Early Brain Development and Its Implications for Learning and Early Childhood Education

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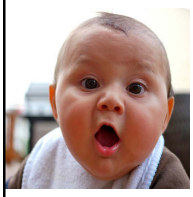
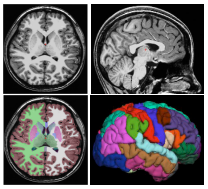


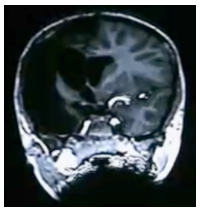


Early Brain Development and Plasticity

UNIVERSITY OF MINNESOTA
INSTITUTE OF CHILD DEVELOPMENT

The Story of Jody Miller

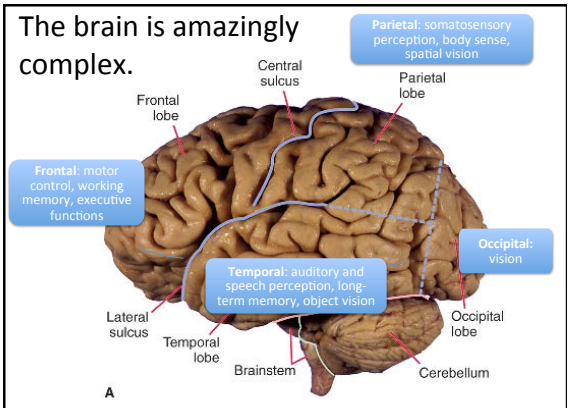
- **Rasmussen's Encephalitis**
  - symptoms: frequent and severe seizures, loss of motor skills and speech, *hemiparesis* (paralysis on one side of the body), and eventually, *dementia*
  - treatment: **hemispherectomy**



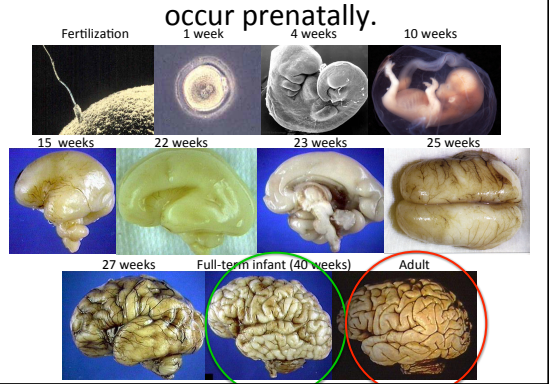
How can a child function without half of her brain? What are the limitations to the brain's ability to adapt?

Plasticity

The brain is amazingly complex.

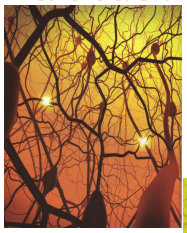


Major changes in brain development occur prenatally.

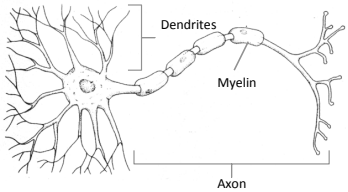


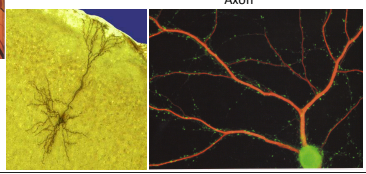
Basic building blocks of the brain

Neurons & Glia

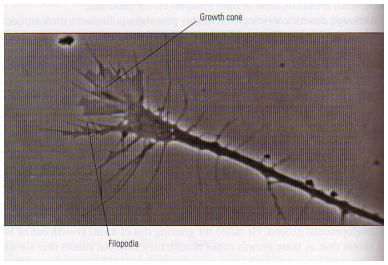


Restak, 2001. *The Secret Life of the Brain.*





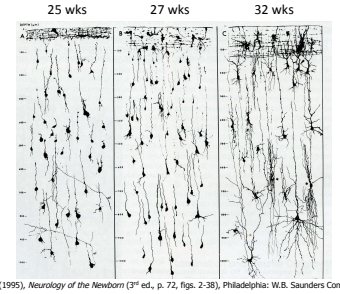
Axons carry electrical and chemical signals from the active neuron to other neurons in the network.



