

How children develop a sense of quantity?

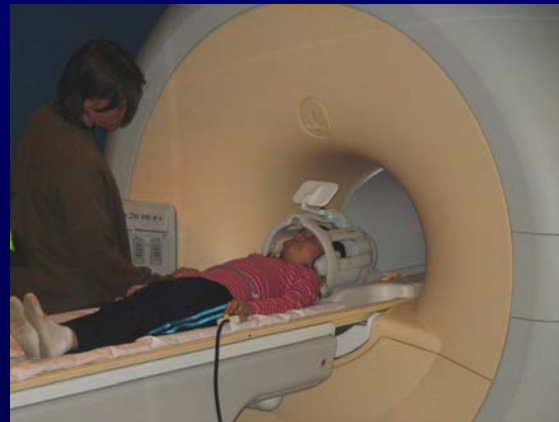
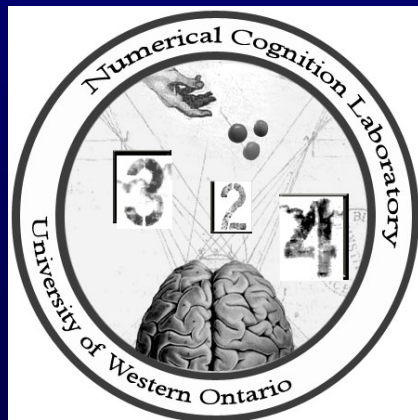
Evidence from brain and behavior

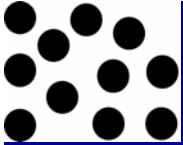
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Central points

- The brain is shaped by evolution to process number
- The ability to process numerical quantity develops before school
- Development of number is about understanding quantity
- Understanding of symbol – quantity mapping is crucial

Evidence from Animals

Evidence from Animals

- Matsuzawa et al. - Chimpanzee Ai
- Learning a task vs. learning a concept

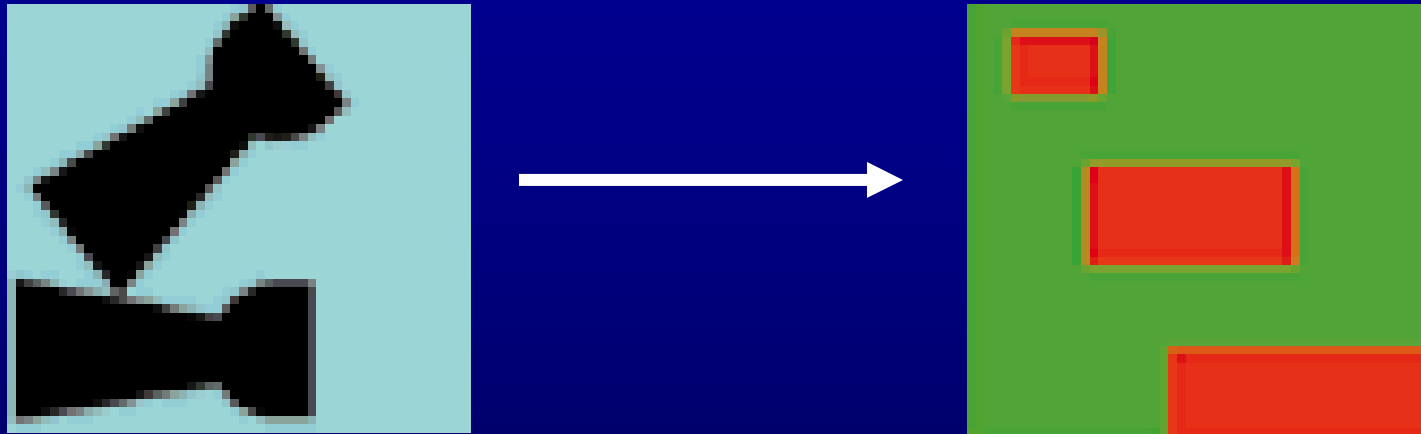


Evidence from Animals

- Brannon & Terrace (1999)
- Monkeys trained to order numerosities



Evidence from Animals



Monkeys learnt to order pairs of numerosities 1-4

Evidence from Animals

- Surprisingly:
 - **Generalize** to 5-9 without further training
 - Suggests true sense of ordinality
 - *What underlies this ability?*

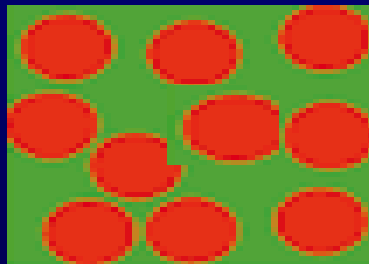
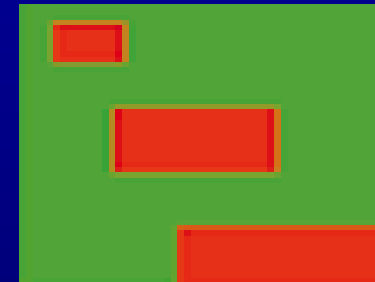


Evidence from Animals

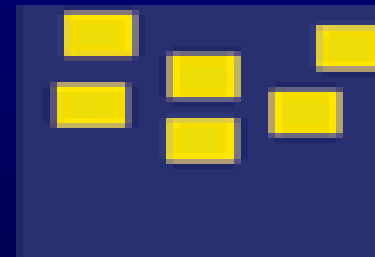
What stimulus parameter predicts performance ?



