” can lead to damage of body and brain systems
  - Poorly controlled stress-response systems
  - Overly reactive or slow to shut down when faced with threats
  - Children may experience anxiety or feel threatened when no real threat exists
  - Can lead to mental health problems (depression, anxiety, substance abuse) and physical health problems (heart disease, diabetes, stroke)

Toxic Stress Derails Healthy Development

- Harvard Center for the Developing Child
- http://developingchild.harvard.edu/resources/toxic-stress-derails-healthy-development/

Hypothalamus-Pituitary-Adrenal (HPA) axis



HPA Axis function / dysfunction

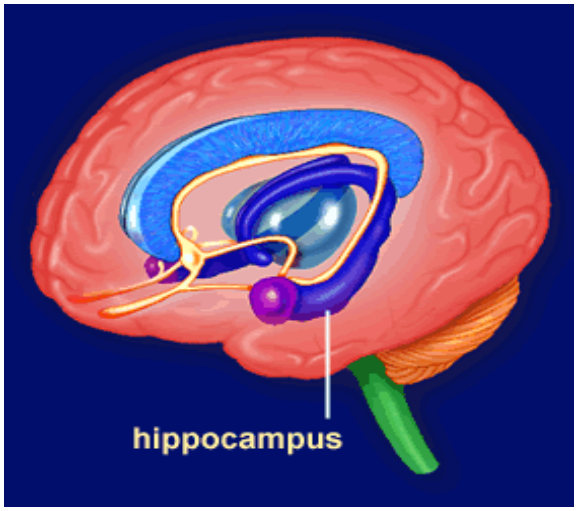
- When cortisol is released suddenly and turned off quickly
  - Mobilizes energy, enhances memory, activates immune response
- If stress is chronic and cortisol release is dysregulated,
  - Immune function can be suppressed
  - Memory suppression
  - Metabolic syndrome, bone loss, muscle atrophy

Three brain regions dramatically affected by stress

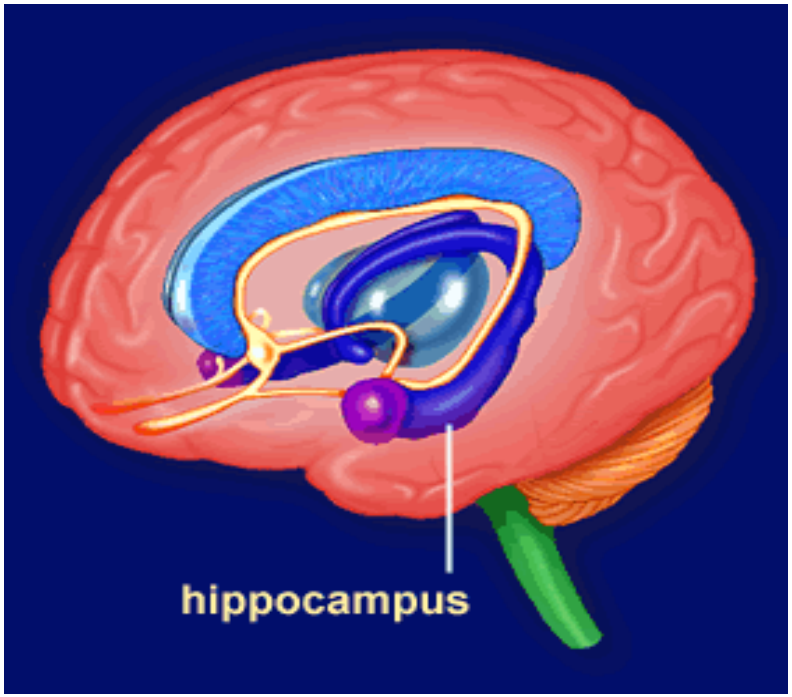
- Hippocampus
- Amygdala
- Prefrontal cortex

Hippocampus

- Essential for
  - Memory
  - Navigation
- High levels of glucocorticoid receptors

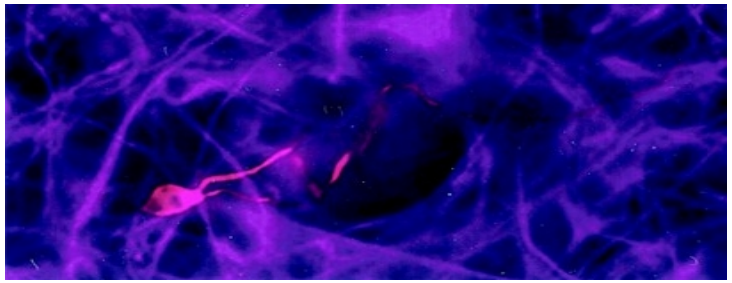


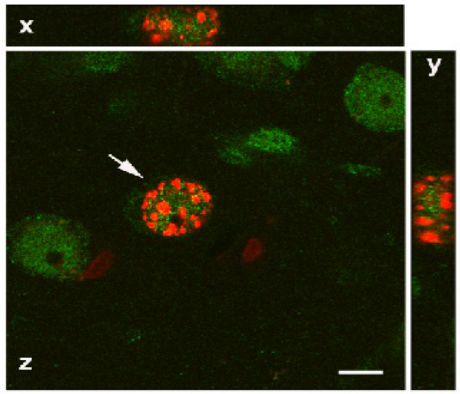
How does stress influence hippocampus development?



Animal studies

- Stress or stress hormone application
  - Suppresses neurogenesis
  - Alters neurotransmitter activity
  - Dendritic remodeling
  - Smaller hippocampal volumes
  - Learning tasks dependent on the hippocampus





Rodent model of maternal care: Licking and grooming

Champagne et al., 2008, Journal of Neuroscience

Natural variation in LG behavior

- Offspring of low LG mothers show
  - Increased HPA responses to stress
  - Enhanced emotionality
  - Impaired performance on spatial learning and object recognition tasks
- These effects are reversed if offspring of low LG mothers are “cross-fostered,” i.e., reared by high HG mothers

How does maternal care affect features of the hippocampus?

- Morphology (structure) of hippocampal neurons
- Long-term potentiation (LTP) in vitro
- Behavioral (learning/memory) performance

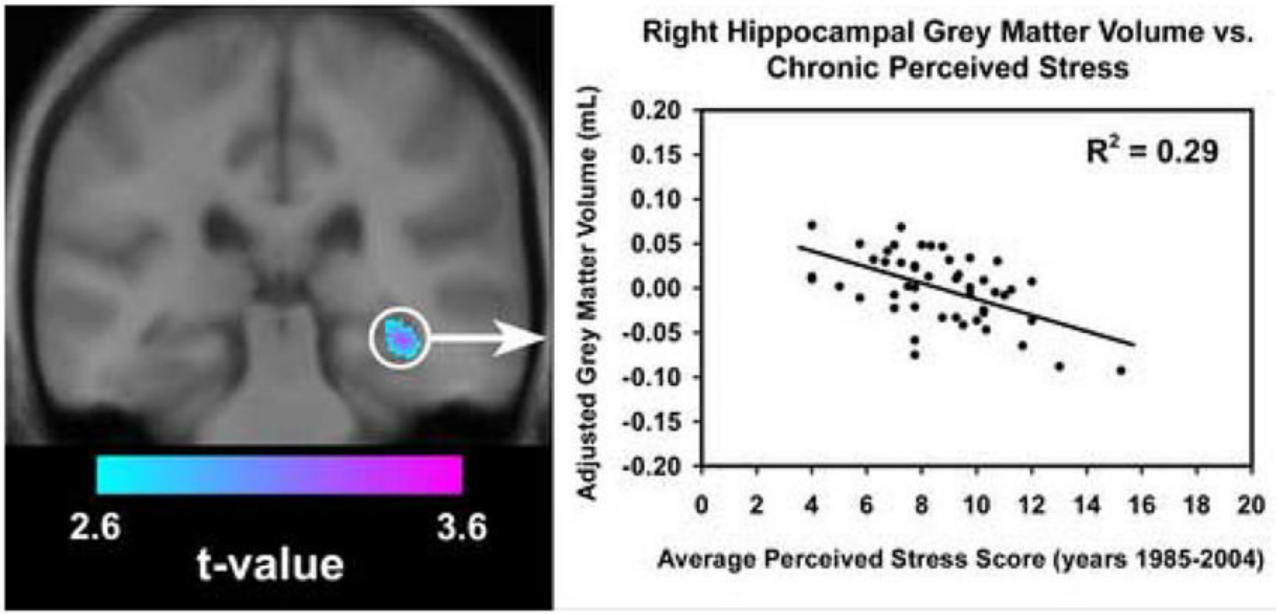
Champagne et al., 2008, Journal of Neuroscience

How is stress associated with hippocampal structure in humans?

- In people, can't measure cellular structure or function
- But can measure hippocampal volume (MRI)

Gianaros et al., 2007, NeuroImage

Higher perceived stress associated with smaller hippocampal volumes



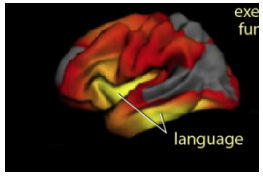
– Adjusted for age, total gray matter volume, time since menopause, use of hormone therapy, depressive symptoms, educational attainment, BMI, smoking and alcohol history

Gianaros et al., 2007, NeuroImage

Other human studies

- Acute and chronic stress impairs function of hippocampus
- Stress may reduce hippocampal volume
  - PTSD
  - Healthy middle-aged and older adults
  - Some evidence in children
- …Or small hippocampal volume may predispose to experience stress differently?

Tottenham and Sheridan 2010, Arnsten 2009



SES

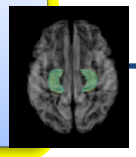
Home language environment

Left hemisphere language cortex

Language

Family Stress

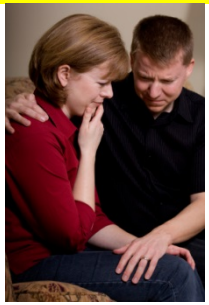
Hippocampus

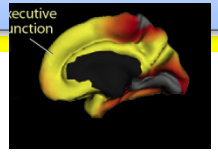


Memory

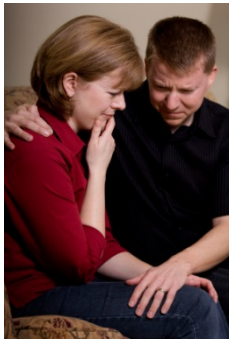
Prefrontal/Limbic circuitry

Cognitive and Emotional Regulation

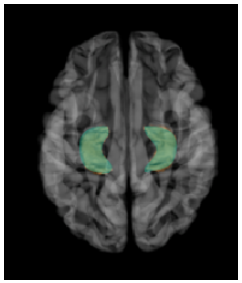


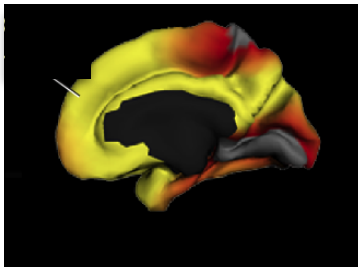


Socioeconomic disadvantage associated with higher family stress

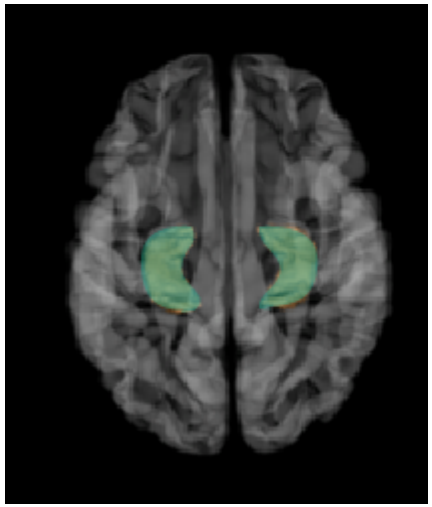


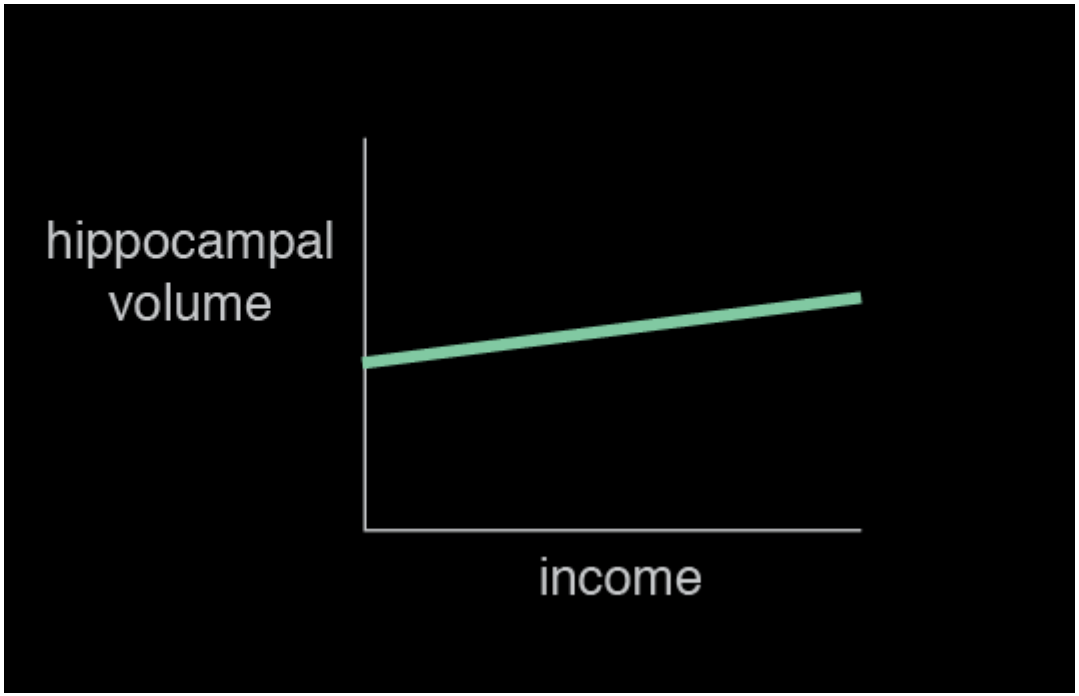
- Socioeconomically disadvantaged children may have altered levels of stress hormones





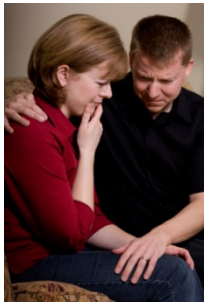
Higher family income is associated with greater hippocampal volume

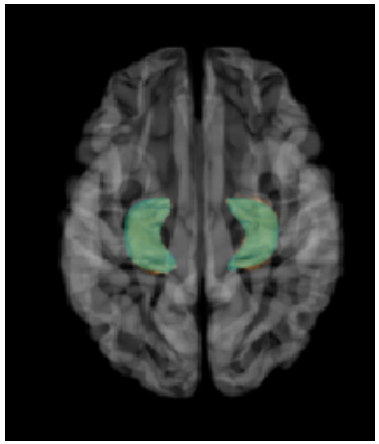


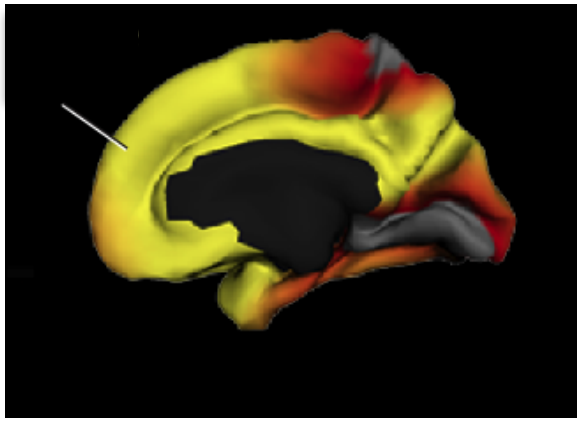


Noble et al, 2012,
Developmental Science

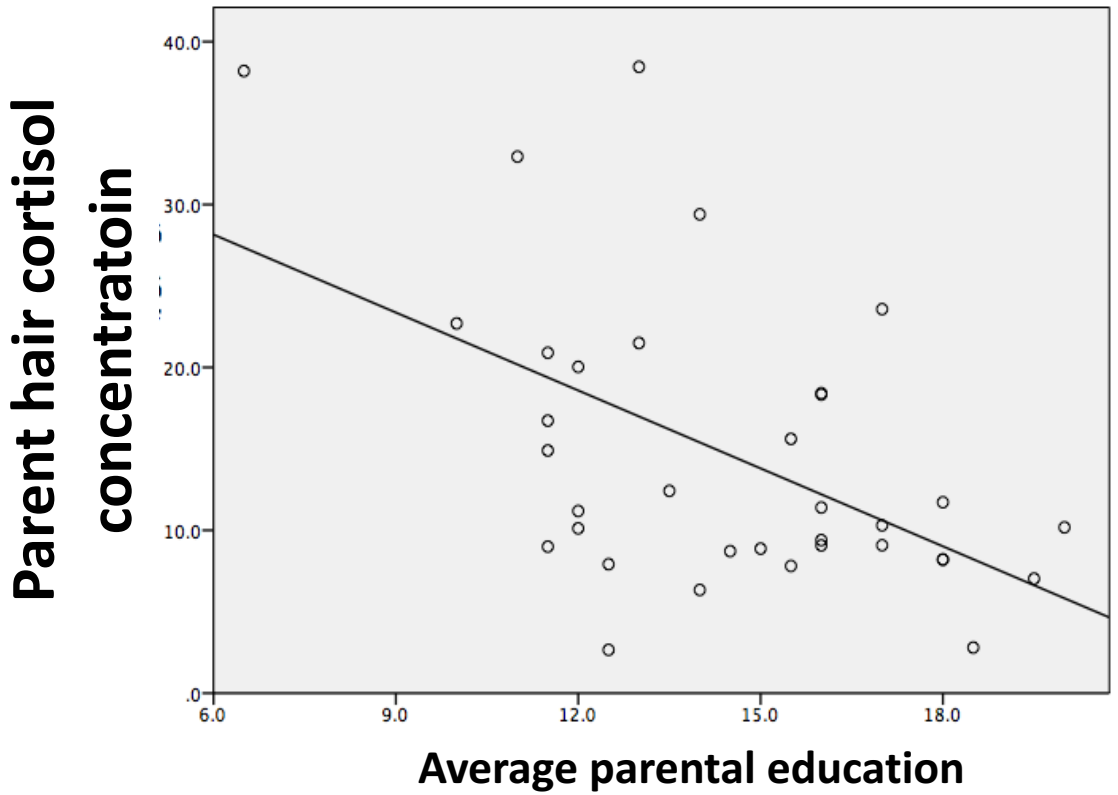
Does chronic stress explain SES differences in the brain?