Bloom, F., Nelson, C., and Lazerson, A., 2001. *Brain, Mind, and Behavior* (3rd Ed).

Growing axons must sample their local environments to determine which direction to grow.

Dendrites "listen" to the activity of other neurons in the network.



Volpe (1995), *Neurology of the Newborn* (3rd ed., p. 72, figs. 2-38), Philadelphia: W.B. Saunders Company.

Dendrites develop prenatally during the third trimester of pregnancy.

Some glial cells can generate myelin, an insulating layer that speeds up the signal transmission along an axon.

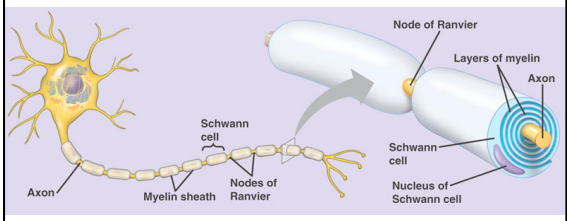


Image downloaded from http://kvhs.nbed.nb.ca

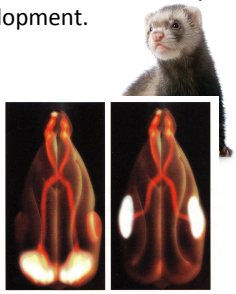
* Lack of myelin can result in poorer motor control and slower thinking.

Wiring the brain is a developmental process.

The brain is not pre-wired for function.
Input from the environment is essential for many aspects of typical brain development.

Development of the brain's visual system requires light input into the eye.

Light is translated into a neuronal signal by the retina, and this neuronal firing initiates the functional development of visual regions of the brain.

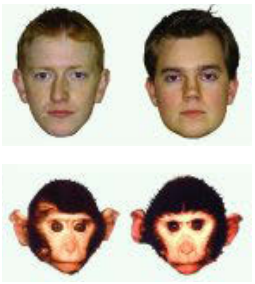


Auditory cortex can become visual cortex if it receives visual input.

Restak, R. (2001). *The Secret Life of the Brain.*

The infant brain performs some tasks better than the adult brain.

Johnson & Morton, 1991, *Psychological Review*

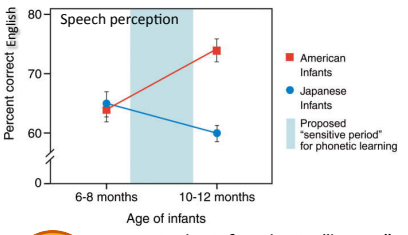


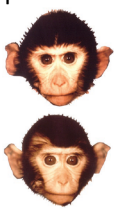
Pascalis, de Haan, & Nelson, 2002, *Science*.

Infants are world language learners.

Six-month-olds can discriminate speech sounds that their parents cannot.

With development, we sacrifice some of our flexibility for efficiency and expertise.





How is the infant brain "better" at these tasks?

Plasticity → The brain is flexible and learns from experience.

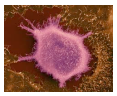
Pruning → Use it or lose it.

Plasticity can also leave us vulnerable to negative environments & experiences.


Environmental Toxins

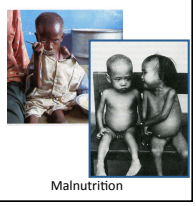

Prenatal Drug Exposure


Deprivation & Maltreatment


Maternal Infection

Premature Birth


Hypoxia (lack of oxygen)

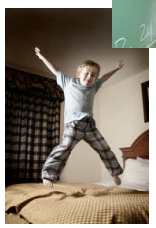

Malnutrition

The prefrontal cortex seems to be especially vulnerable to early adverse experience.