Distance = 1

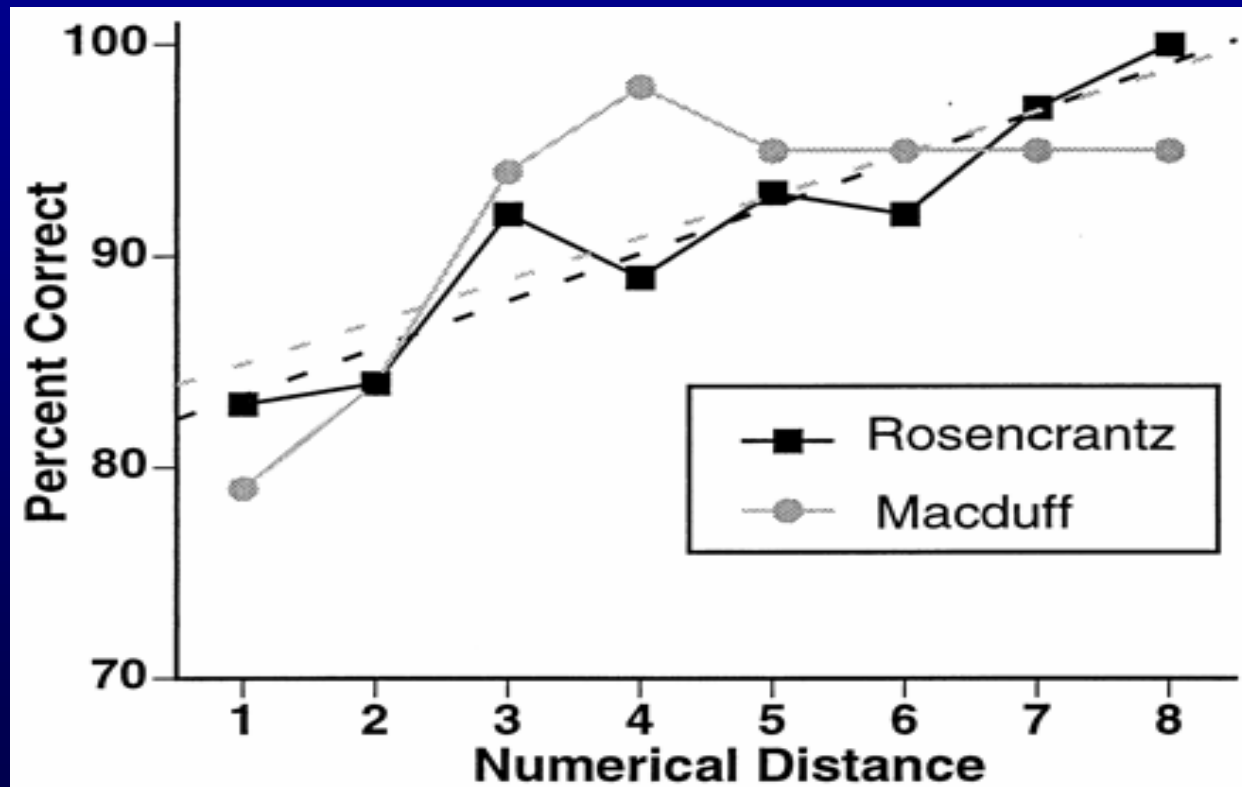


Distance = 4



Evidence from Animals

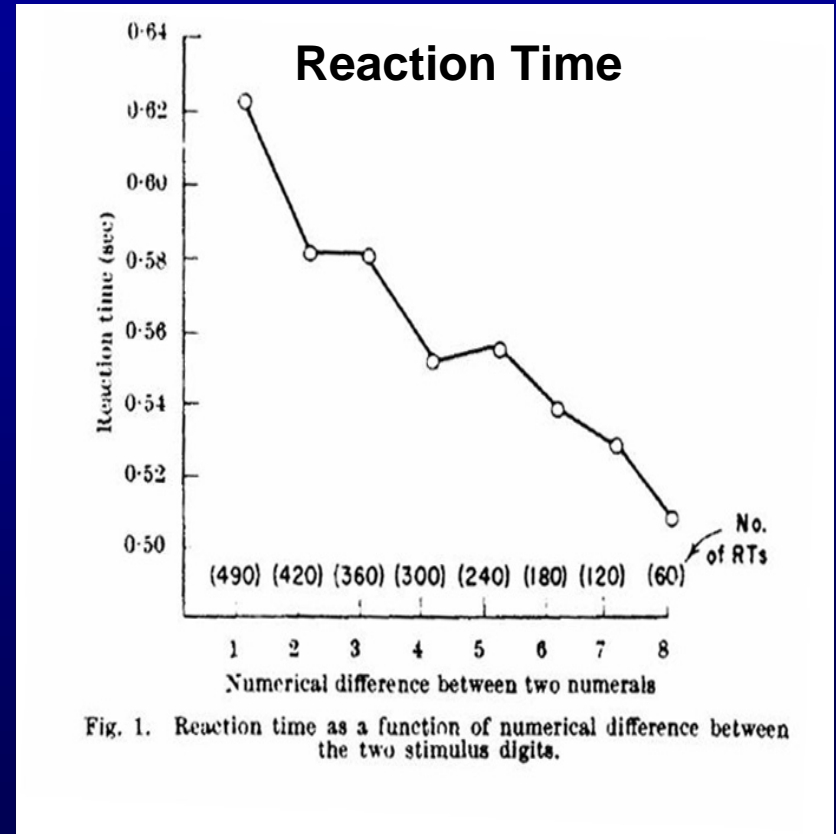
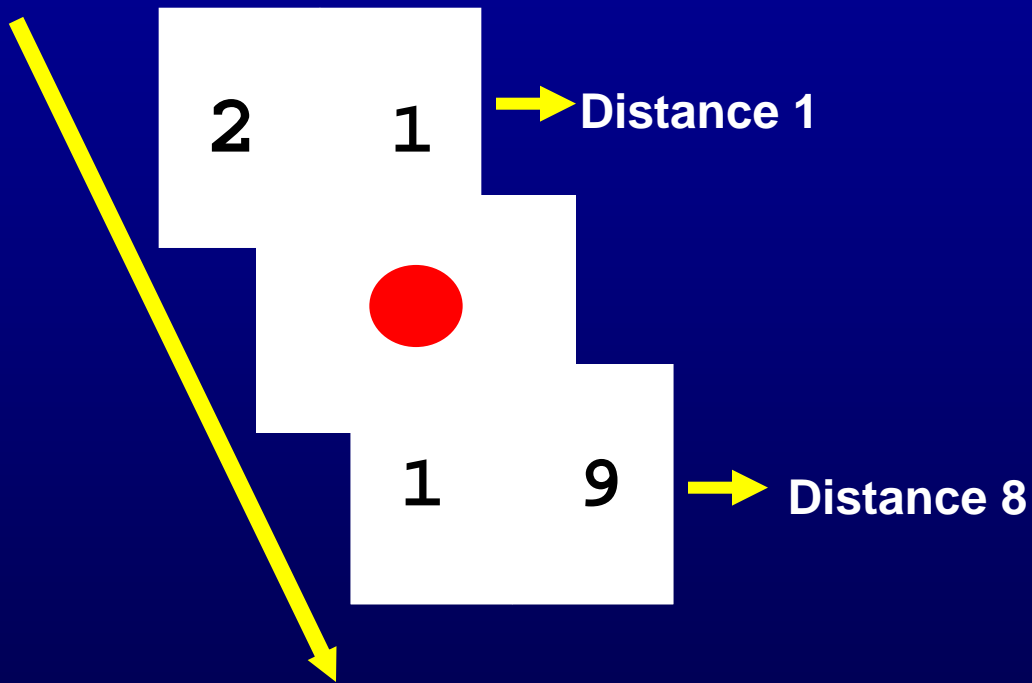
- Distance effect



Brannon, E. M., & Terrace, H. S. (1998)