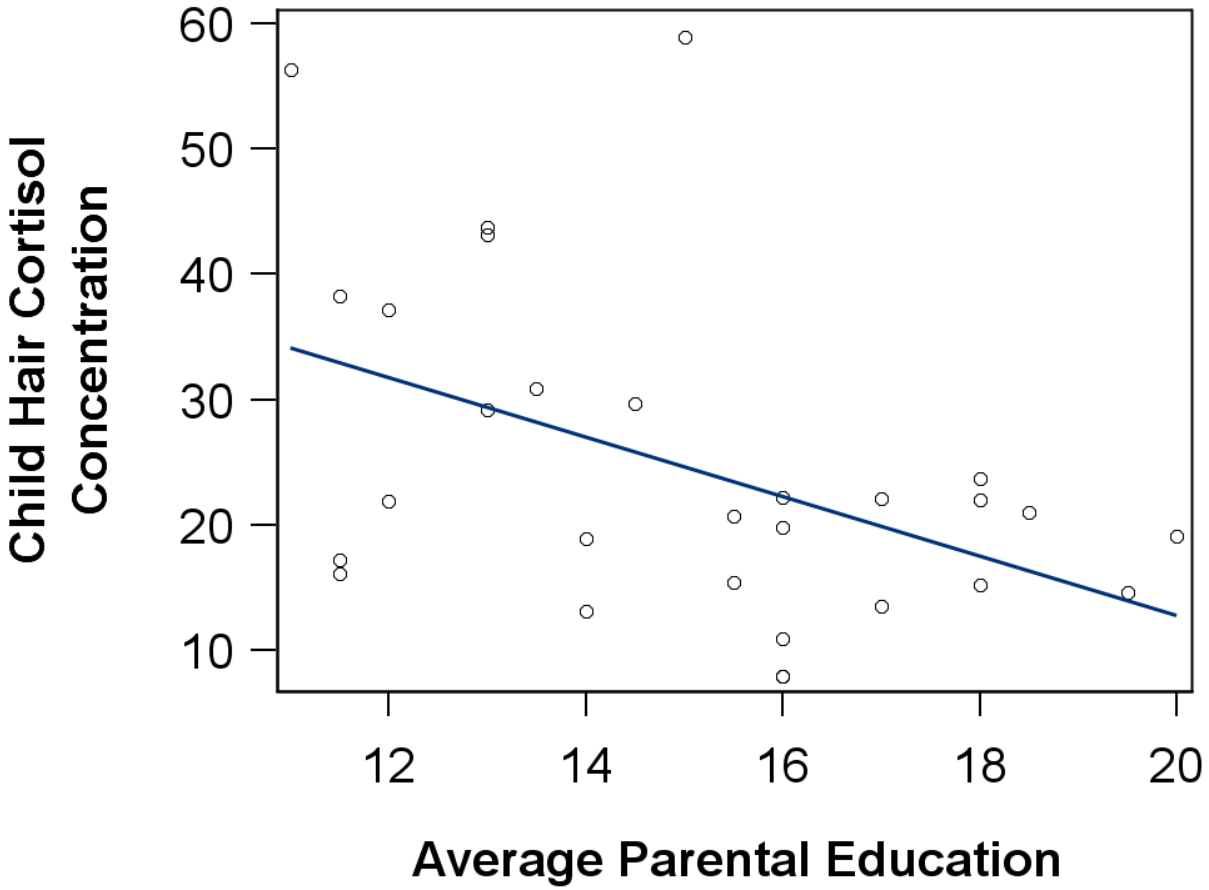


Higher parent education is associated with reduced parent hair cortisol



Ursache, Merz et al, 2017, *Psychoneuroendocrinology*

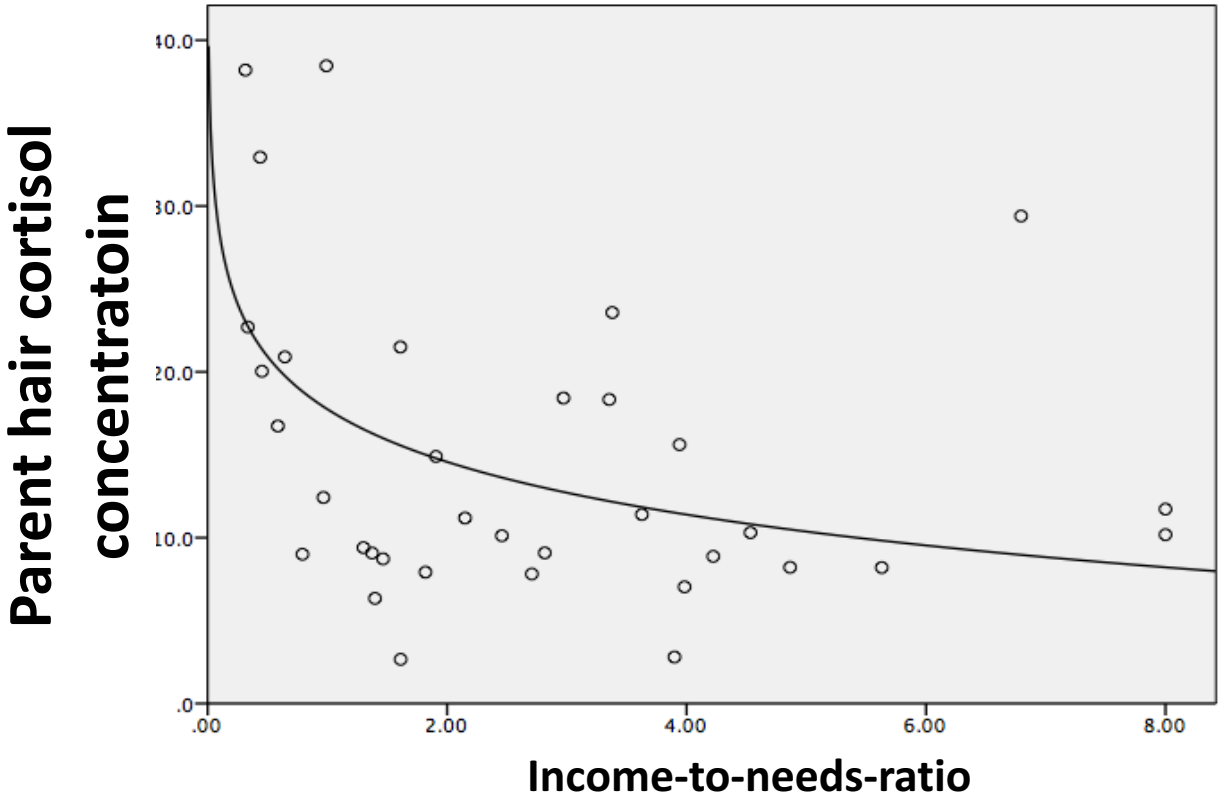
Higher parent education is associated with reduced child hair cortisol



Holds when adjusting for parent hair cortisol

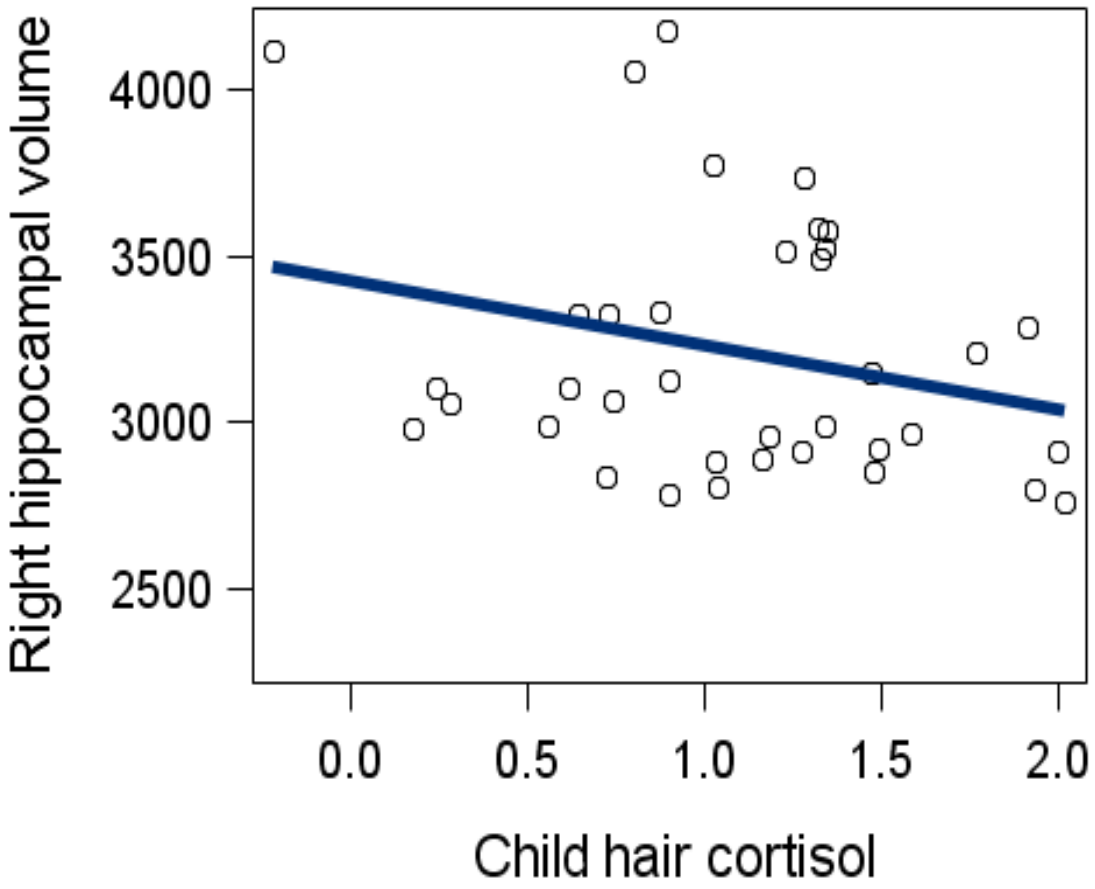
Ursache, Merz et al, 2017, *Psychoneuroendocrinology*

Higher family income is nonlinearly associated with reduced parent hair cortisol



Ursache, Merz et al, 2017, *Psychoneuroendocrinology*

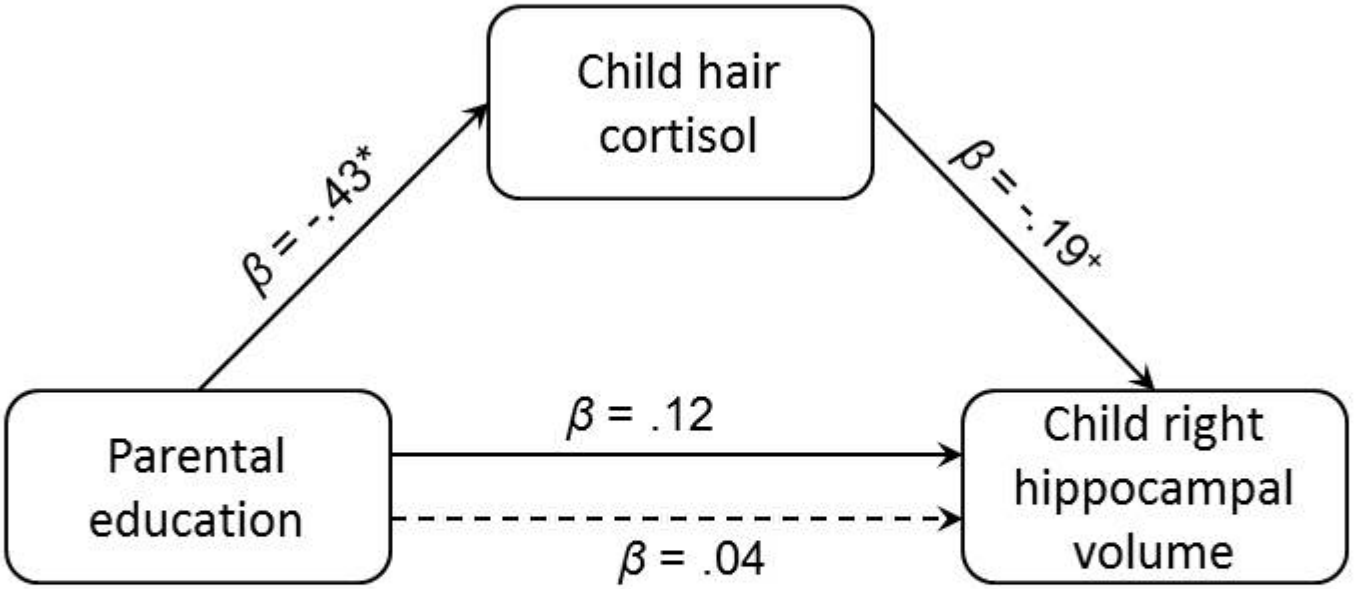
Higher child hair cortisol associated with reduced hippocampal volume



Specifically in CA3 and the dentate gyrus

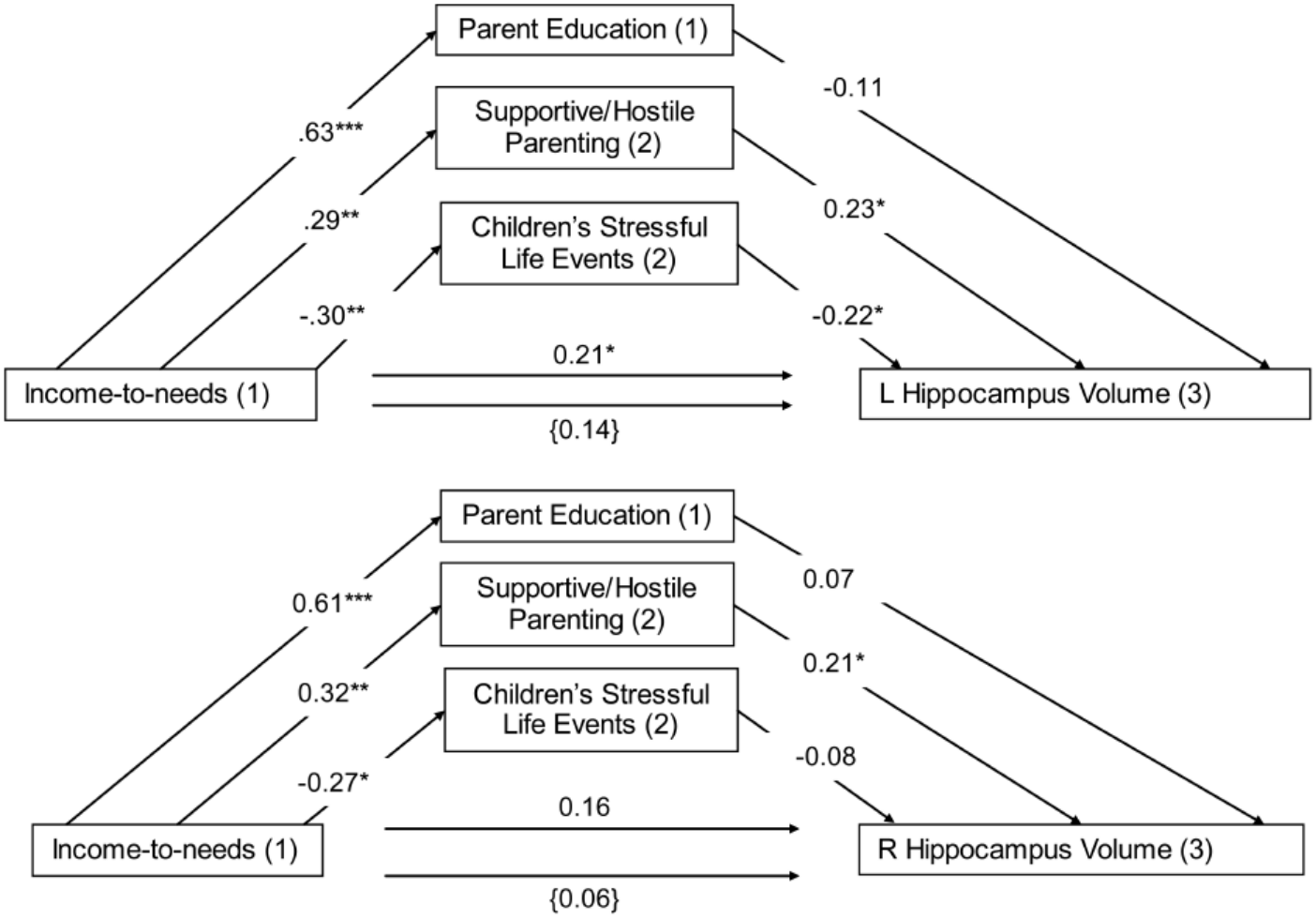
Merz et al, under review

Child stress partially explains link between family SES and children's hippocampal volume



Merz et al, under review

Income and hippocampal volume: mediated by parenting, stress



Luby et al, 2013

Is childhood SES or adult SES driving brain development?