- Prematurity
- Malnutrition
- **Deprivation**
- Maltreatment

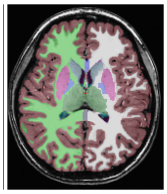
Example: Orphanage care

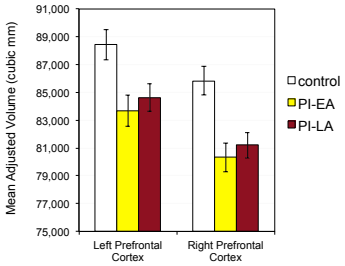
Deprivation is associated with:



- Speech and motor delays
- Learning difficulties
- Behavior problems
- Increased anxiety
- Social isolation
- Being bullied

Early orphanage rearing is associated with smaller prefrontal cortex in adolescence.



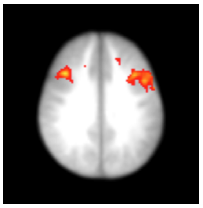


Hodel et al, 2015, *NeuroImage*

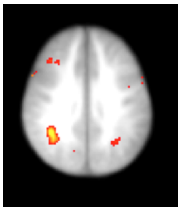
These effects did not vary as a function of the duration of deprivation.

Differences in brain activity do not always explain differences in behavior.

Both early and later adopted youth showed altered activity in the prefrontal cortex.



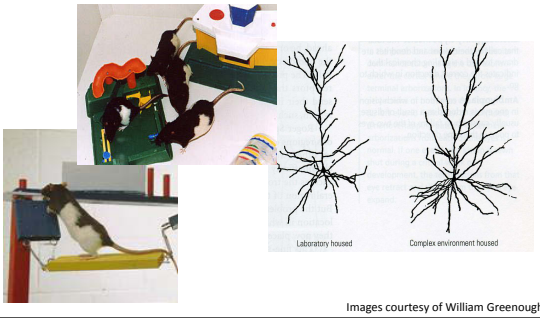
However, this activity did not explain performance on the task.



Activity in the parietal cortex varied by age at adoption, and was correlated with task performance.

Thomas et al, (2015), *abstract*

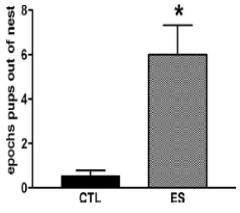
Positive environments can result in positive effects on brain development.



Images courtesy of William Greenough

Lack of sufficient resources can disrupt maternal care.

http://www.pos.org/wgens/nova/nature/genes-behavior.nfml



Lack of nesting materials (early stress, ES) leads to disrupted maternal care.

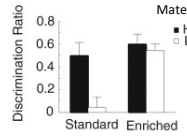
Baram et al (2008) *Neuroscience*

http://www.workingmomsbreak.com/2010/04/12/mothers-and-the-rat-race/

Environmental enrichment can prevent stress-related cognitive outcomes in adulthood.

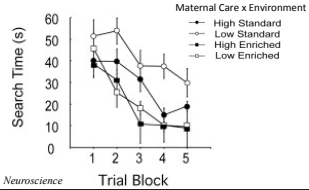
Object Discrimination

http://www.noldus.com/animal-behavior-research/research-learning-and-memory-rodents



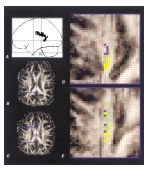
Morris Water Maze

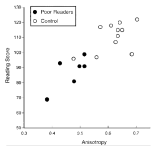
http://www.neuralwiki.org/index.php?title=NMDA_mediated_learning_and_memory



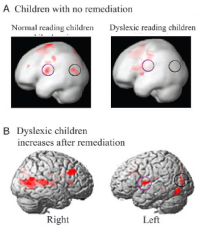
Bredy et al (2003) *Neuroscience*

Behavioral interventions can change the brain in children.