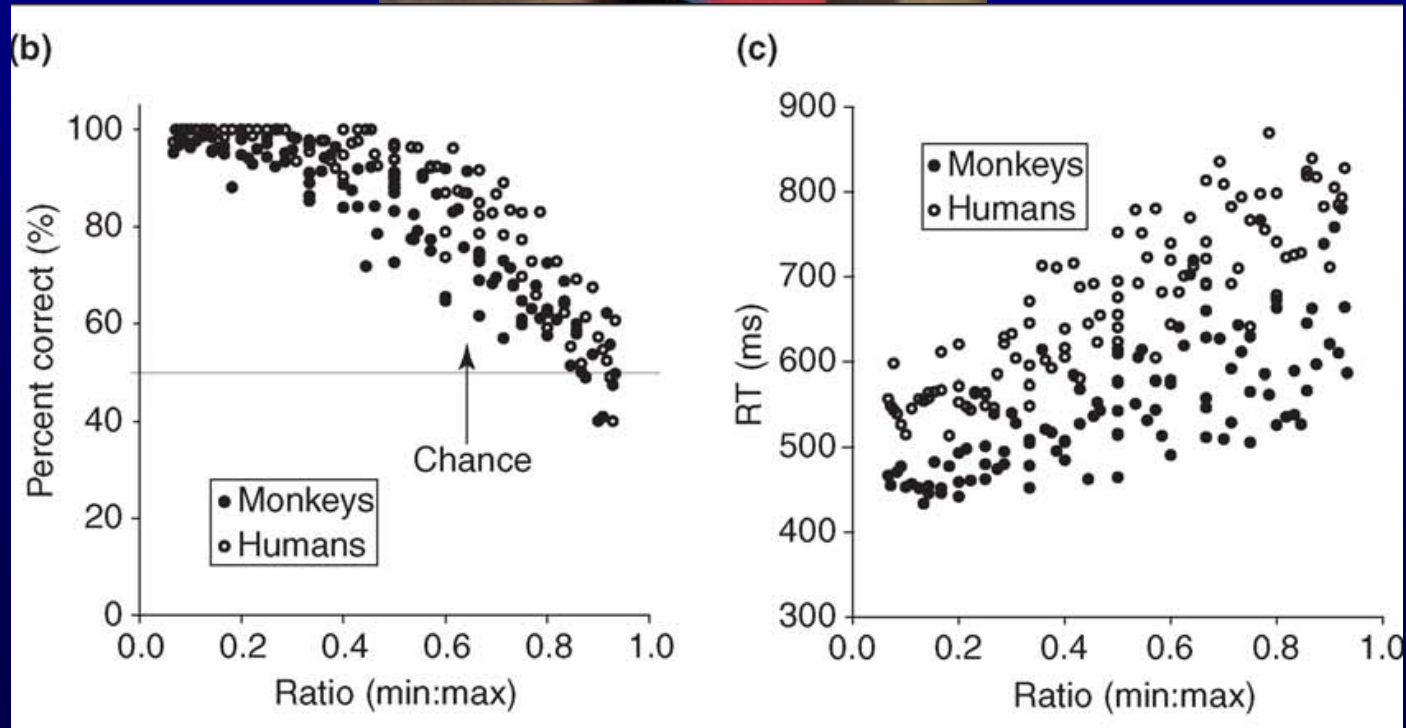
Distance Effect

Adults



From: Moyer & Landauer(1967)
replicated for over 40 years

Evidence from Animals



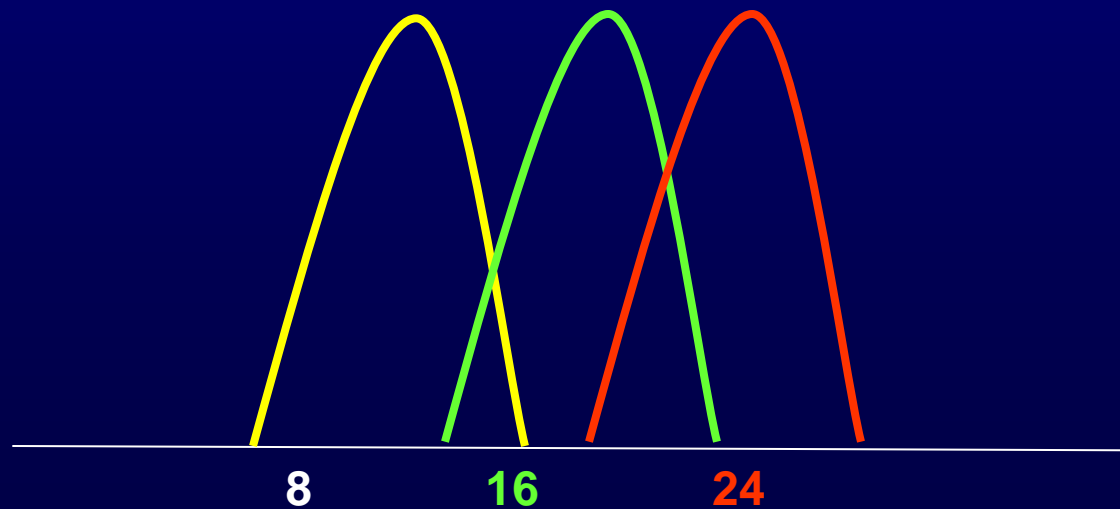
From: Cantlon & Brannon (2006)

Evidence from Animals

- Animals can discriminate numbers
- Similar evidence from other species
 - Even Salamander's!
- Clear psychophysical characteristics:
 - *Accuracy predicted by the numerical distance or by the ratio between magnitudes*

Distance or Ratio Effect

- Reveal features of underlying *quantity* system
- Noisy mental “Number Line”



Evidence from Infants

Evidence from human infants

- Can infants represent number?

But how to test?