- 238 64-65-year-olds born in 1936
- Collected childhood SES at age 64
  - Number of “public rooms” in the family home
  - Number of people asked to share a bathroom
  - Paternal occupation when the individual was 11 years old
- Adult SES
  - Number of years of education the participant received
  - Participant’s occupation
  - “Local area deprivation” based on home address

Staff et al, 2012

Is childhood SES or adult SES driving brain development?

- Childhood SES was associated with hippocampal volume, adjusting for covariates
- Adult SES was not

Staff et al, 2012

Make no mistake…

- Poverty is associated with early exposure to chronic stress, in ways that we believe are harmful to the developing brain.
- This effect is much less severe than the profound harm caused by depriving young children of their families.
- The science is clear that isolating children from families leads to abnormal health and development.
- Nurturing relationships are absolutely fundamental to normal human development and resilience.
- Abusive policy is likely to have long-term effects on the physical and mental health of these children.

BREAK

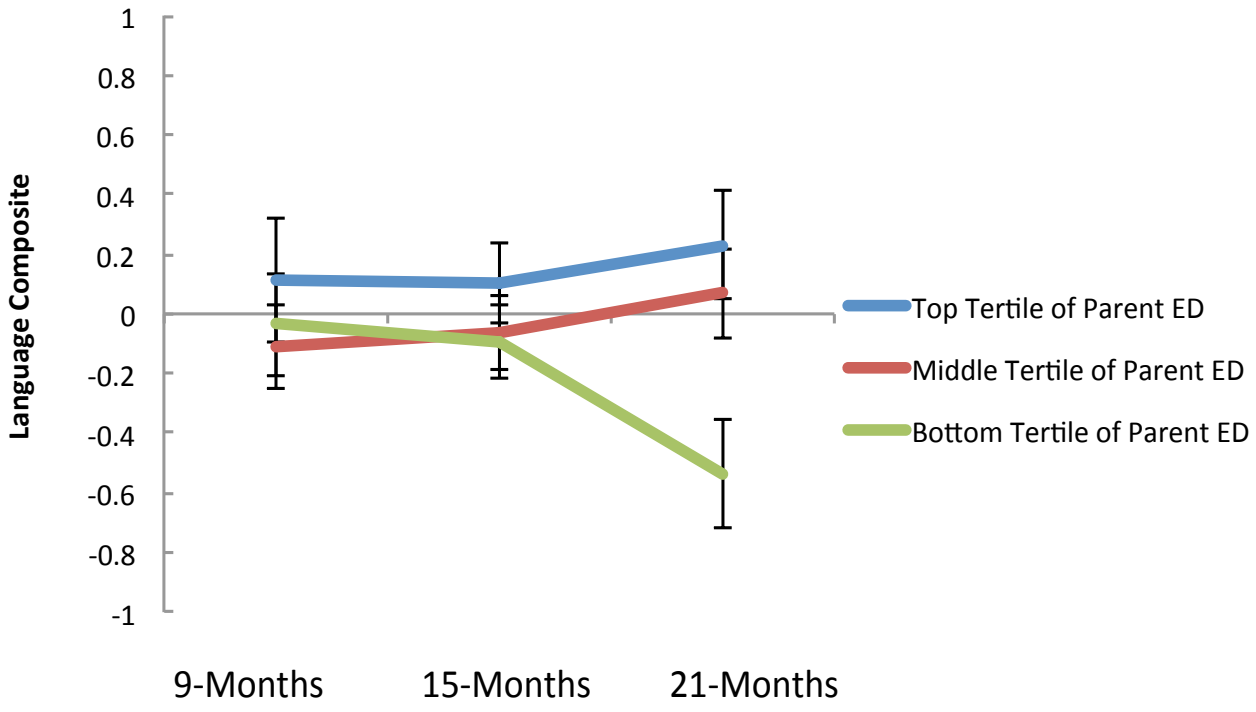
SES and the brain Part 3: Brain function

(It’s not all about looks…)

How early are effects detectable?

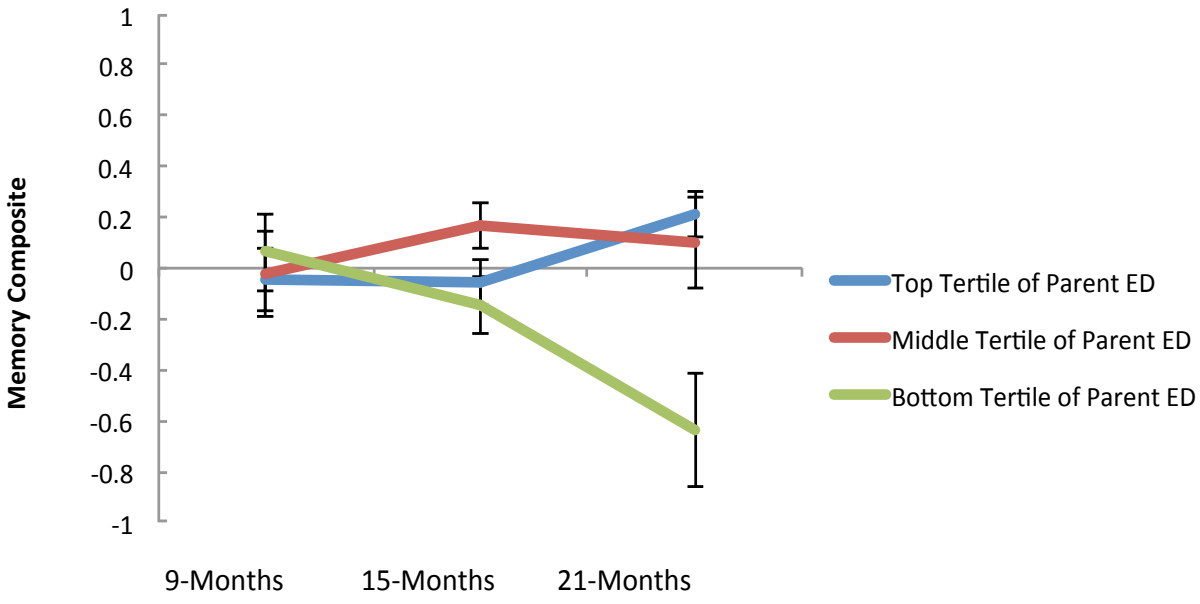
- Behavior: second year of life
- Brain: first year of life

Children of more highly educated parents have better language skills by 21 months



Noble et al, 2015,
Developmental Psychobiology

Children of more highly educated parents have better memory skills by 21 months



Noble et al, 2015,
Developmental Psychobiology

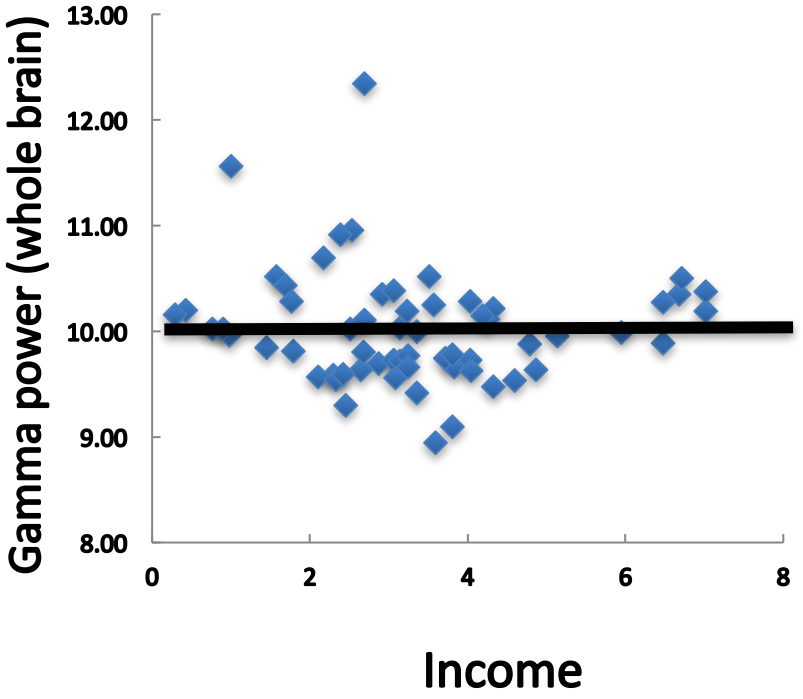
On EEG, children at-risk for learning and attention disorders tend to exhibit

Excess low-frequency oscillations

Gamma: 30-100+Hz Peak performance, flow	
Beta: 12-30Hz Awake, normal alert consciousness	
Alpha: 8-12Hz Relaxed, calm, lucid, not thinking	
Theta: 4-7Hz Deep relaxation and meditation, mental imagery	
Delta: .1-4Hz Deep, dreamless sleep	

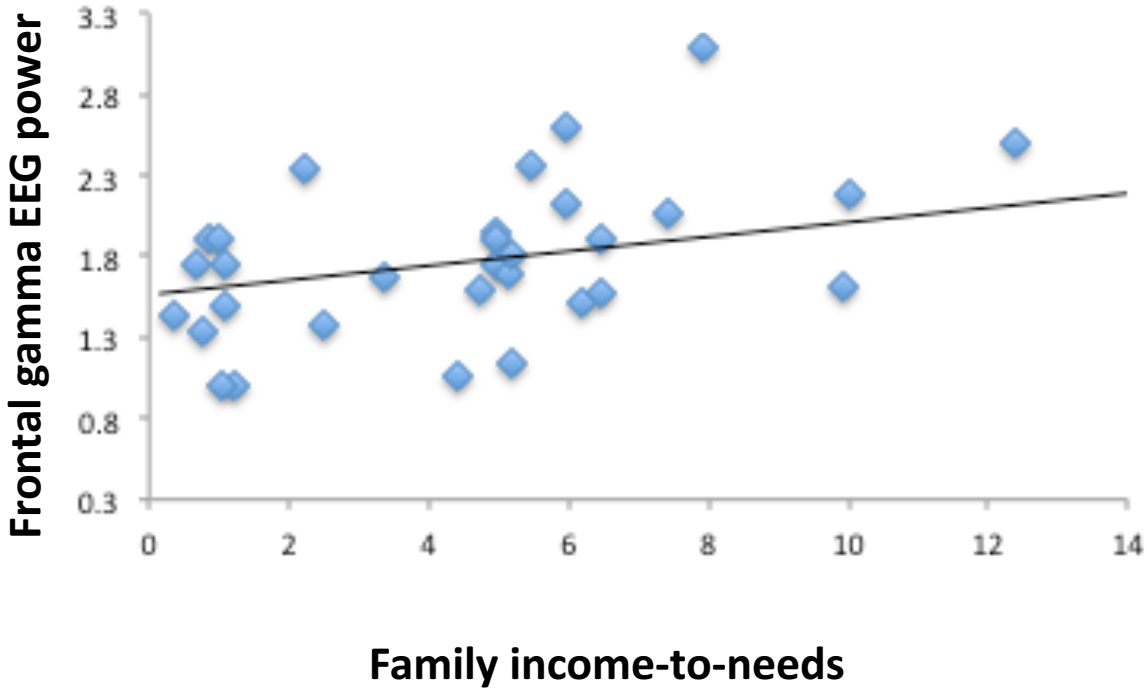
Deficit of high-frequency oscillations

No socioeconomic disparities in brain function at birth



Brito, Fifer, Myers, Elliott, & Noble, 2016
Developmental Cognitive Neuroscience

Family income associated with increased high-frequency power in the first year of life



N=60

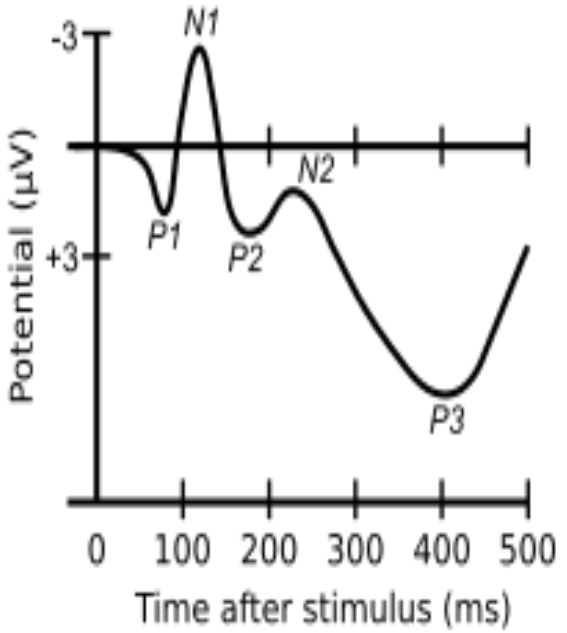
6-to-12-month-old infants

R=.37, p=.04

Brito et al*, in prep*

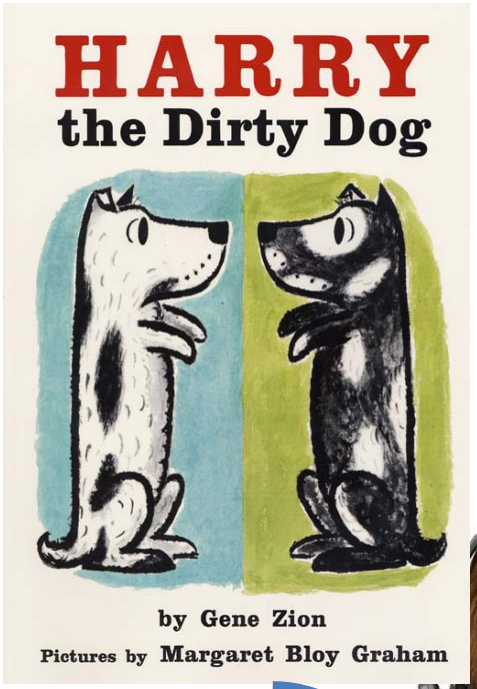
Event-Related Potentials (ERP)

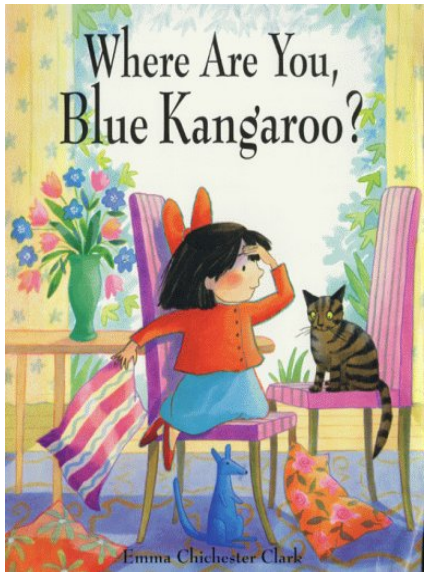
- ERP measures neural response to a particular set of stimuli, such as words or pictures
- Multiple trials of a type of stimulus are presented and then averaged over trials
- Reduces noise from unrelated variation in brain electrical activity
- Plotted with negative voltages upward
- Certain components of the waveform have classic associations with function



Does family SES relate to a child's ability to pay attention to relevant information and ignore distracting information?