Klingberg et al (2000), *Neuron*



Temple et al (2003), PNAS

Behavioral interventions in children with dyslexia have resulted in more typical activation and stronger white matter connections in brain systems involved in reading and phonological awareness.

Some individuals show resilience, even in the face of adverse conditions.

Like dandelions, they can grow just about anywhere.

Concepts from Ellis & Boyce (2008), *Curr Dir Psych Sci*

Others individuals are highly sensitive to their environment.

Like orchids, when given the perfect environment, they will thrive and surpass dandelions. But, they wither and wilt without the necessary care and attention.

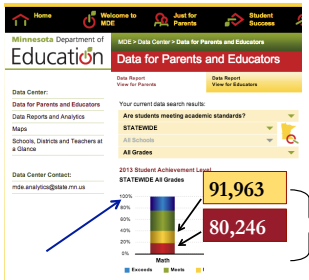
Concepts from Ellis & Boyce (2008), *Curr Dir Psych Sci*

Interim Summary

- Biology and environment cannot be viewed independently. Brain development is tuned by experience in the world.
- Plasticity mechanisms allow us to take advantage of learning opportunities, but also leave us vulnerable to adverse experiences.
- Some individuals are more sensitive to the environment than others.
- Interventions provide means by which we can harness or potentially even enhance plasticity.

Implications for Learning and Early Education: *Early Mathematical Thinking*

Many children in MN* are at risk for poor math outcomes



*similar to rates across other U.S. States

~40% of students only partially meet, or fail to meet, math achievement standards.

Since many aspects of math achievement are malleable, we can raise both "ends" of the "curve" and thereby promote better math outcomes for all students.

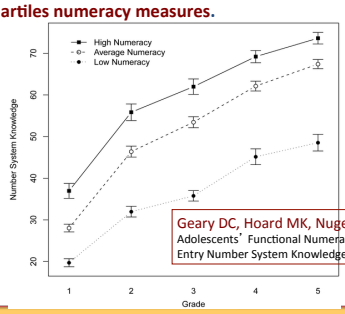
Why focus on mathematics?

Early math achievement is correlated with several indicators of quality of life later in development:

- *academic* success, *employment*, *occupational success*.
- *health* outcomes – e.g., health care risk assessment and decisions (e.g., Reyna & Bainard, 2007)
- financial and social *decision making* (McCloskey, 2007)
- *daily skills*: remembering numbers, judging time to arrival, planning schedules and travel routes, budgeting; solving problems
- *leisure activities* sports, cooking, card and board games, home improvement, wide range of hobbies/interests

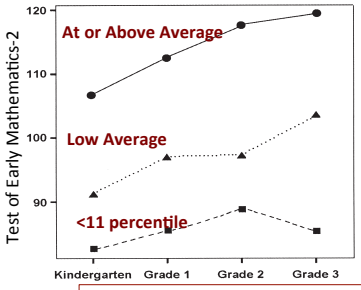
Does early math matter? YES

Number Systems Knowledge from Grades 1 to 5 for 7th Graders in the bottom (Low), the two middle (Average), and top (High) quartiles numeracy measures.



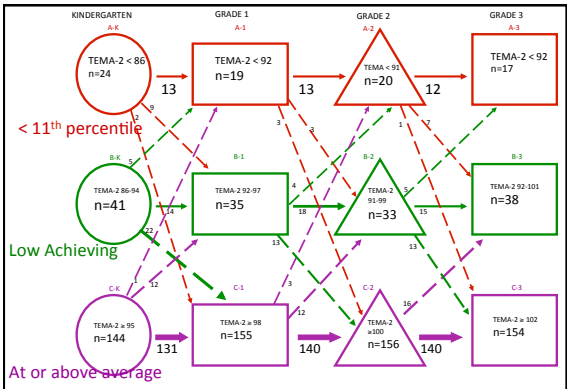
Geary DC, Hoard MK, Nugent L, Bailey DH (2013) Adolescents' Functional Numeracy Is Predicted by Their School Entry Number System Knowledge. PLoS ONE 8(1)

Trajectory of Mean Test of Early Math Ability Scores from Grades K to 3, same students over time, for students with scores in the bottom 10%, 11-25%, and >25%iles.