I can't talk

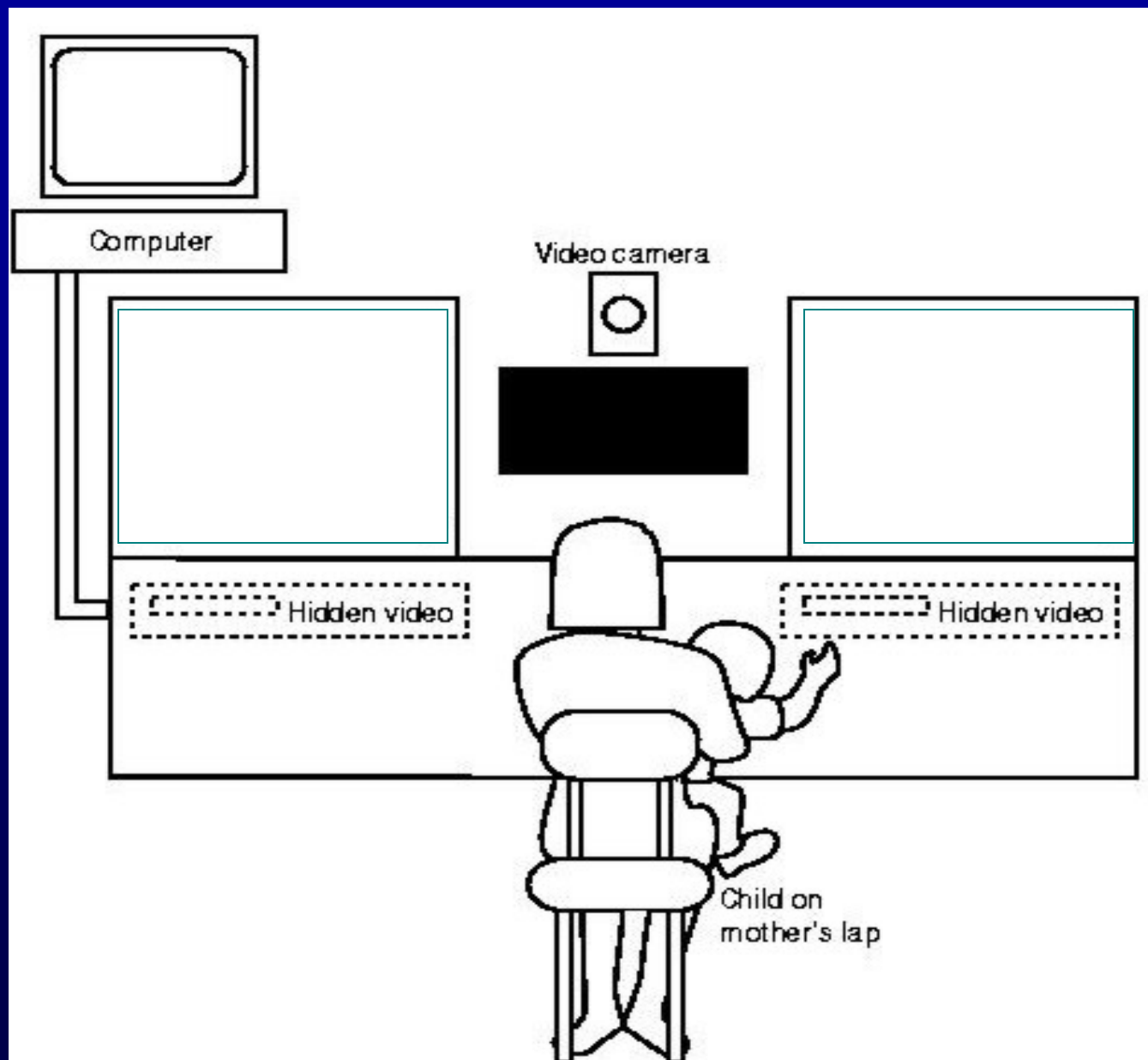
I can't move very well

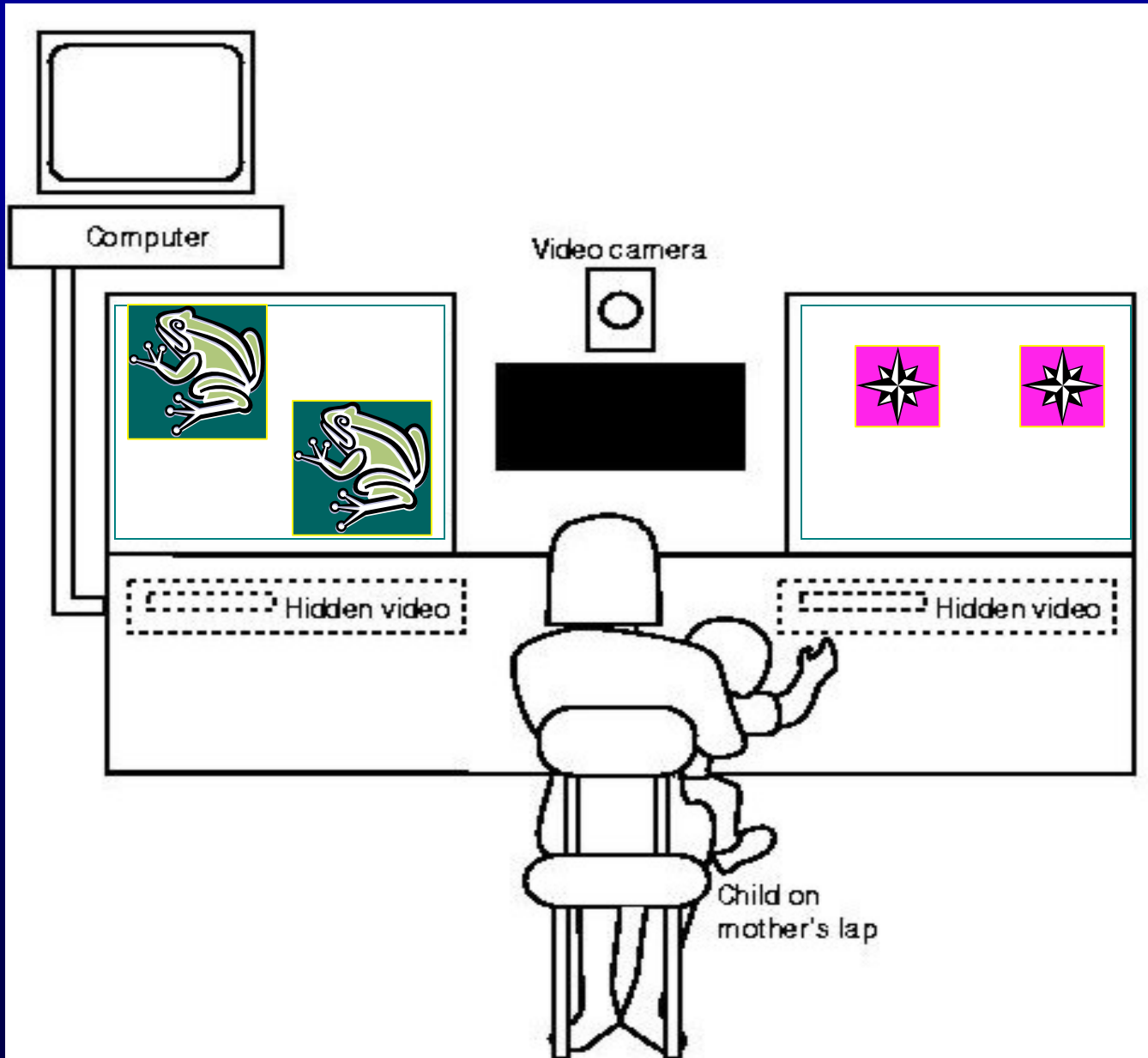
I can't draw