Dichotic listening paradigm





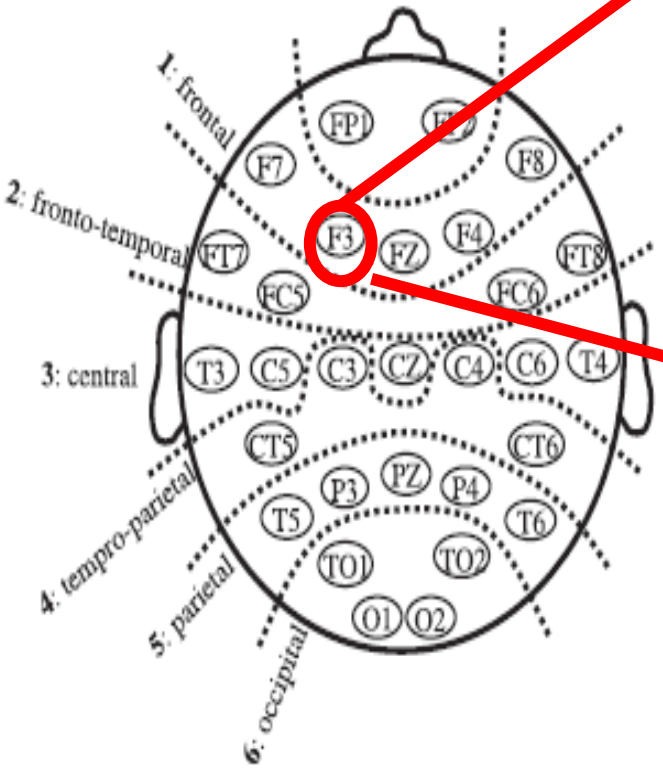
Stevens et al., 2009, Developmental Science

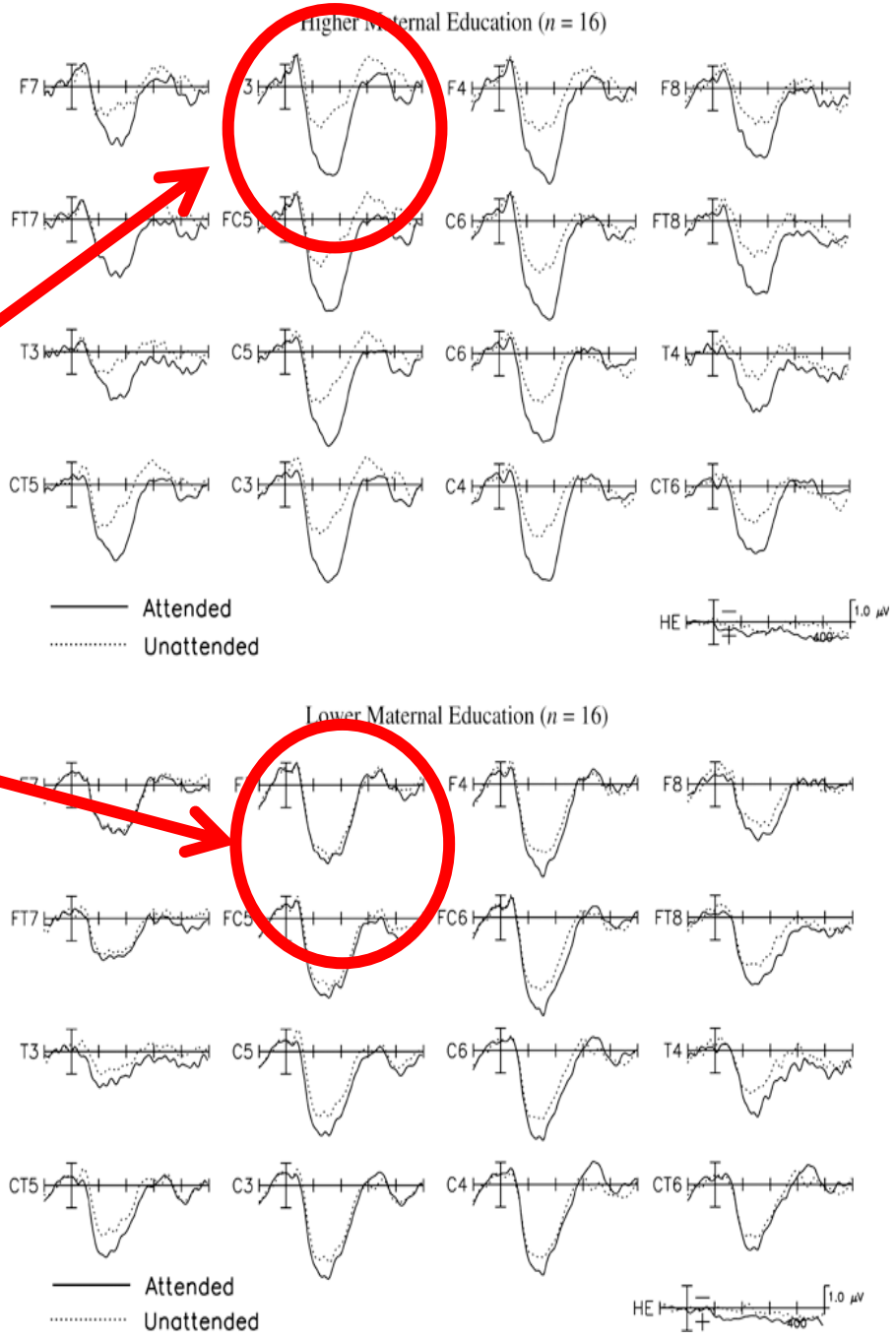
Family SES and selective attention

- 32 healthy 3-to-8-year-olds
- Mostly white
- At least 25th percentile on language composite
- Maternal education used as SES measure
  - Higher maternal ed: at least one year of college
  - Lower maternal ed: no more than high school
- Recorded ERPs while listening to the two stories

Stevens et al., 2009, Developmental Science

Higher Parental Education Group

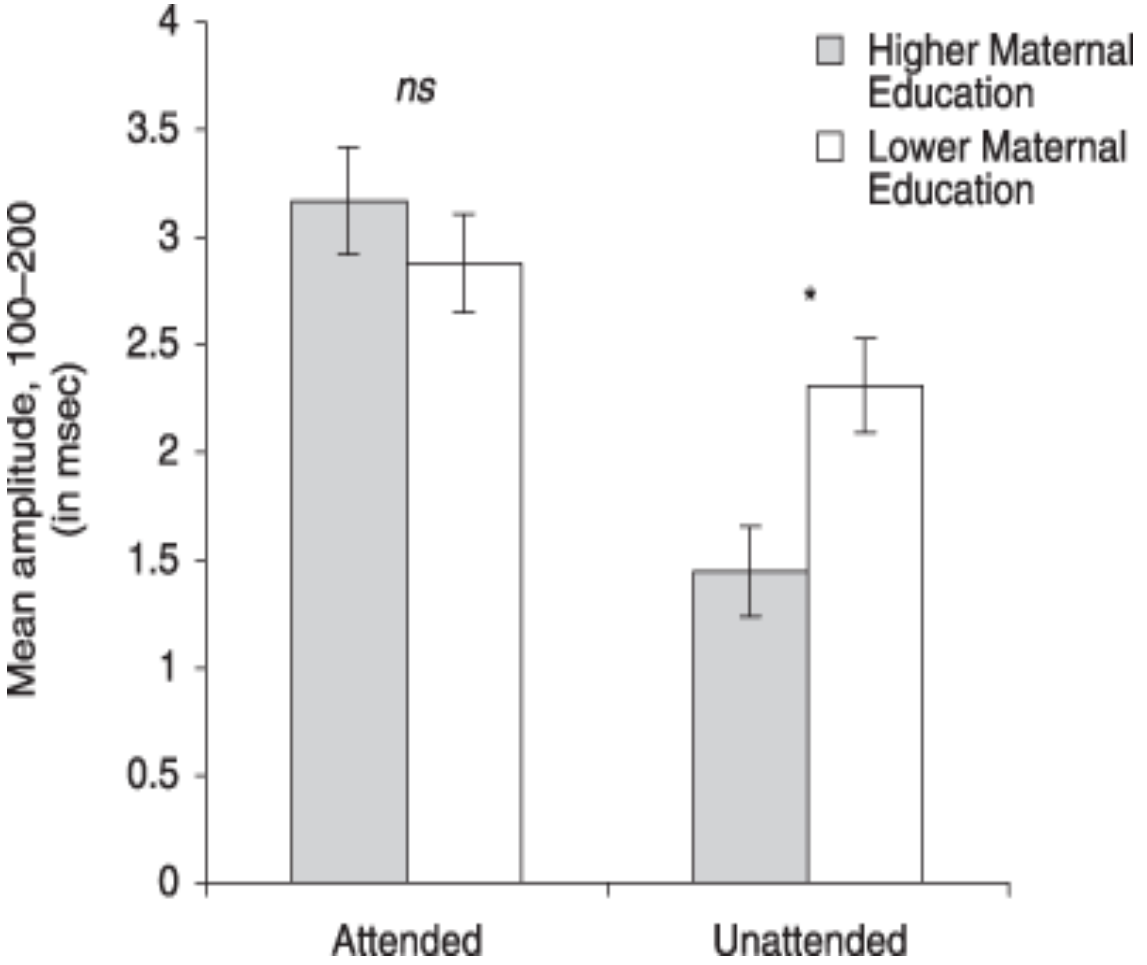




Lower Parental Education Group

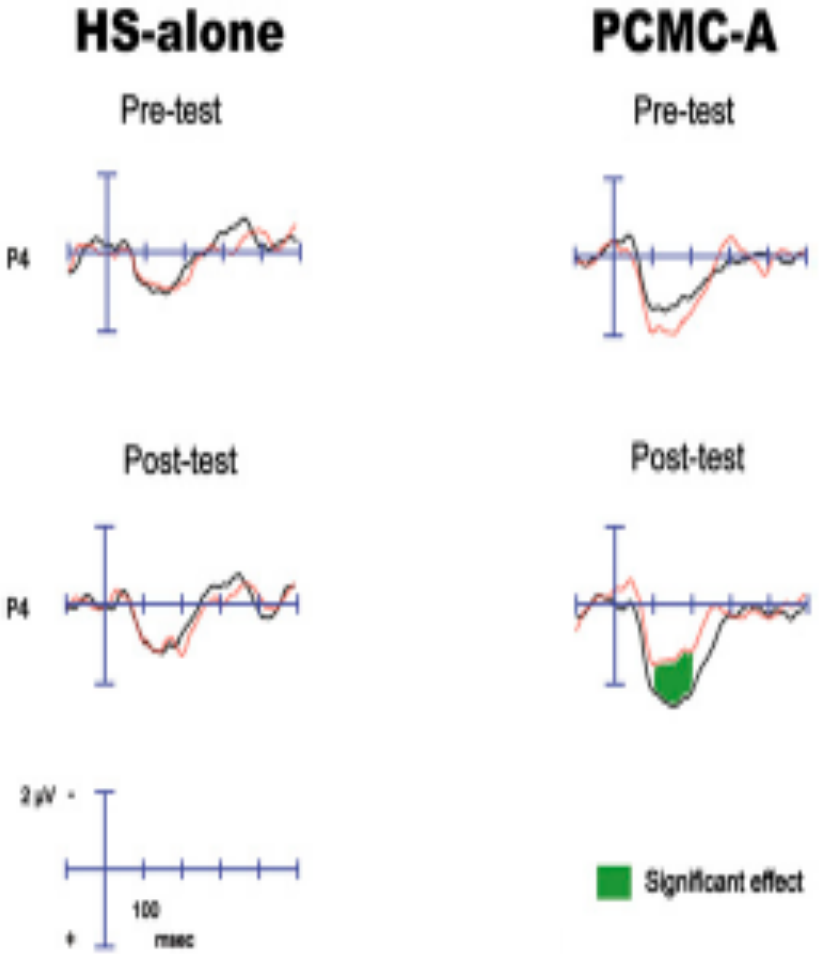
Stevens et al., 2009,
Developmental Science

Children of higher educated mothers better able to suppress distracting stimuli



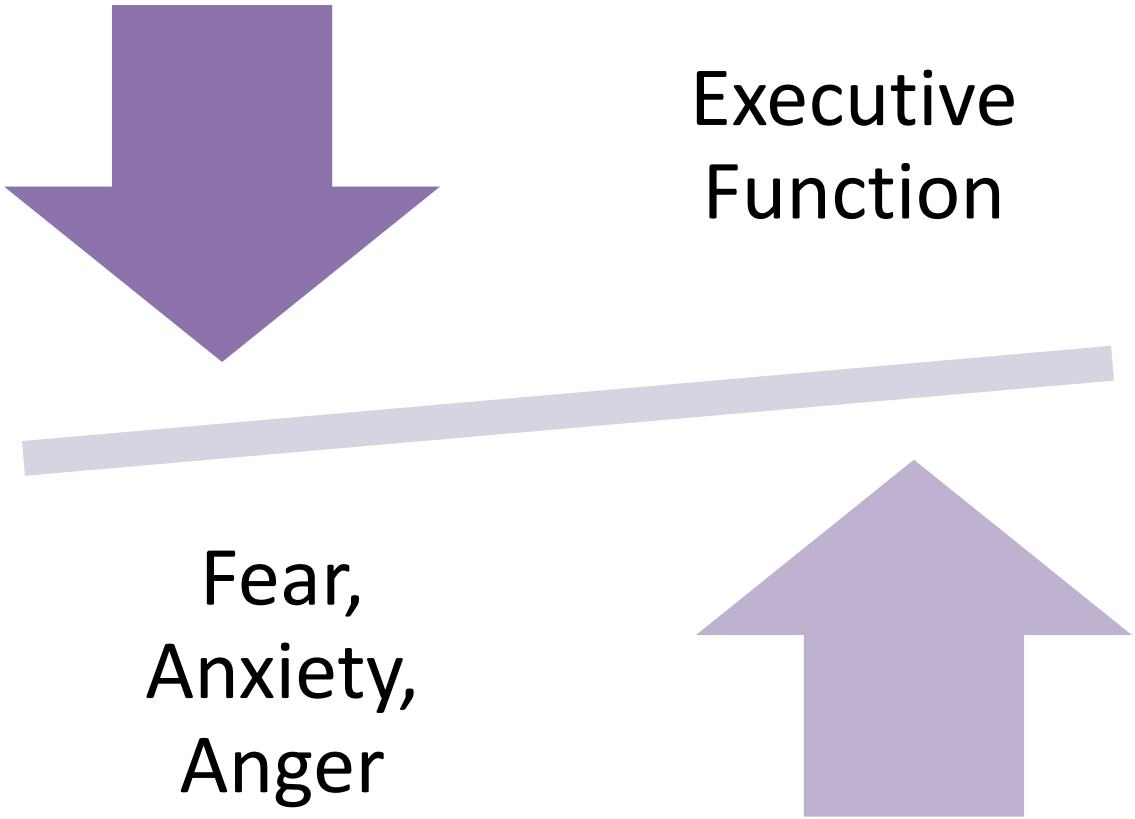
Stevens et al., 2009, Developmental Science

Training can improve children's selective attention



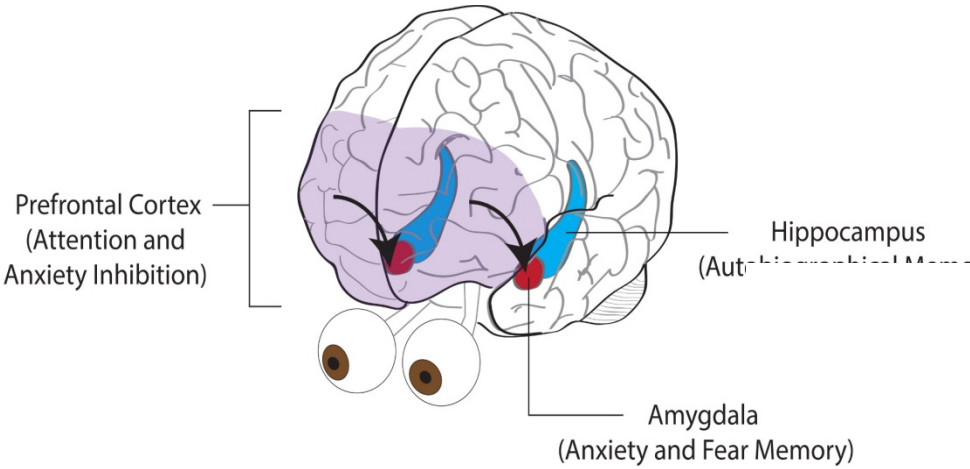
Neville et al., 2013, PNAS

Executive function and emotion regulation



Emotion regulation is a balance between the amygdala and prefrontal cortex

- The amygdala detects and responds to threats from the environment, activating physiological stress responses
- The PFC is a “top-down” regulator of the amygdala in adulthood
- Increased activity in parts of the PFC associated with
  - Diminished amygdala activity to negative stimuli
  - Diminished negative affect
- Aberrant PFC-amygdala regulation thought to underscore impaired emotion regulation in psychiatric disorders such as depression, anxiety and disorders of impulsivity



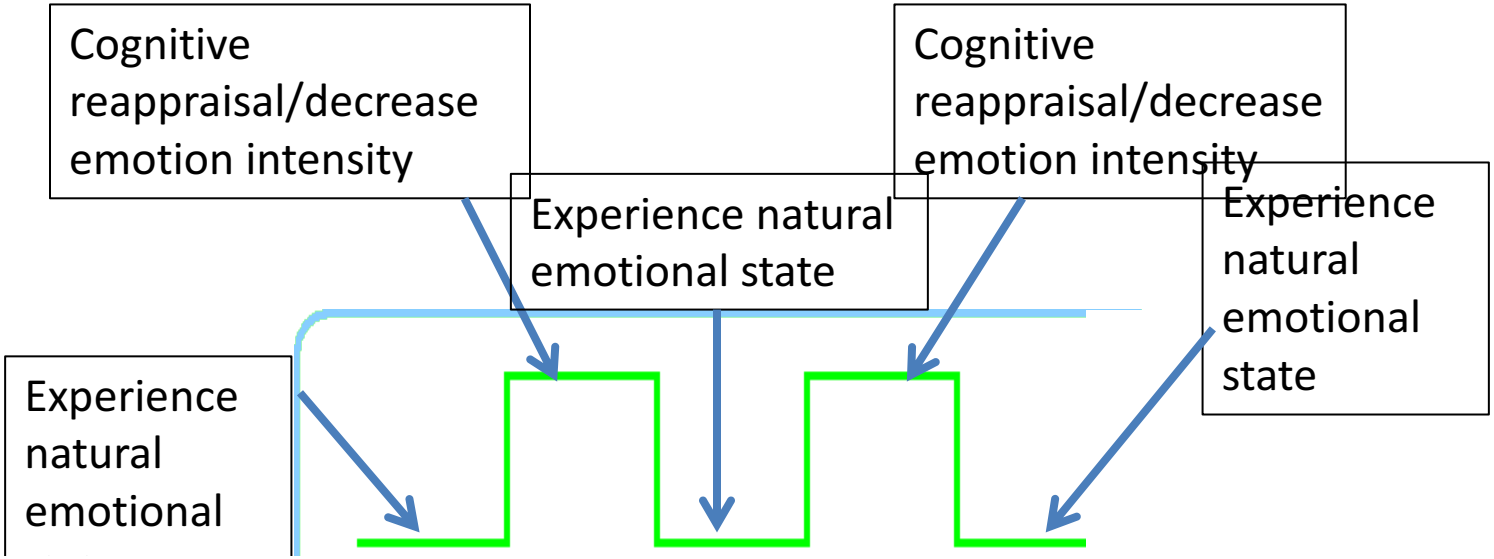
Does childhood poverty predict adult emotion regulation?