Kindergarten number skills predicted which children would remain in this lowest performing group four years later.

Murphy, Mazzocco, Hanich, & Early 2007, *Journal of Learning Disabilities*



Children's math performance levels change over time Mazzocco & Myers, 2001

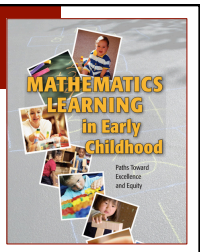
What influences an individual child's early math trajectory?

Math Content

Math skills/ approaches to learning

Informal math experiences

Focus on appropriate *content* in early childhood (NRC 2009)



- Number
  - whole numbers
  - operations
  - relations
- Geometry
  - shape awareness
  - spatial relations
  - measurement
- [Patterns]

(NRC 2009)

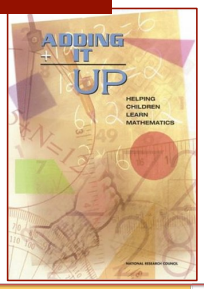
What is the focus of early math instruction in the U.S.?

What is the focus of early mathematics education?		
	U.S. (67 teachers)	China (74 teachers)
3 year olds	Counting	Sorting and sequences
4 year olds	Counting	Counting to 10
5 year olds	Counting	Addition; Counting to 20
4 to 5 year olds		Decomposition/composition
4 to 5 year olds		Neighbor numbers
4 to 5 year olds		Ordinal numbers

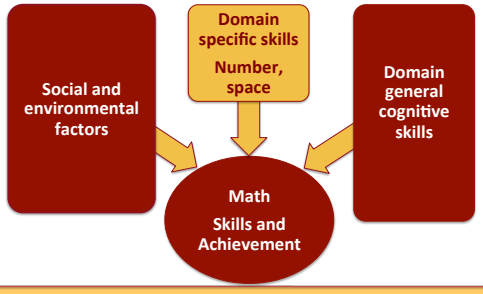
*Li, Chi, DeBey, & Baroody (in press)
A study of early childhood mathematics teaching in U.S. and China

Attend to the essential elements of math proficiency (NRC 2001)

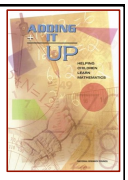
- *Conceptual understanding*
- *Procedural fluency*
- *Strategic competence*
- *Adaptive reasoning*
- *Productive disposition*



Promote early experiences in areas that make affect math skills and achievement



"Productive disposition"



Math is important, useful, and achievable with effort

Research demonstrates that math dispositions are:

- Emerge in early grades (Beilock et al., Mazzocco et al., 2012)
- influenced early in life
- *malleable…*
- and measurable

Whole-brain and Region of Interest regression results with math- or word-cues and tasks.

TASKS:

Problem verification:
True or false?
2(7 + 4) = 30

Word verification:
Is the reverse a word?
noollab

PRECEDED BY CUE

INSp: dorso-posterior insula

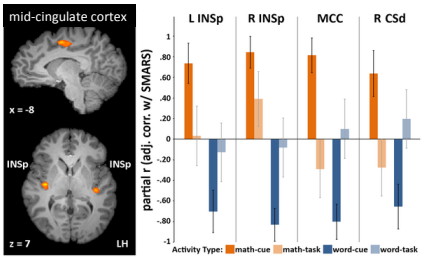
MCC: mid-cingulate cortex

CSd: dorsal central sulcus (not pictured)

ROIs implicated in pain perception

Lyons IM, Beilock SL (2012) When Math Hurts: Math Anxiety Predicts Pain Network Activation in Anticipation of Doing Math. PLoS ONE 7(10): e48076. doi:10.1371/journal.pone.0048076