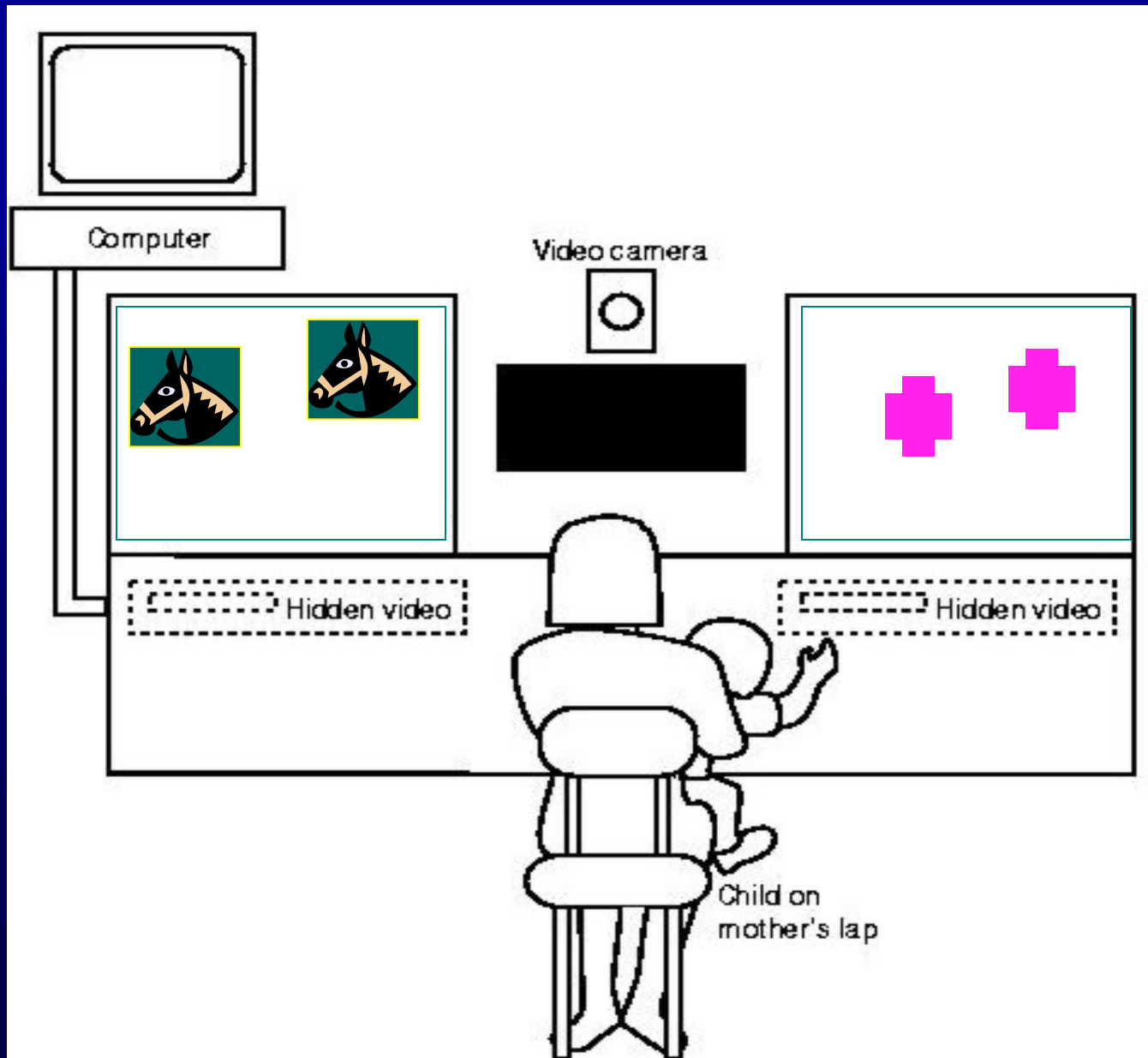
I can't count

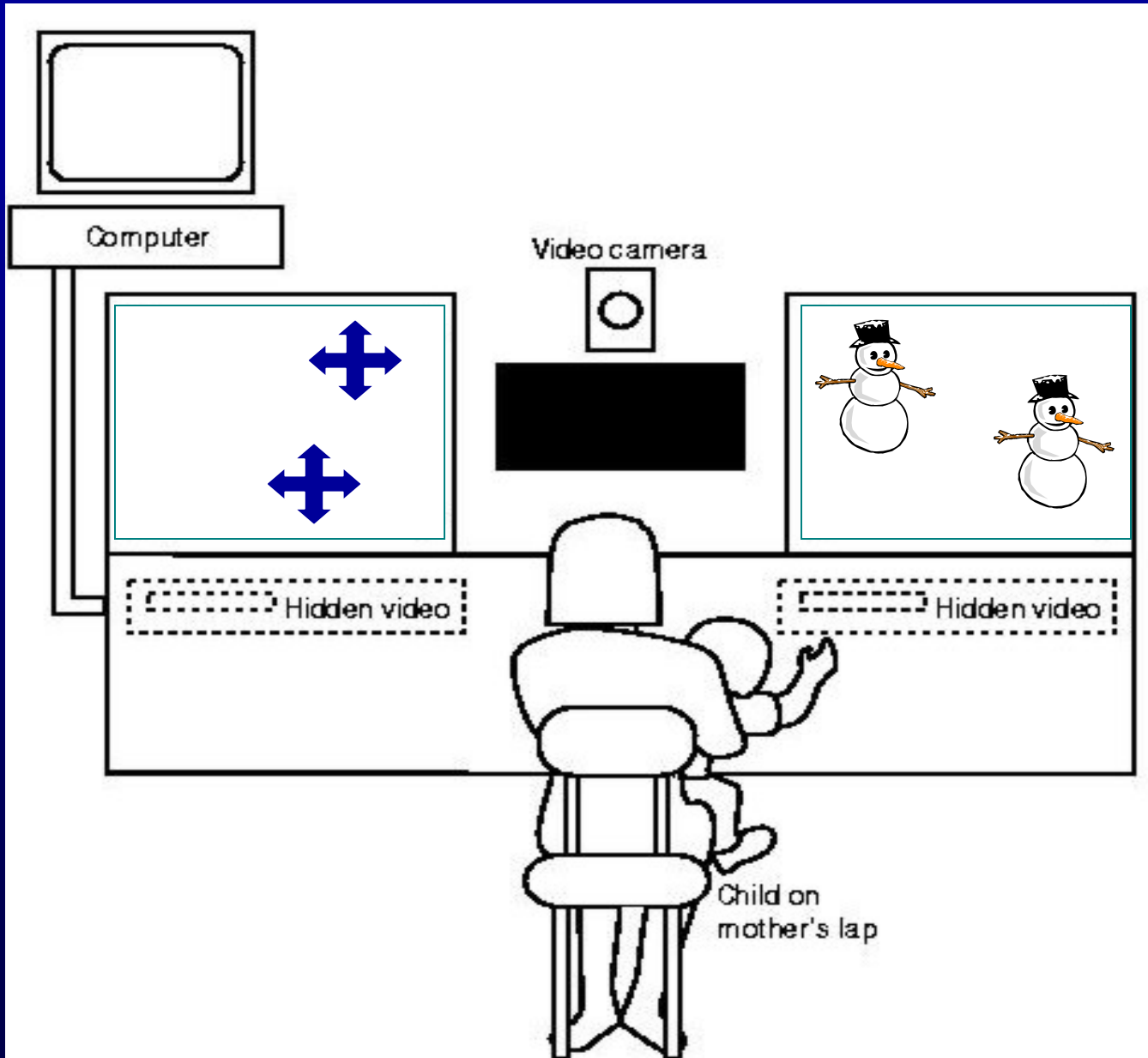
**All I can do is suck, look
and turn my head**