- Examined associations between childhood poverty at age 9 and adult neural circuitry during emotion regulation at age 24.
- N=49
- Rural sample
- Longitudinal assessments – ages 9, 13, 17
- Measured chronic stress as a mediator:
  - Psychosocial risk: child-family spearation, violence, family turmoil
  - Physical risk: noise, crowding, housing quality
  - Maternal and child report, observer report
- Emotion regulation measured as cognitive reappraisal

Kim et al PNAS 2013

Cognitive reappraisal

Cognitive reappraisal paradigm



Questions:

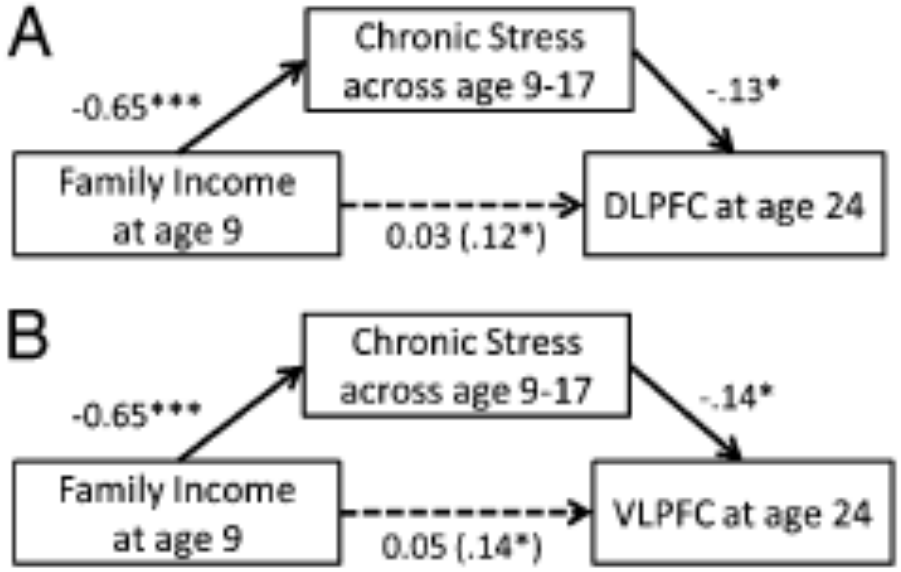
1. Are there areas that respond differently during reappraisal vs. control condition?
2. Are these differences related to childhood SES?

Childhood income related to increased PFC and decreased amygdala activation during emotion regulation in adulthood

Held when controlling for adult income

Kim et al., 2013

Link between childhood poverty and adult prefrontal function mediated by chronic stress



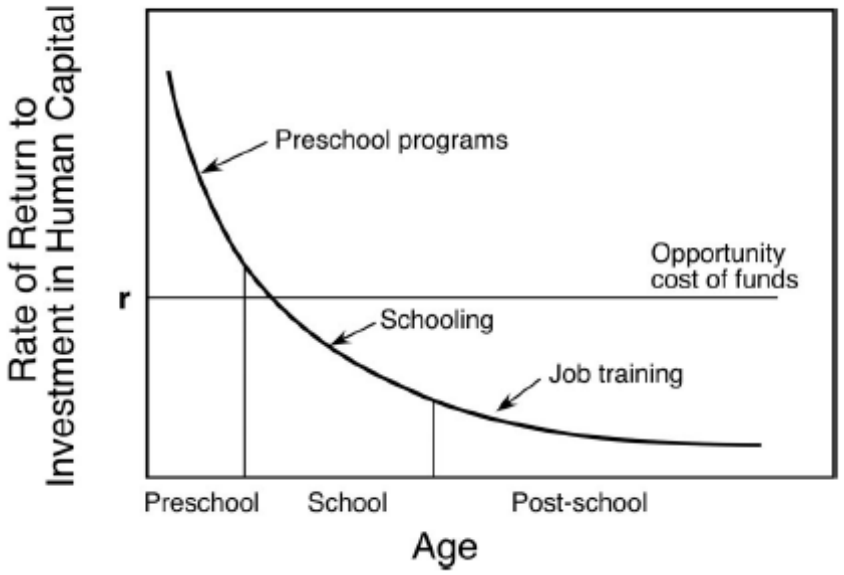
If experience such as the home language environment or family stress matters, can this work inform interventions?

SES and the brain Part 4: Links to achievement and life outcomes

"The most efficient strategy for strengthening the future workforce, both economically and neurobiologically, and improving its quality of life is to invest in the environments of disadvantaged children during the early childhood years."

Knudsen, 2006, *PNAS*

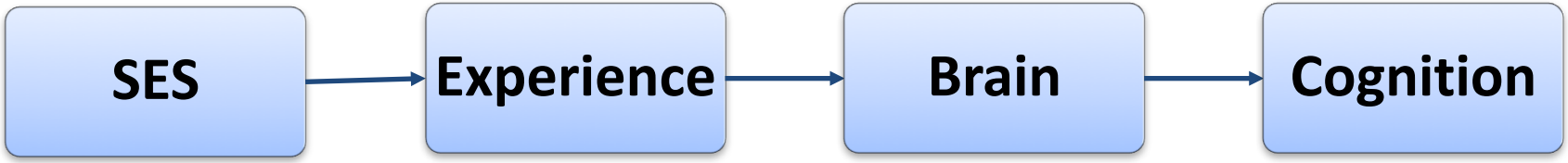
Interventions in early childhood have a higher rate of return than later interventions



Knudsen, 2006, *PNAS*

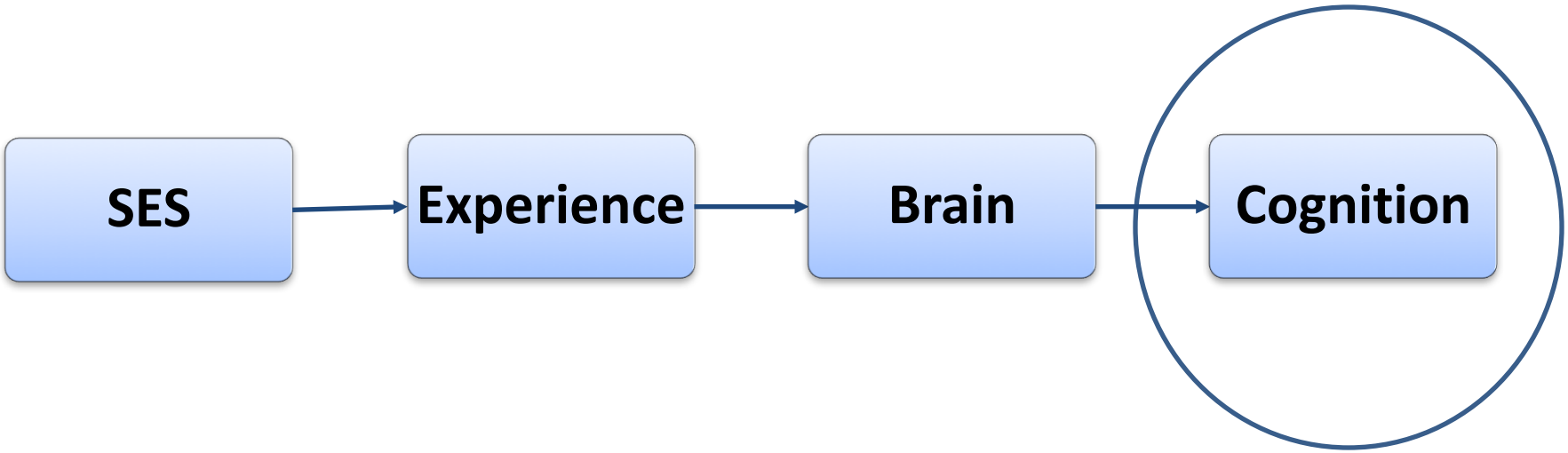
If experience matters, can this work inform interventions?

And what is the right level at which to intervene?

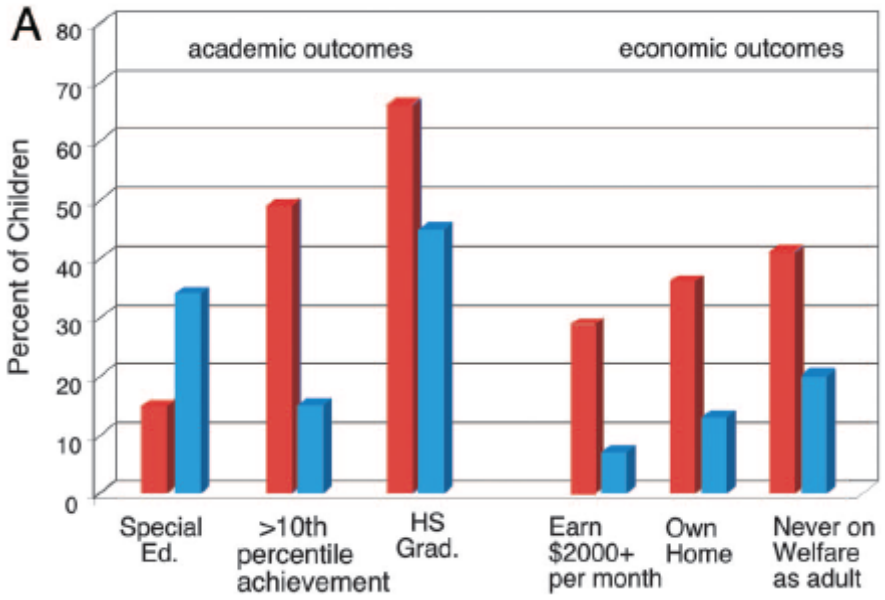


School-based interventions

- Most common form of intervention addressing SES disparities in achievement



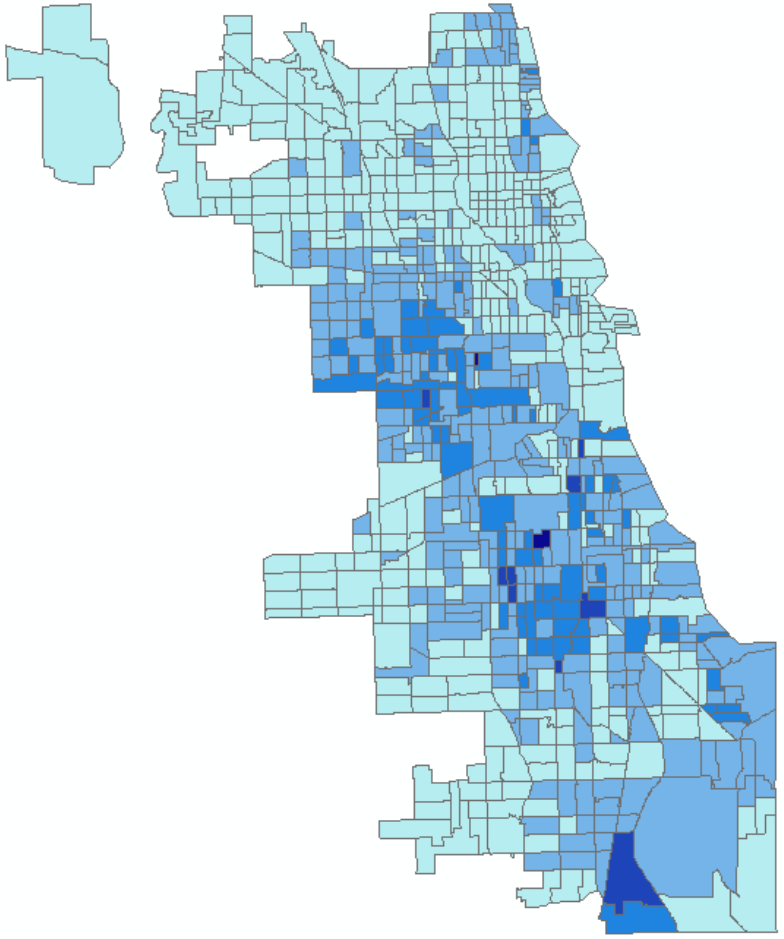
Academic and economic outcomes are improved following high-quality preschool



Knudsen, 2006, *PNAS*

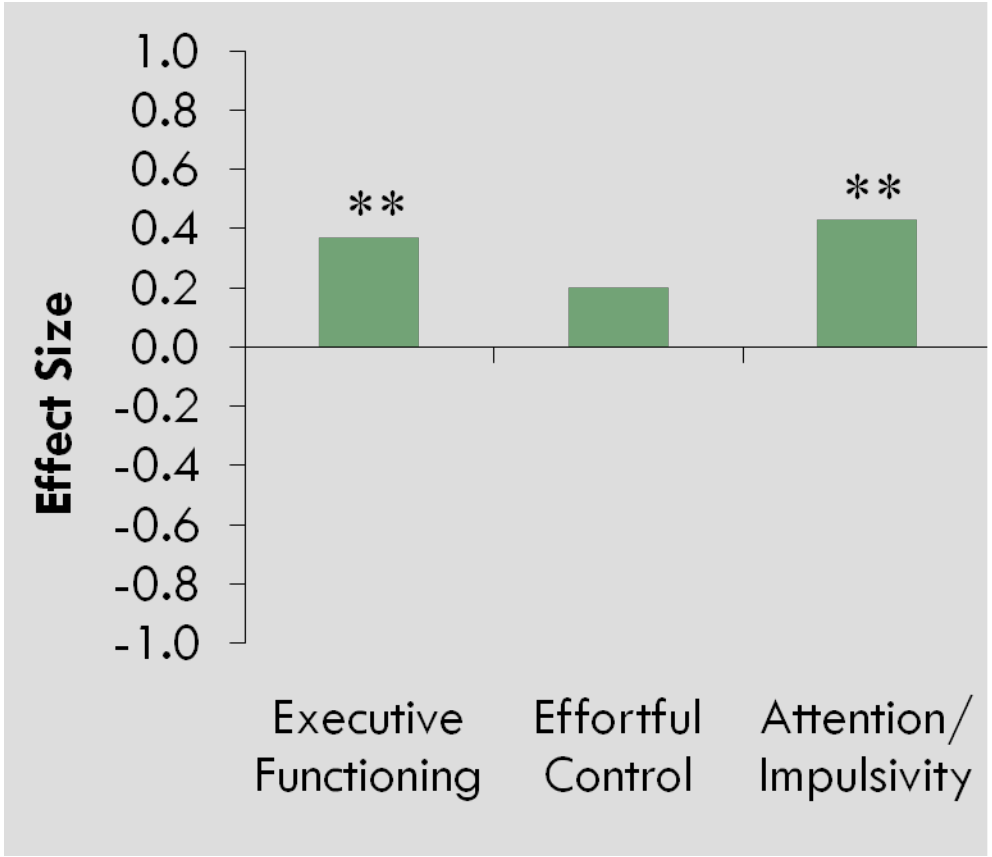
Chicago School Readiness Project

- Cluster-randomized control trial in Head Start settings in some of Chicago's poorest neighborhoods
  - Comprehensive classroom-based intervention targeting emotional and behavioral adjustment
  - Extensive training and support for teachers on effectively managing children's dysregulated behavior



Raver et al 2011 *Child Development*

Impacts on Executive Functions



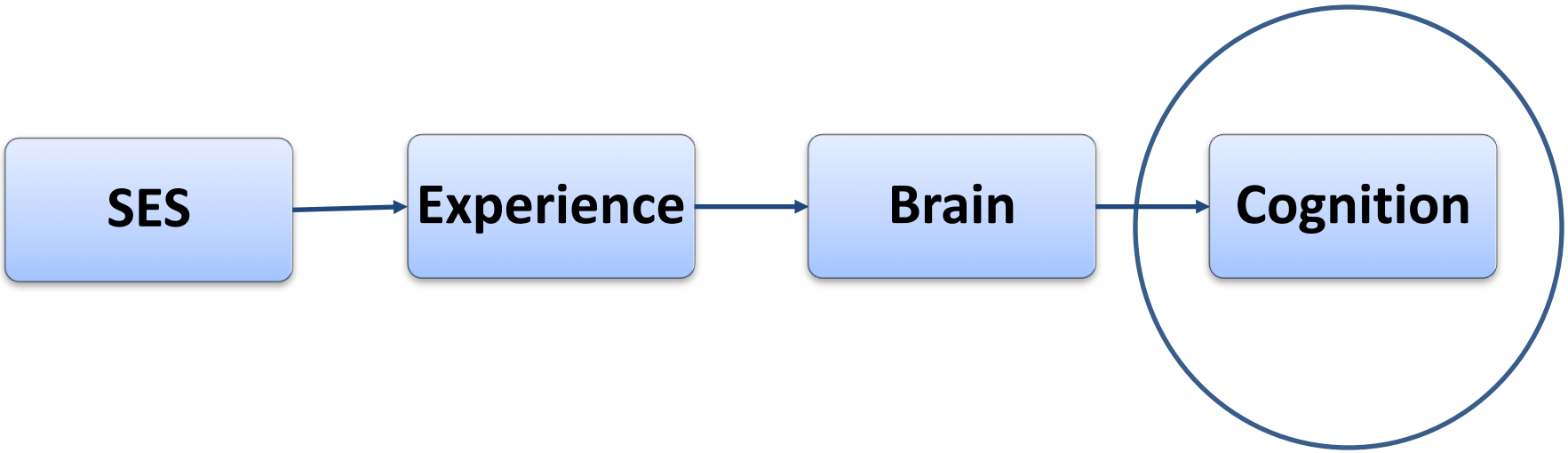
Impacts on Language and Math

(though not explicitly targeted)