Whole-brain and ROI regression results with math- or word-cues and tasks

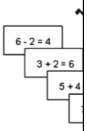


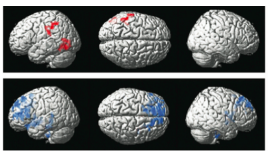
Higher math anxiety is linked to greater activity in regions associated with visceral threat detection, and often the experience of pain itself (bilateral dorso-posterior insula; mid-cingulate cortex) **seen when anticipating, but not engaged in, a math task.**

Lyons IM, Beilock SL (2012) When Math Hurts: Math Anxiety Predicts Pain Network Activation in Anticipation of Doing Math. PLoS ONE 7(10): e48076. doi:10.1371/journal.pone.0048076

Cerebral Cortex November 2005;15:1779–1790
doi:10.1093/cercor/bhi055
Advance Access publication February 16, 2005

Developmental Changes in Mental Arithmetic: Evidence for Increased Functional Specialization in the Left Inferior Parietal Cortex
Rivera et al., 2005

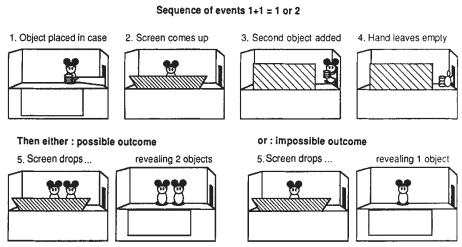




Areas of increased Brain activity with age

Areas of decreased Brain activity with age

Wynn, K. (1992). Addition and subtraction by human infants. *Nature, 358*, 749-750.



On the one hand, number skills are intuitive at an early age, for small numbers...

McCrink, K., & Wynn, K. (2004) *Psychological Science*

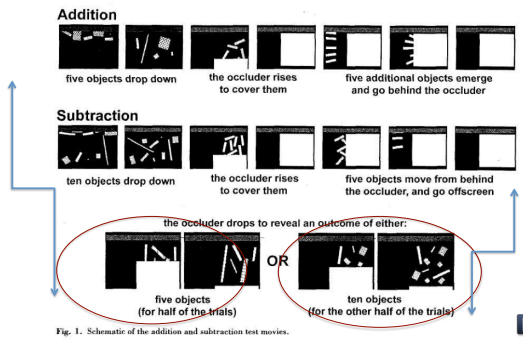


Fig. 1. Schematic of the addition and subtraction test movies.

... and for larger numbers, but...

Halberda et al., PNAS (2012)

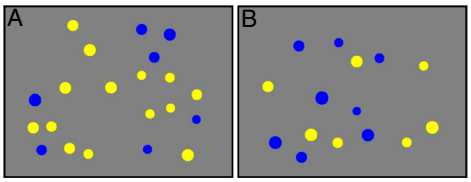
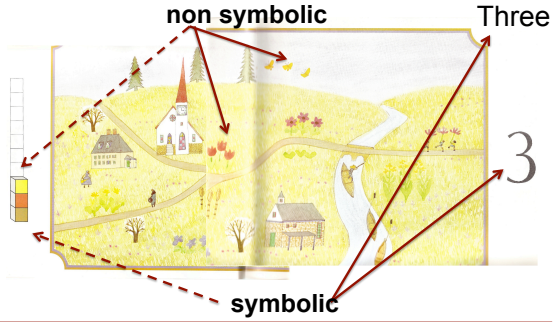


Fig. 1. Method. (*A*) A trial from the ANS dots test in which it is easier to tell that there are more yellow than blue dots with a brief glance. (*B*) A trial from the ANS dots test in which it is more challenging to tell that there are

14:7 **2:1** 8:7 **1.14:1**

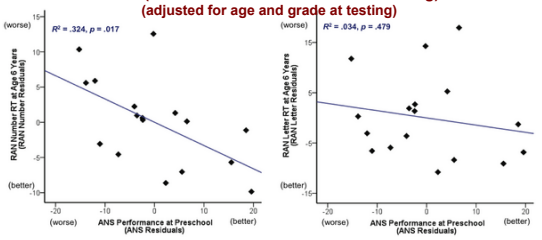
Even 'basic' intuitive number skills continue to develop through the lifespan.