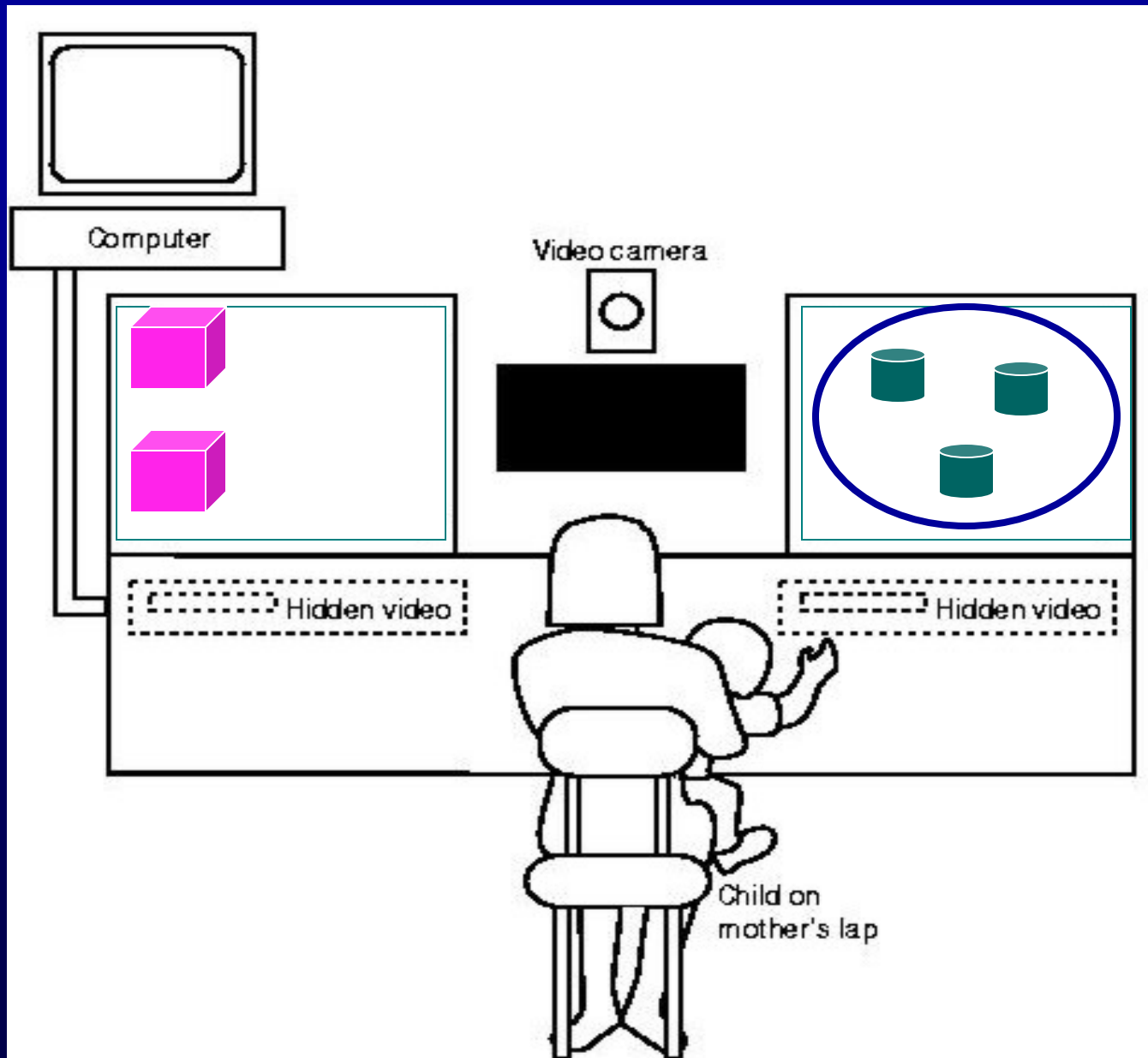






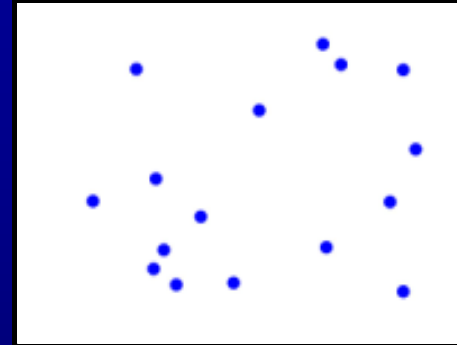
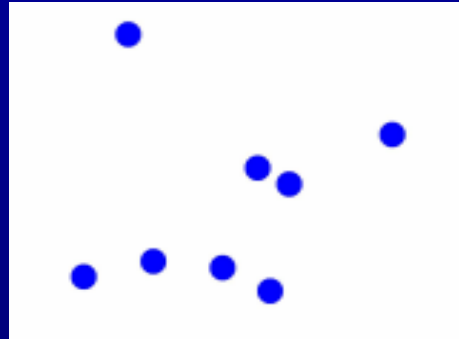




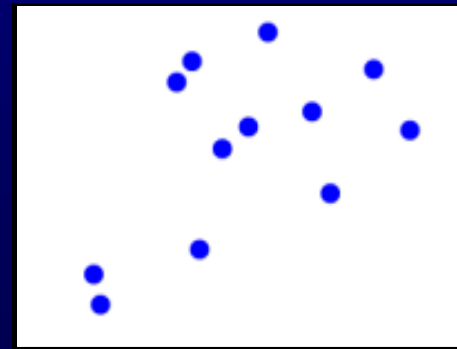
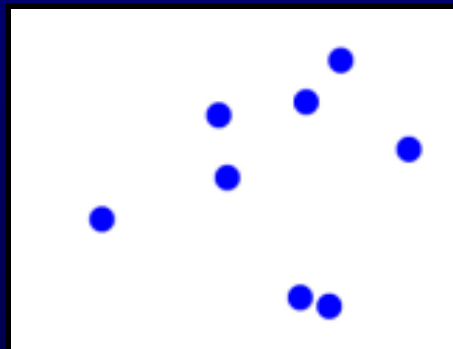




Evidence from Infants



8 vs 16

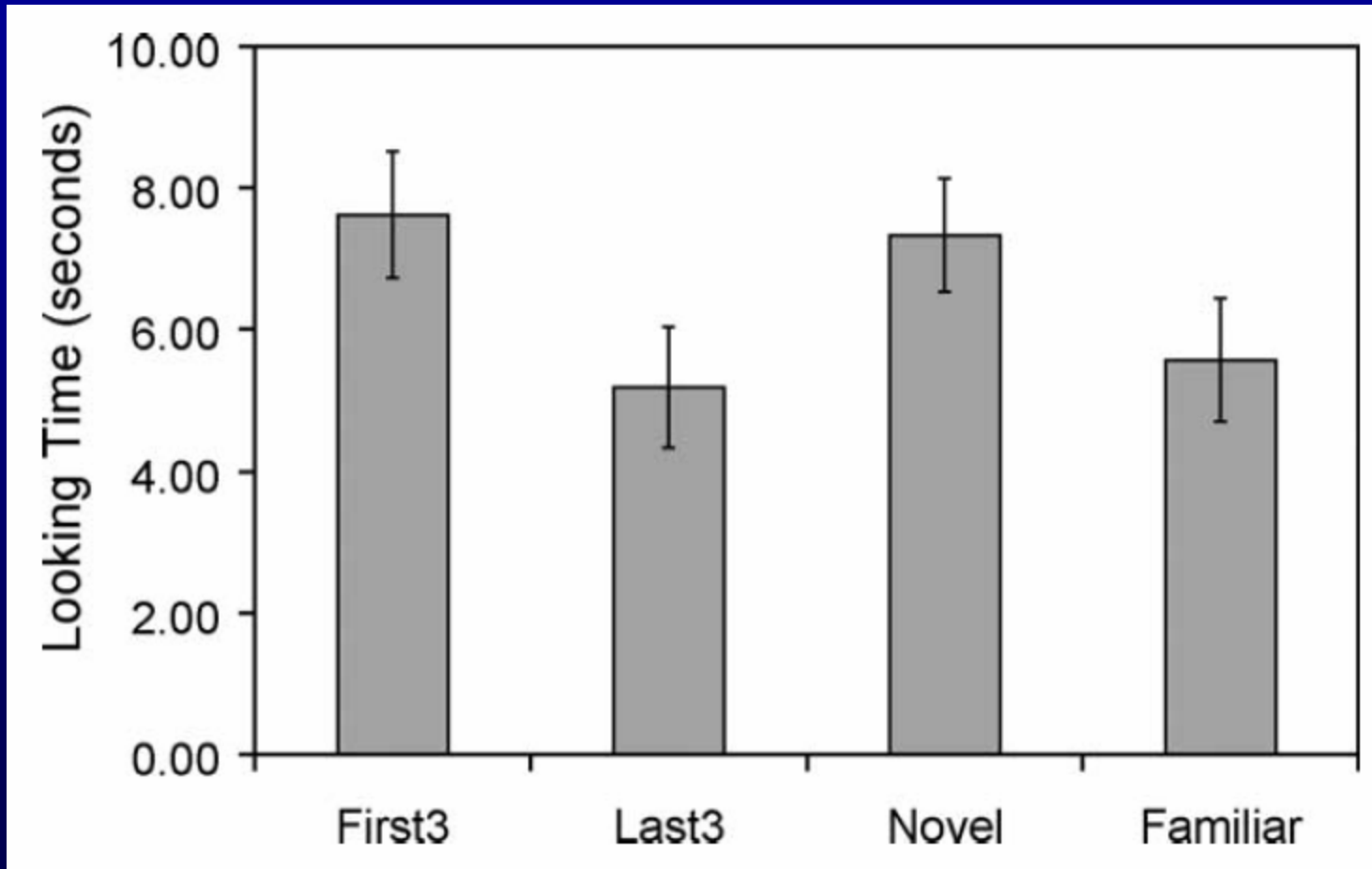


8 vs 12

Evidence from 6-month old infants (from Xu & Spelke, 2000)