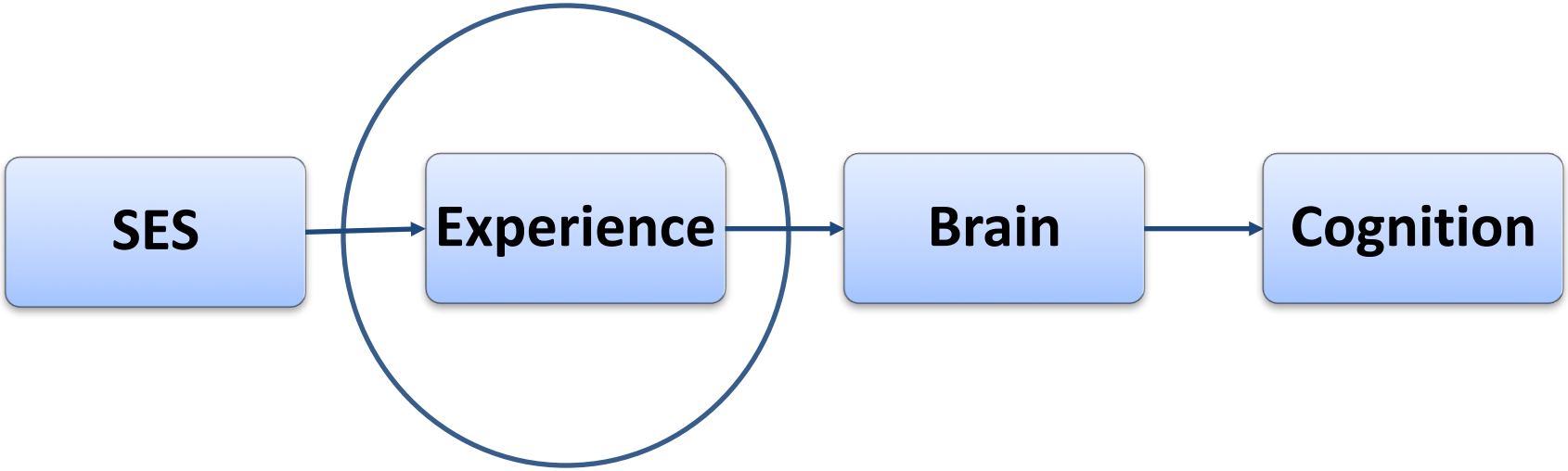
SOURCE: Raver, Jones, Li-Grining, Zhai, Bub, & Pressler (2011), *Child Development.*
NOTES: Significance levels are indicated as * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

School-based interventions

- Results can be very promising…
- Labor-intensive and costly if done right
- Often suffer from “fadeout”
- If waiting until school, likely waiting too late

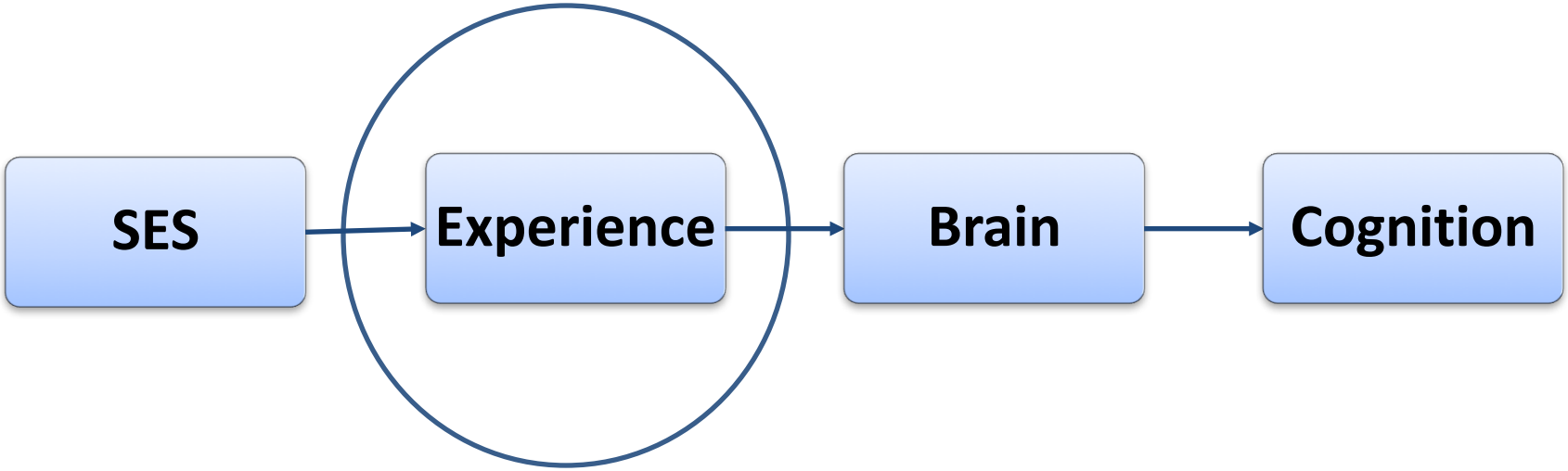


Changing Experience: Parenting interventions

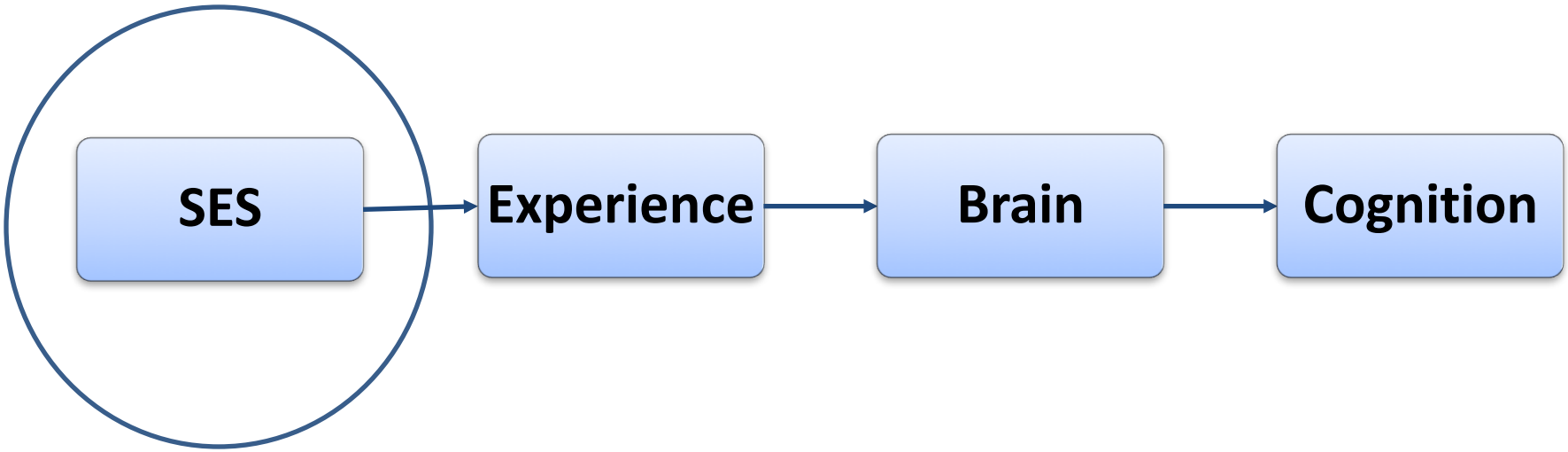


Changing Experience: Parenting interventions

- Traditionally home-based
  - Can be effective…
  - Labor-intensive and costly if done right
  - Challenges due to fadeout, lack of uptake, attrition
  - Difficult to scale up



Intervening most distally: Changing SES itself



Income boosts can have big effects

- $4,000 increase in annual income between the prenatal year and age 2:
  - increased adult earnings
  - increased time in the labor force
  - Some evidence for improved health in adulthood
- **But can we move past correlation to understand if income is *causing* these differences?**

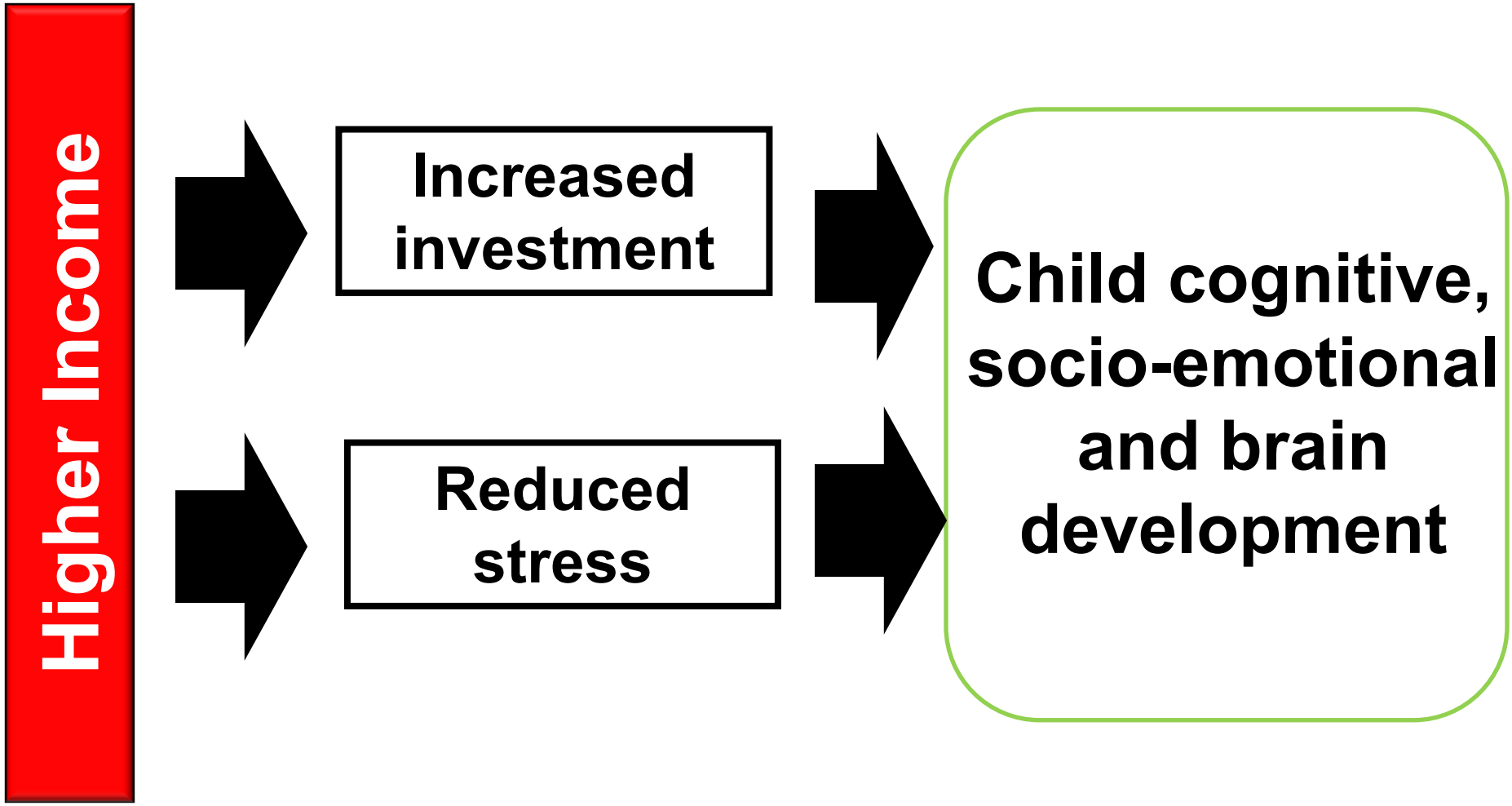
Dahl and Lochner, 2012
Ziol-Guest et al 2012

First clinical trial of poverty reduction in early childhood

- 1000 low-income mothers recruited in hospital after giving birth
- All participants receive unconditional cash transfer for 40 months
  - Treatment group: $333/month ($4000/year)
  - Control group: $20/month ($240/year)
- Monthly reload via debit card
- Causal impact on children's cognitive, emotional and brain development
  - Age 1 & 2: Home visit with survey, observation/video of parenting, stress physiology, cognitive development
  - Age 3: Lab visit with in-depth assessments of children's cognitive, emotional and brain development
- Funded by NIH and a consortium of foundations
- Launched May, 2018!




Developmental theory of change



Highly feasible

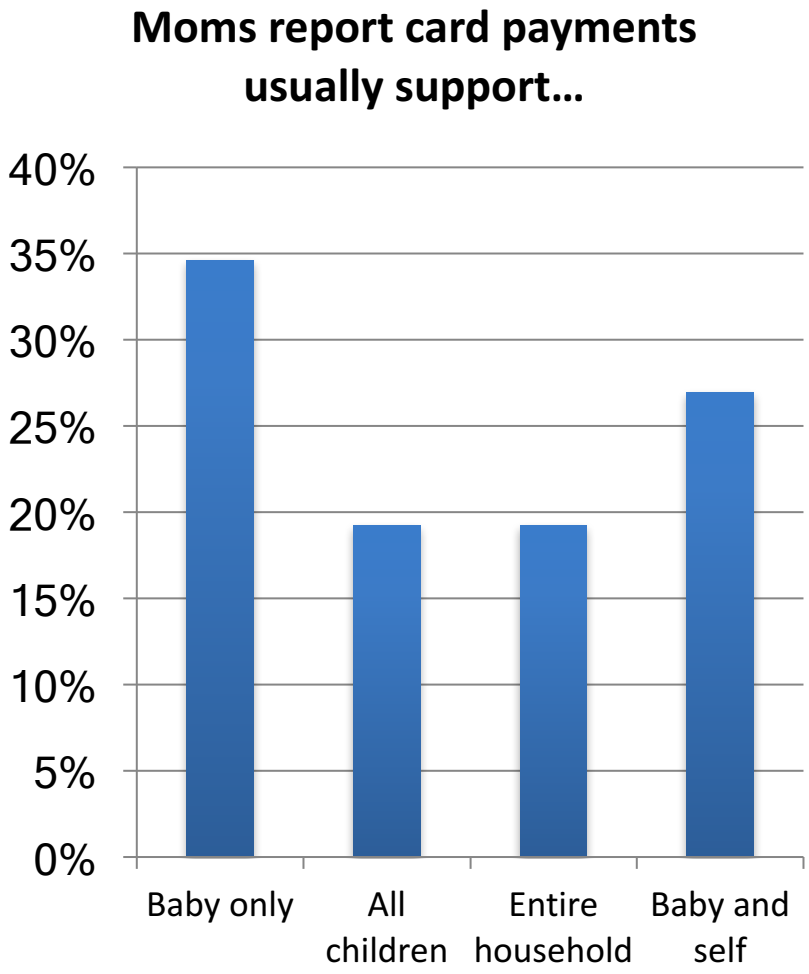
- Pilot study with 30 low-income moms in NYC
- 93.3% retention over 12 months
- Very few problems with debit card implementation

Even in small amounts, money makes a big difference

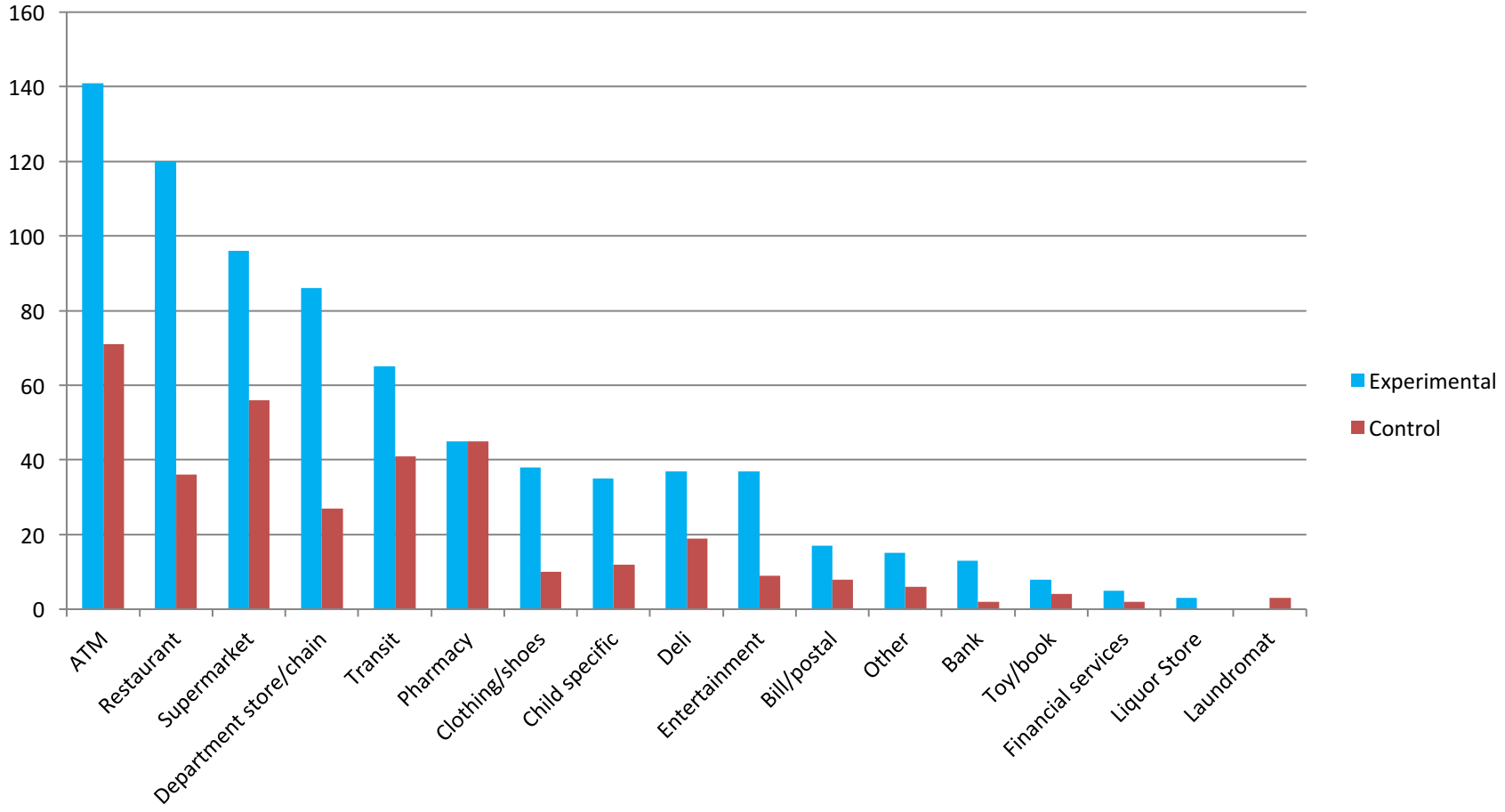
"Believe it or not even an extra $20 helps…there were times I found myself completely broke... I go and I use it and that [means] I can make it for another week."

