Linking Changes and Differences in Children's Early Number and Math Skills to Brain Systems

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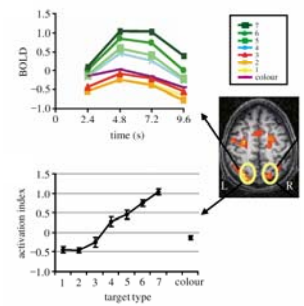
Adults

Insights into Exact Enumeration

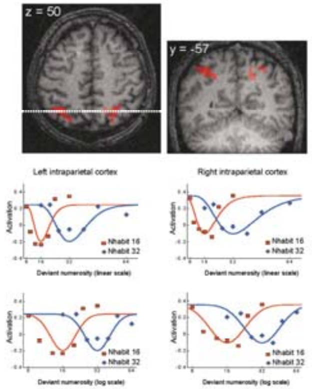
Brain mechanisms involved non-symbolic numerosity processing:
- Subitizing: rapid, highly accurate estimation of small quantities (1-4)
- Counting: serial process of one-by-one enumeration.

fMRI studies suggest that functions depend on the intraparietal sulcus (IPS) in adults
- Counting activates the IPS differently than subitizing
- Single-trial evidence for different processes.



Piazza et al., 2003

Insights into Estimation

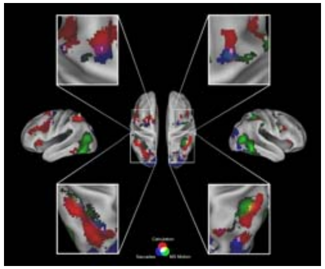


- fMRI-adaptation shows that the IPS adapts to repeated presentation of arrays with the same numerosity. (controlling for area, dot density, novelty etc.)
- Adaptation curves give a metric of neural sensitivity to quantity.
- Curves suggest a compressed representation of approximate numerosity: i.e. symmetry on a logarithmic axis,

Piazza et al., 2004

Insights into the Embodiment of Number Symbols: number line and spatial cognition

- Behavioral studies suggest numbers represented on a spatial "mental number line" (MNL).
- fMRI of basic addition and subtraction (red), eye-movements (blue) and multi-sensory motion (green).
- Calculation mostly separate from eye-movements and MS motion.
- Calculation shown to overlap with frontal and parietal regions involved in eye-movements
- Less overlap between calculation and MS motion.
- fMRI data are consistent with role of spatial processes in MNL.



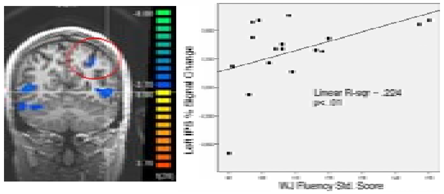
Hubbard et al., under revision

Children

fMRI of Individual Differences in Mathematics

- Cross modal matching tasks focus attention on either the name of a number or its magnitude
- Task modulation of bilateral IPS regions predicts fluency with this an other number tasks in adults.
- We developed an age appropriate version for children as young as 6 years-of-age.
- Successful completion rate was approximately 85% (17 subjects total).
- Demonstrated significant brain-behavior correlations between IPS activation level and standardized math scores.

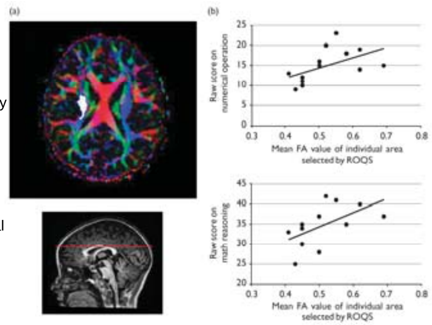
- No significant relationship to standardized reading scores.
- Indicates that math skills vary with individual differences in ability activate IPS in response to number semantics vs. number phonology.



Hannula et al., submitted

DTI of Individual Differences in Mathematics

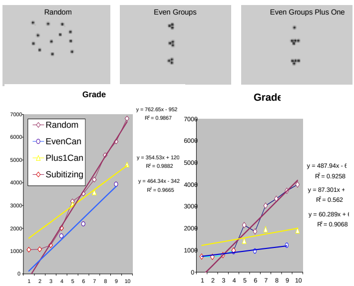
- White matter tract properties predict typically developing 7-9 year old children's skill in:
  - Numerical Operations
  - Mathematical Reasoning
- Increased fractional anisotropy (FA) in left temporo-parietal regions correlates with better performance on both tests.
- Is this reflecting differences in maturation of the implicated brain regions, stable individual differences, or the impact of instruction and learning on brain and behavior ?



van Eimeren et al., 2008

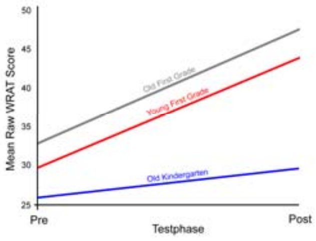
Relating Individual Differences in Cognitive Processes of Enumeration to Early Math Achievemnt

- Studied the role of set size and array structure for simple enumeration abilities in 1st-5th graders using:
  - Random arrays
  - Structured arrays
- Set size effects for random arrays (counting) correlate with math fluency for 1 -2nd graders math fluency (r=-.33 p<.05)
- Set size effects for grouped arrays (set semantics) correlate with 3-5th graders math fluency (r=-.51 p<.002)



Schooling

Separating Maturation and Education



Morrison et al., 1997

The School Cutoff Design

- 6 year old children are selected with birthdays within 2 months above or below the September 30th cutoff date, which segregates them into 2 groups:
  - Young First-Grade Group (YFG)
  - Older Kindergarten Group (OKG)
- Group membership is linked to changes in cognitive skills related math and reading

The Current Study

- Short term longitudinal design (Before and After School Year):
  - fMRI, DTI, ERP, Cognitive assessments in Number and Math Skills
- 6 year old children will be selected with birthdates within 2 months above or below the September 30th cutoff date, which segregates them into 2 groups:
  - Young First Grade (YFG)
  - Older Kindergarten Group (OKG)
- **Group** x **Time** interactions reflect schooling specific effects

Table 1. Benchmarks and timeline for study activities.

Grant Year	Quarter	Cohort 1	Cohort 2
Year 1	Spring	Recruitment/Screening	
	Summer	Pretest fMRI/DTI	
	Fall	Pretest Beavioral/ERP	
	Winter	Pretest Analysis	
Year 2	Spring	Posttest Behavioral/ERP	Recruitment/Screening
	Summer	Posttest fMRI/DTI	Pretest fMRI/DTI
	Fall	Posttest Analysis	Pretest Beavioral/ERP
	Winter		Pretest Analysis
Year 3	Spring		Posttest Behavioral/ERP
	Summer		Posttest fMRI/DTI
	Fall		Posttest Analysis
	Winter		Writeup-dissemination

Central Questions

Do the increased cognitive challenges of early formal arithmetic lead to changes in brain mechanisms associated with number and math?

Do individual differences in brain mechanisms of number skills at school entry predict growth in math skills over the school year?

Are elementary numerical cognitive operations and their underlying brain mechanisms in some sense foundational for further higher level mathematics training?

Is there a reciprocal relationship between advances in formal arithmetic skills and advances in elementary numerical cognition?

What aspects of early formal instruction might be most important in driving such changes?