Signature of the Distance Effect

Evidence from Infants

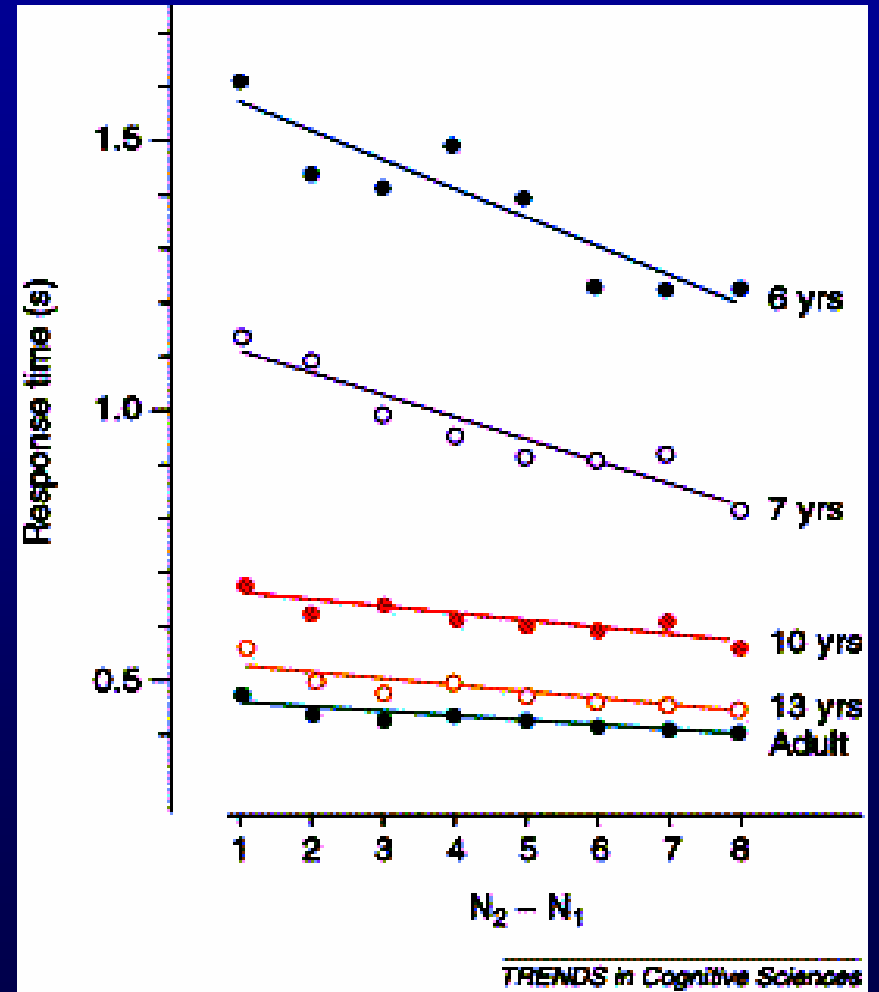
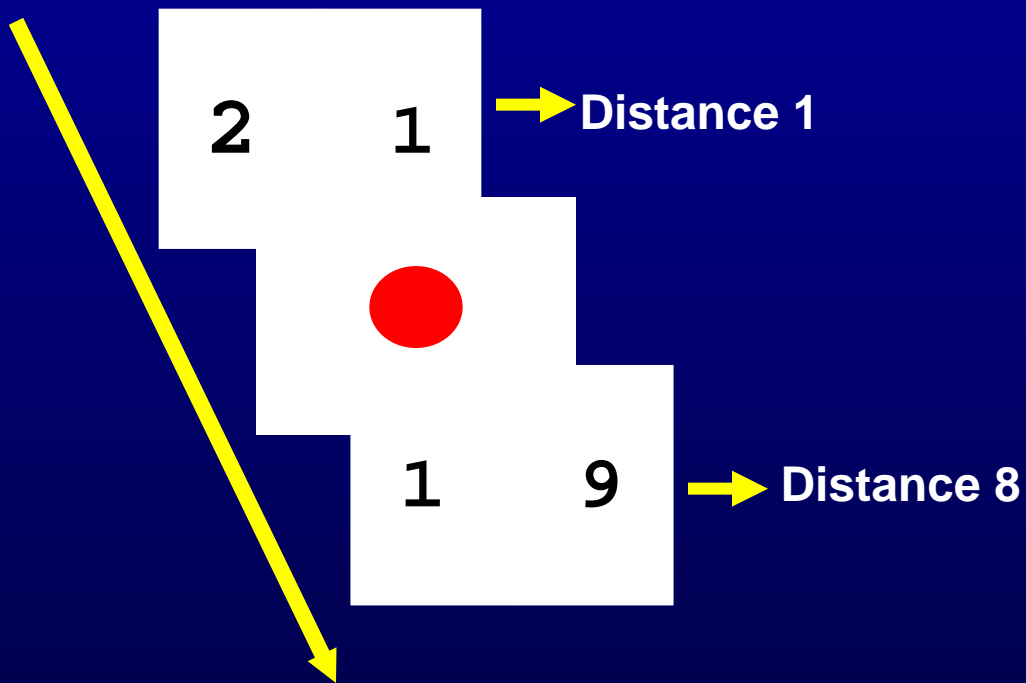


from: Brannon et al. (2003)