"The money from the card … really, really helped me out, especially [one] month that we didn't have the food stamps; we didn't have anything at all."

Most moms use the card for the baby



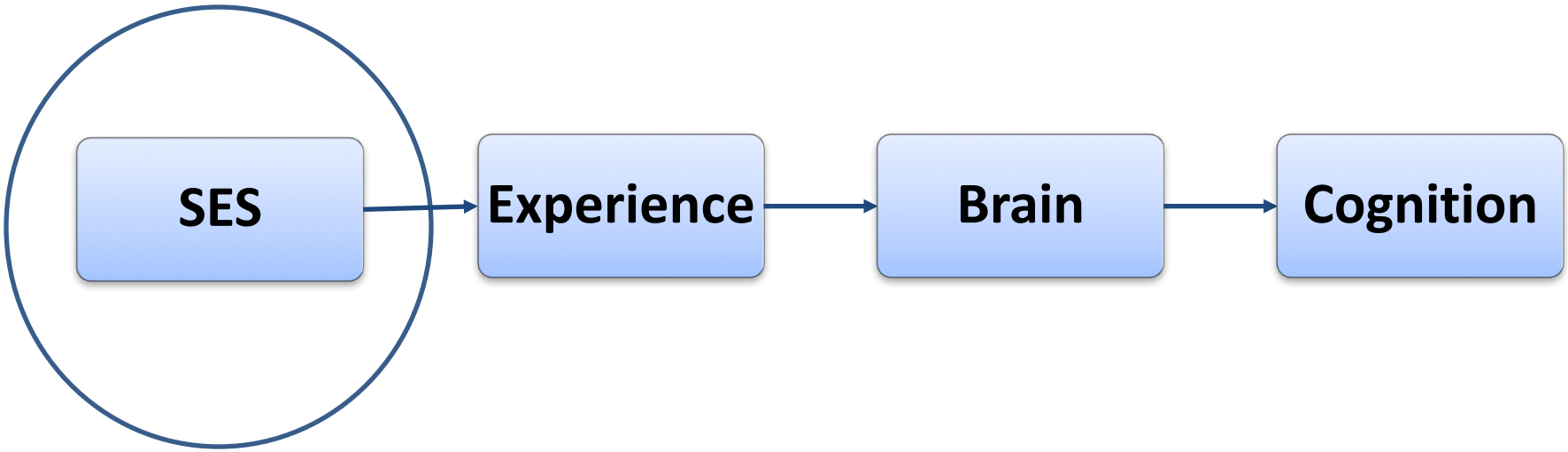
Debit card use: 1112 transactions over 12 months



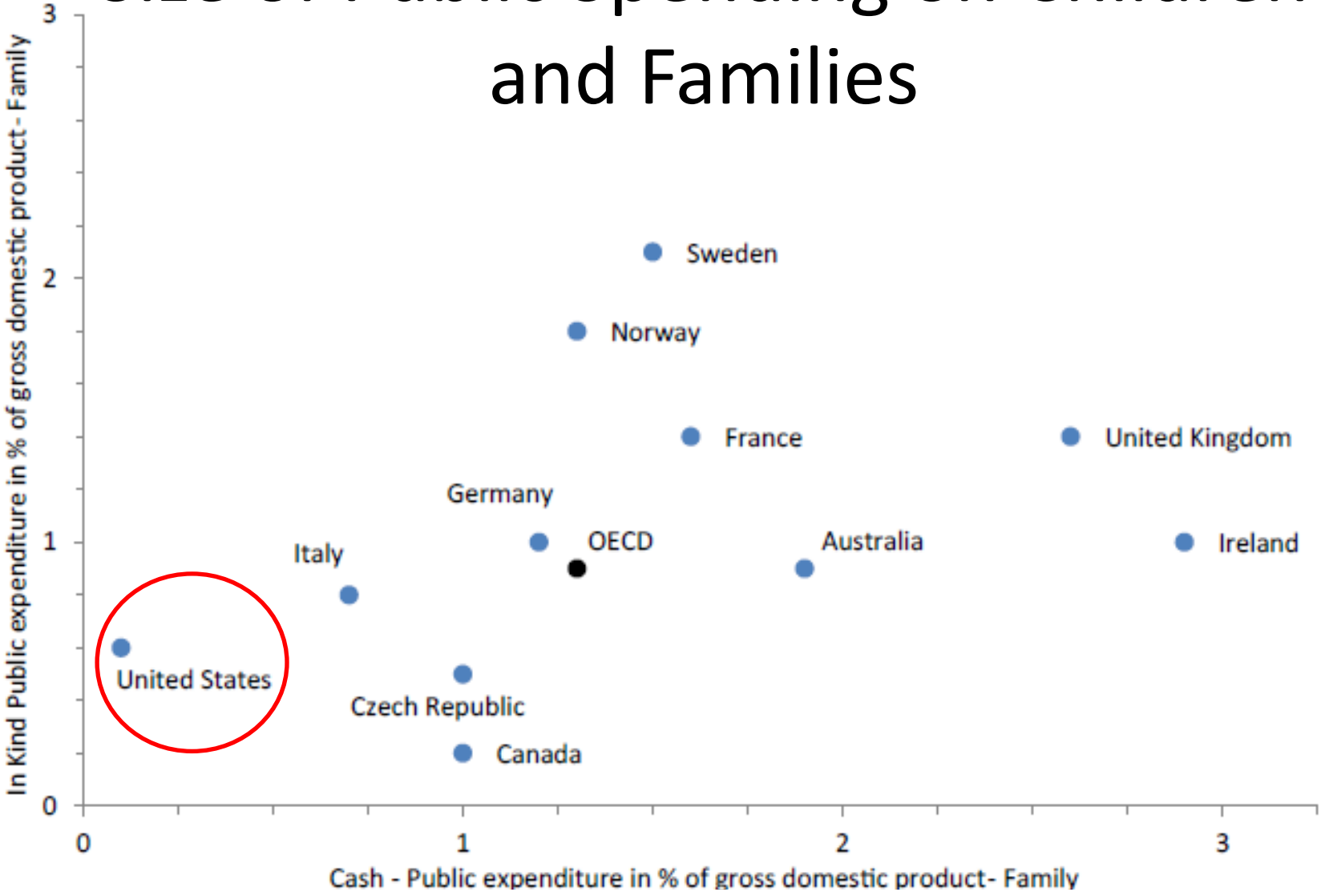
Intervention group showed preliminary benefits relative to control group

- Small sample size, but patterns suggest
  - Higher center-based child care expenditures
  - More frequent mother-child activities
  - Less household chaos
  - Less parenting stress

Can boosting family income change children's trajectories?



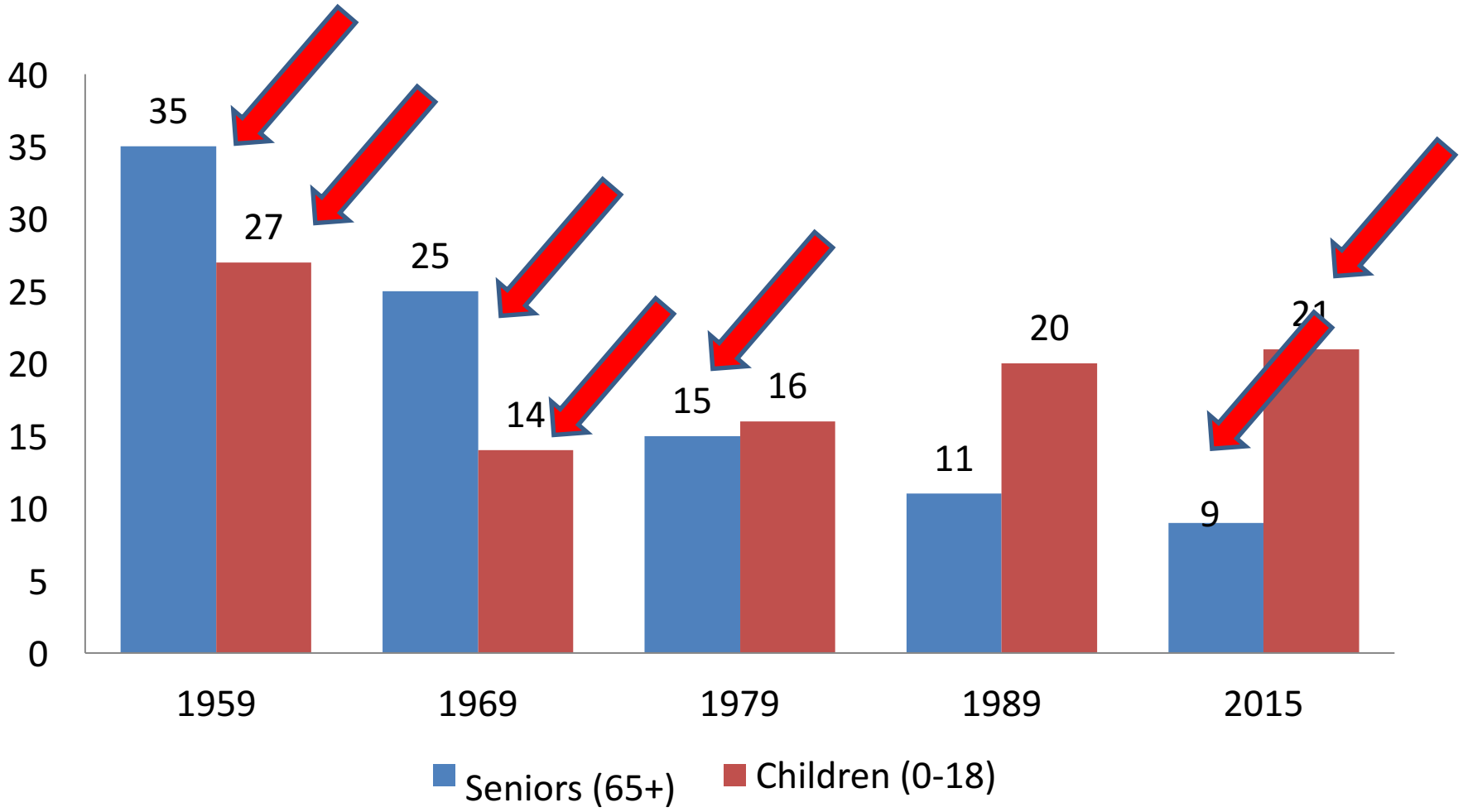
Size of Public Spending on Children and Families



Smeeding, Thevenot. Academic Pediatrics Supplement. 2016

Slide courtesy Benard Dreyer, MD

% Poverty Over Time: 1959-2014
Seniors Vs. children



Slide courtesy Benard Dreyer, MD

Sachs JD. The Price of Civilization. 2011, Random House, NY. Chapter 10, pp. 185-208

Policy implications

- Has the potential to provide direct evidence of the effects of poverty reduction on the developing brain and mind
- Informs debates on the generosity or cuts to existing or new social service programs that affect families with young children
  - SNAP
  - WIC
  - TANF
  - housing vouchers
  - paid family leave
  - minimum wage

Income may not the only or the most important factor in children's brain development, but it may be most manipulable from a policy perspective.

Acknowledgements

@kimberlygnoble

Neurocognition, Early Experience, and Development (NEED) Lab

www.columbia.edu/cu/needlab

Eunice Kennedy Shriver National Institute of Child Health and Human Development
R01HD087384-01

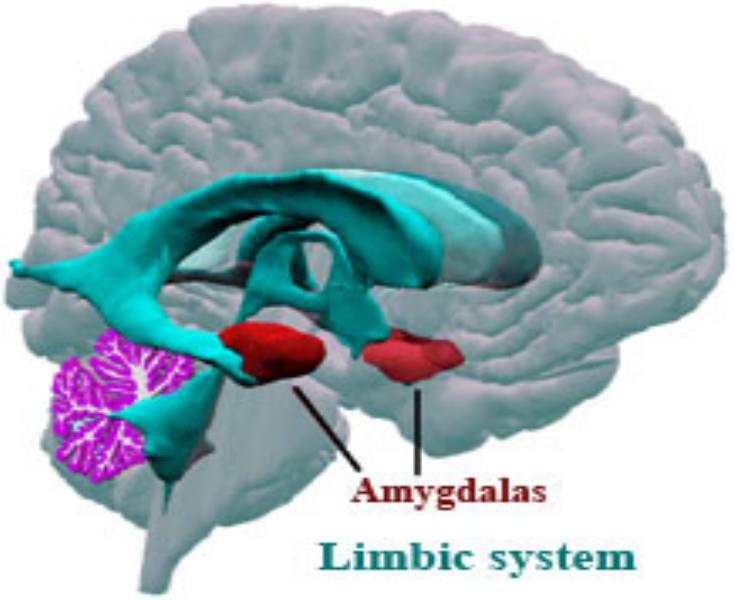
Lab Members
- Emily Merz, Ph.D.
- Sonya Troller-Renfree, Ph.D.
- Pooja Desai
- Lauren Meyer
- Cindy Wiltshire
- Rehan Rehman

Collaborators
- Greg Duncan, Ph.D., UC, Irvine
- Katherine Magnuson, Ph.D., UW-Madison
- Lisa Gennetian, Ph.D., NYU
- Hirokazu Yoshikawa, Ph.D., NYU
- William Fifer, Ph.D., Columbia
- Natalie Brito, Ph.D., NYU
- Luciane Piccolo, Ph.D., SUNY-Stonybrook
- Nathan Fox, Ph.D., UMD
- Alexandra Ursache, Ph.D., NYU
- Elizabeth Sowell, Ph.D., USC

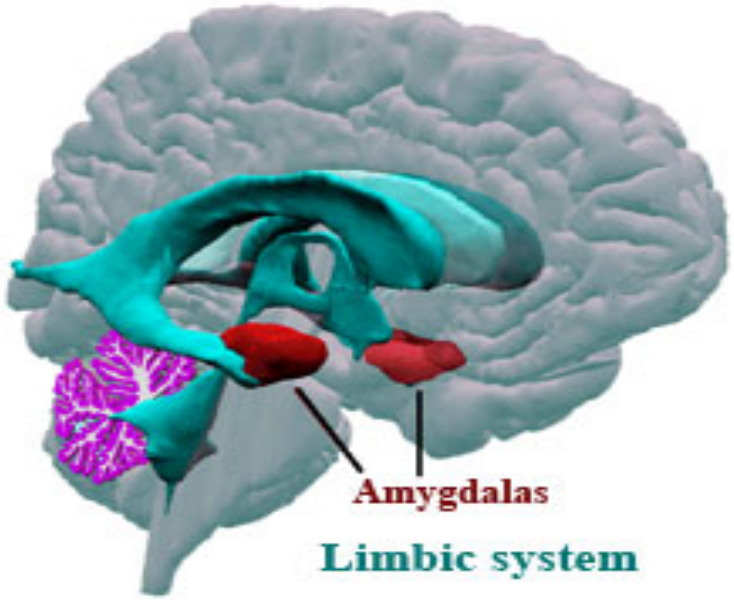
CHAN ZUCKERBERG INITIATIVE
THE ANNIE E. CASEY FOUNDATION
W.K. KELLOGG FOUNDATION
JACOBS FOUNDATION
BILL & MELINDA GATES foundation
Our Promise to Youth
CWF CHILDWELFAREFUND
Smith Richardson FOUNDATION
FORD FOUNDATION
THE Sherwood FOUNDATION
Weitz Family Foundation
Anonymous
Russell Sage Foundation
PRESIDENTIAL SCHOLARS IN SOCIETY AND NEUROSCIENCE

Amygdala

- Essential for experiencing emotions
- Also has a high number of glucocorticoid receptors



How does stress influence amygdala development?