Formal representations of quantities are learned, gradually, over a protracted period

From Anno's counting book

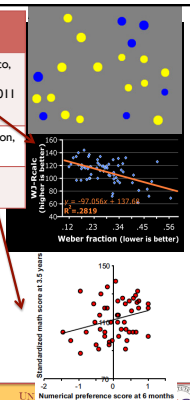
Associations between Approximate Number System accuracy (intuitive performance) and RAN Number or Letter subtest reaction times (formal number skill of number naming) (adjusted for age and grade at testing)



Source: Mazzocco MMM, Feigenson L, Halberda J (2011) Preschoolers' Precision of the Approximate Number System Predicts Later School Mathematics Performance. PLoS ONE 6(9): e23749. doi:10.1371/journal.pone.0023749
http://127.0.0.1:8081/plosone/article?id=info:doi/10.1371/journal.pone.0023749

Intuitive number skills predict formal math skills, but other factors also contribute.

Age measured (n)	Correlated w/ math at age:	R^2 value(s)	Citation
14 years (64)	5 – 11 years; TEMA-2; WJR Calc 15 (PSAT)	.13 to .33 (mean = .23)	Halberda, Mazzocco, Feigenson, **2008**; Mazzocco et al., 2011
3 years (17)	5 – 6 years (TEMA-3)	.278	Mazzocco, Feigenson, Halberda, 2011a
6 months	3.5 years (TEMA-3)	.28	Starr, Libertus, & Brannon, 2013



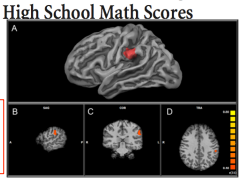
Intuitive number skills predict formal math skills, but other factors also contribute.

Why Mental Arithmetic Counts: Brain Activation during Single Digit Arithmetic Predicts High School Math Scores

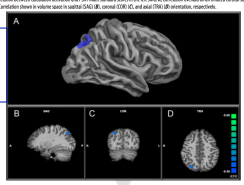
Price, Mazzocco, & Ansari, 2013

7 + 2 = 9 4 + 2 = 6

Negative correlation between activation in right intraparietal sulcus (associated with number processing*) and PSAT Math (corrected for PSAT reading)



Positive correlation between activation in left supramarginal gyrus activation (associated with fact retrieval) and PSAT Math (corrected for PSAT reading)

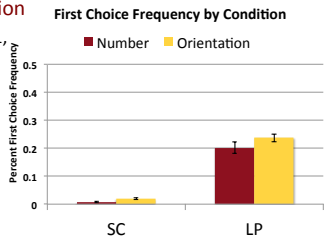


Differences in number processing persist throughout the lifespan.

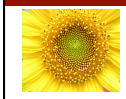
Chan & Mazzocco, in preparation

Context affects frequency of preschool children's awareness of number, such that this awareness can be manipulated.

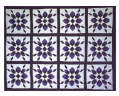
- Main effect of condition
  - F(1,30)=48.32, p<.001,
  - η^2=.617
- SC (shape, color)
- LP (location, pattern)



Take home messages



There is more to number (and to early math) than counting!



Productive disposition
- important for math proficiency
- emerges early
- influenced by adults

Domain general skills
support mathematical thinking and learning

Early exposure to numbers, shape, and early mathematics talk – it makes a difference!

Early risk is not a predetermined outcome!

Early Brain Development and Its Implications for Learning and Early Childhood Education

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Brainerd, MN