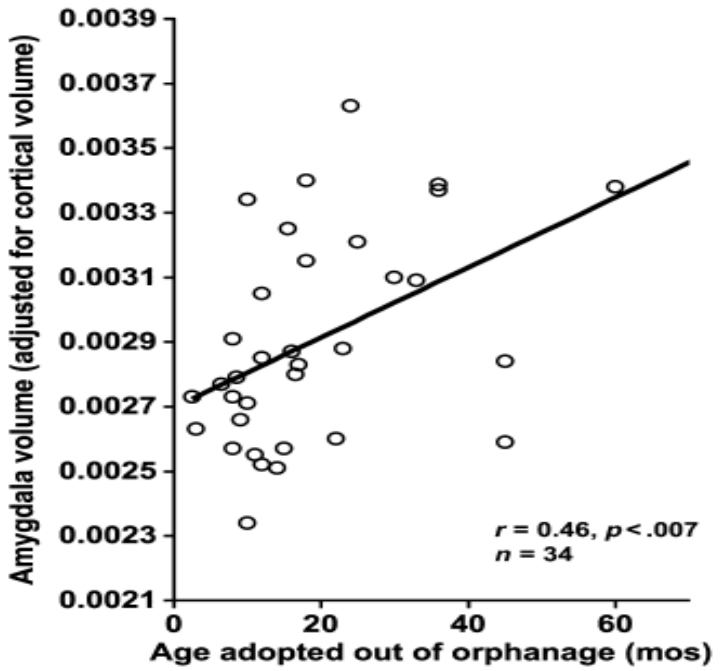
Stress and amygdala: Animal studies

- Chronic stress
  - leads to cellular changes in the amygdala
  - Augments amygdala-based startle response
- Poor caregiving accelerates amygdala development

Tottenham and Sheridan 2010

Stress and amygdala: Human studies

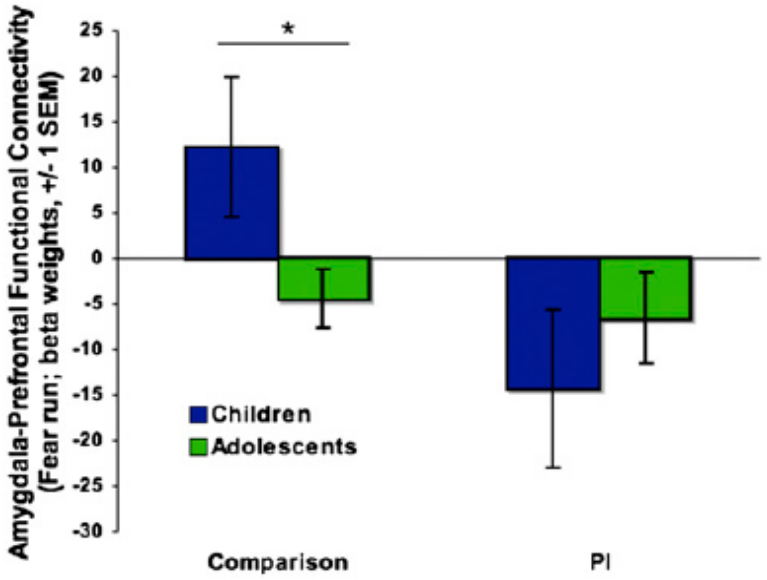
- Prolonged childhood stress associated with larger amygdala volume



Tottenham and Sheridan 2010
Tottenham et al 2009
Gee et al 2013

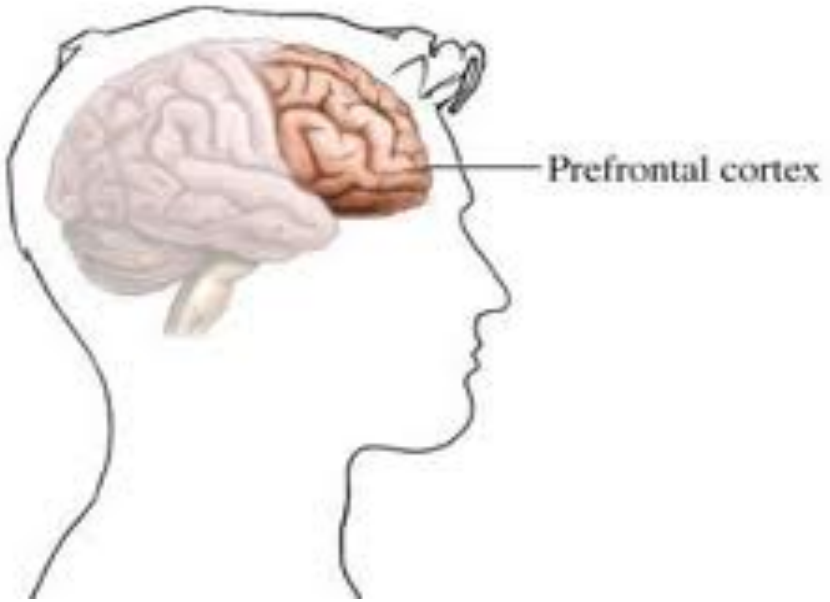
Stress and amygdala: Human studies

- Prolonged childhood stress associated with early maturation PFC-amygdala functional connectivity



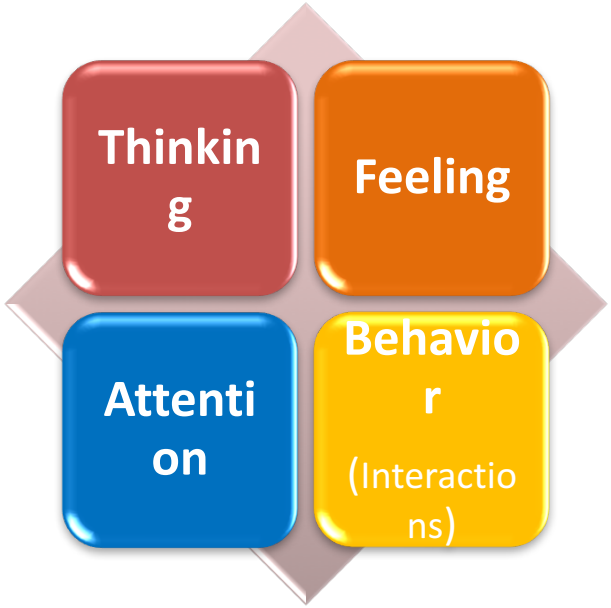
Tottenham and Sheridan 2010
Tottenham et al 2009
Gee et al 2013

Prefrontal cortex



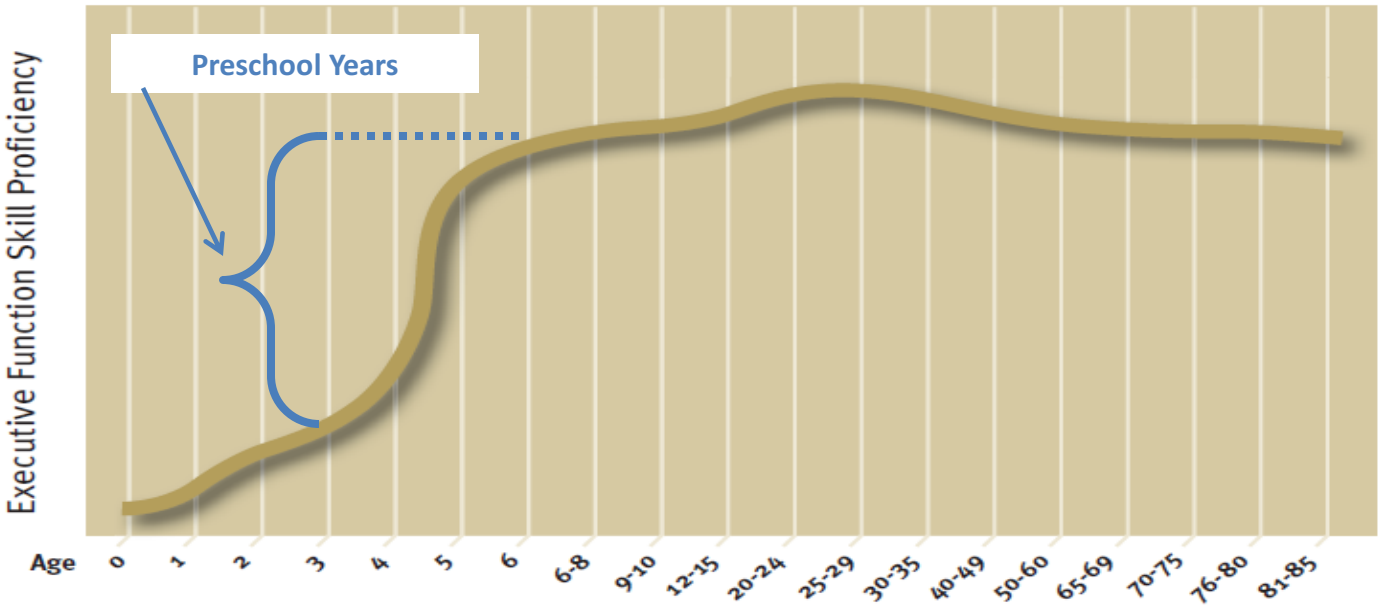
PFC is essential for self-regulation

The deliberate control of …



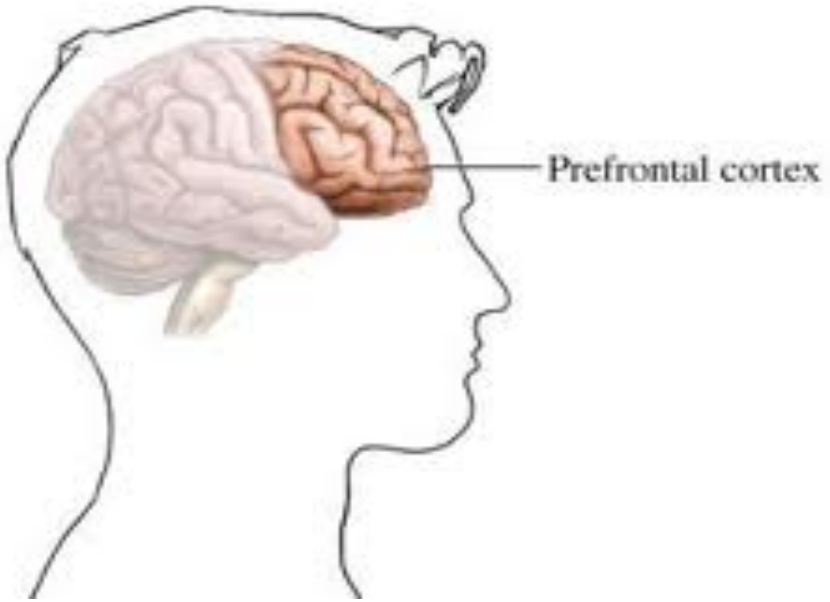
… in order to meet specific goals.

Improves dramatically in early childhood, but continues to show improvement through adolescence



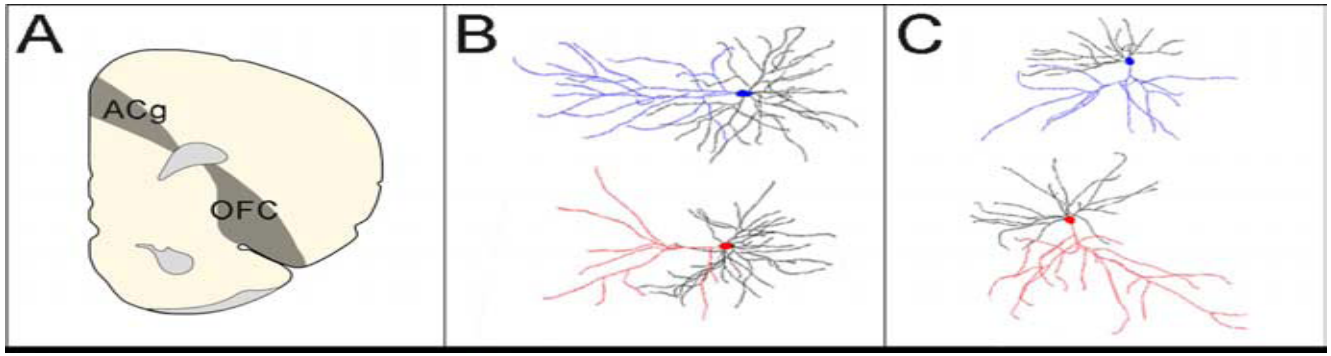
(Center on the Developing Child, 2011)

How does stress influence prefrontal cortex development?



Stress and PFC: Animal studies

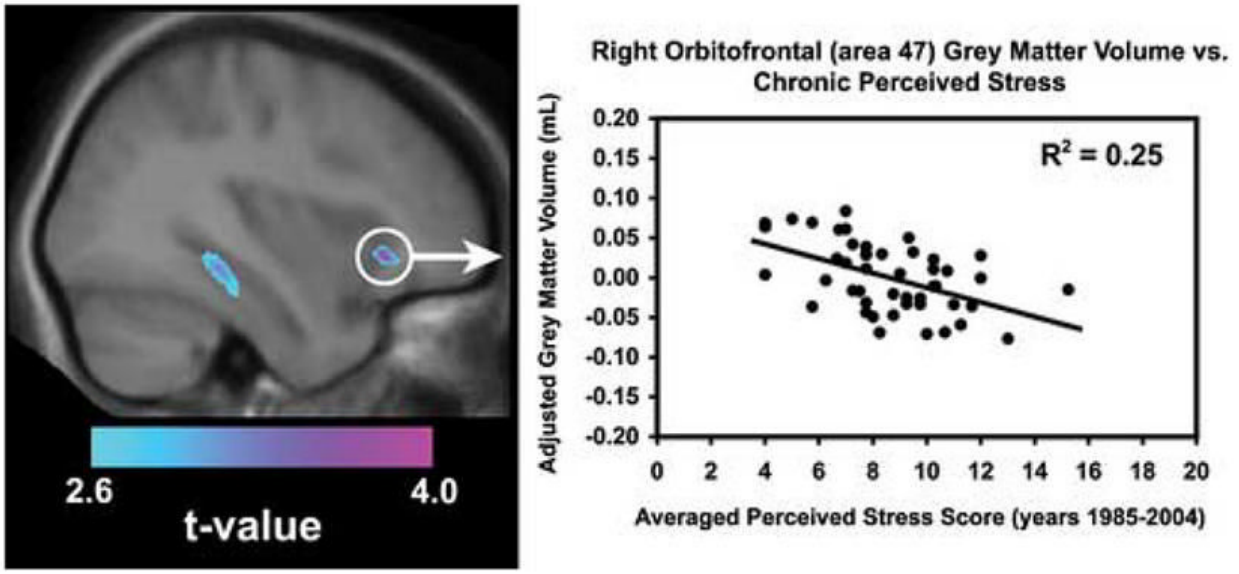
- Repeated exposure to stress
  - Synapse loss
  - Changes in dendritic branching



  - Morphological changes predictive of worse performance on animal analogues of human executive functioning tasks

Liston et al 2006

In humans, higher perceived stress associated with smaller right orbitofrontal cortex



Gianaros et al., 2007, NeuroImage

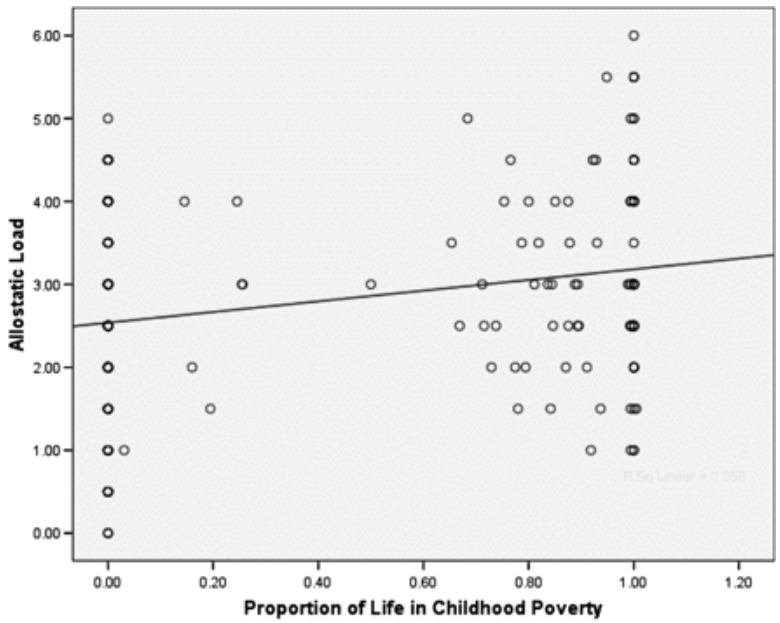
SES, chronic stress, and working memory

- 195 young adults
- Longitudinal study of rural poverty, cumulative risk, and child development
- Half grew up below the poverty line
- Duration of poverty birth through age 13
- Chronic stress on the body ("allostatic load") - BP, stress hormone levels, body mass index measured at 9 & 13
- Working memory assessed at age 17

Evans and Schamberg, 2009

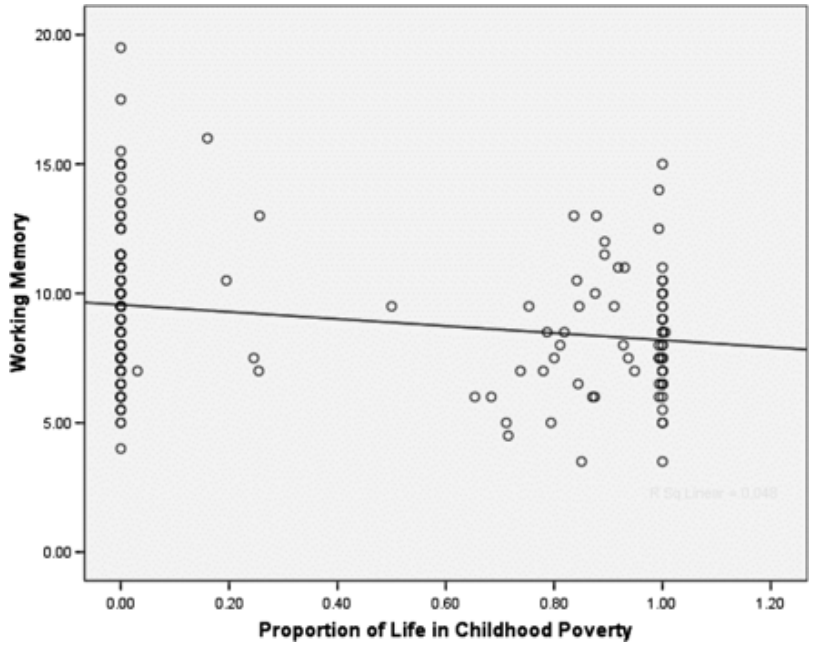
SES, Stress, and Working Memory

Allostatic Load



Proportion of childhood in poverty

Working Memory



Proportion of childhood in poverty

- Poverty→allostatic load→working memory

Evans and Schamberg, 2009