Evidence from Children

Approximate system

Evidence from children and adults

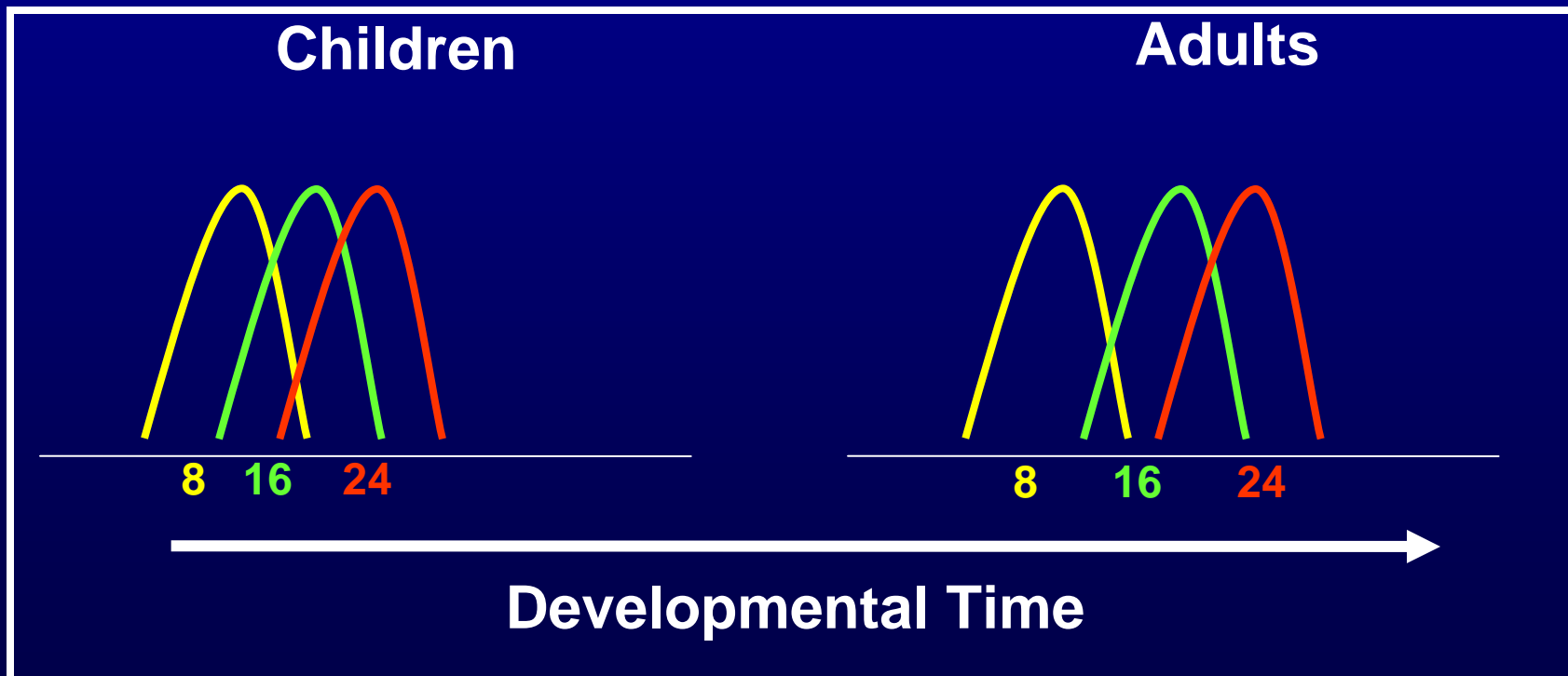


from: Sekuler & Mierkiewicz (1977)

Distance Effect

Development

- Decrease of distance effect over dev. time
- Decrease in noise \longrightarrow increase in precision



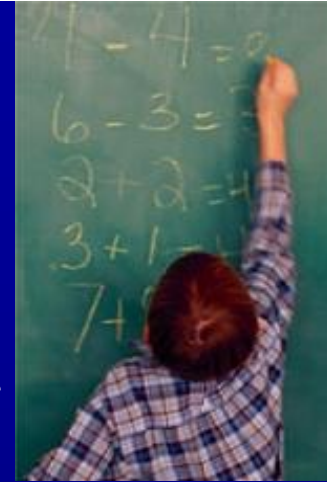
Implications

- *Development is crucial*
- Basic processing of symbolic and non-symbolic magnitude not fully developed upon entry into primary school

Do these developmental changes
have educational significance?

Dyscalculia

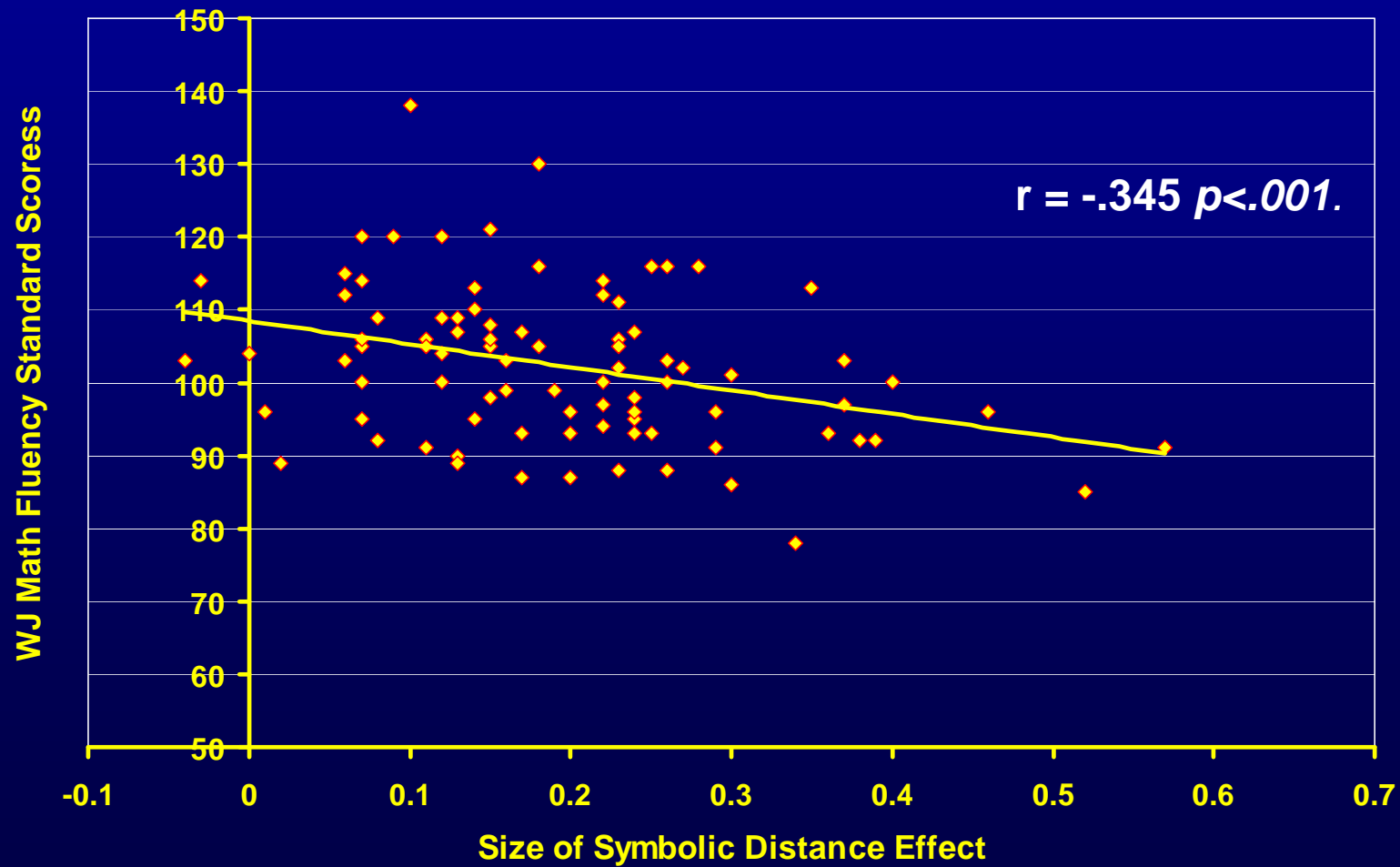
- 3-10% of children suffer from *specific* difficulties in mathematics
- Have difficulties with understanding of numerical magnitude (e.g. Landerl et al., 2004)
- Early difficulties with magnitude processing predictive of later outcomes



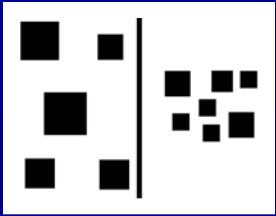
Typical Development

Distance effect - Predictive measure?

Size of Distance Effect = (larger RT – Small RT/ Large RT)



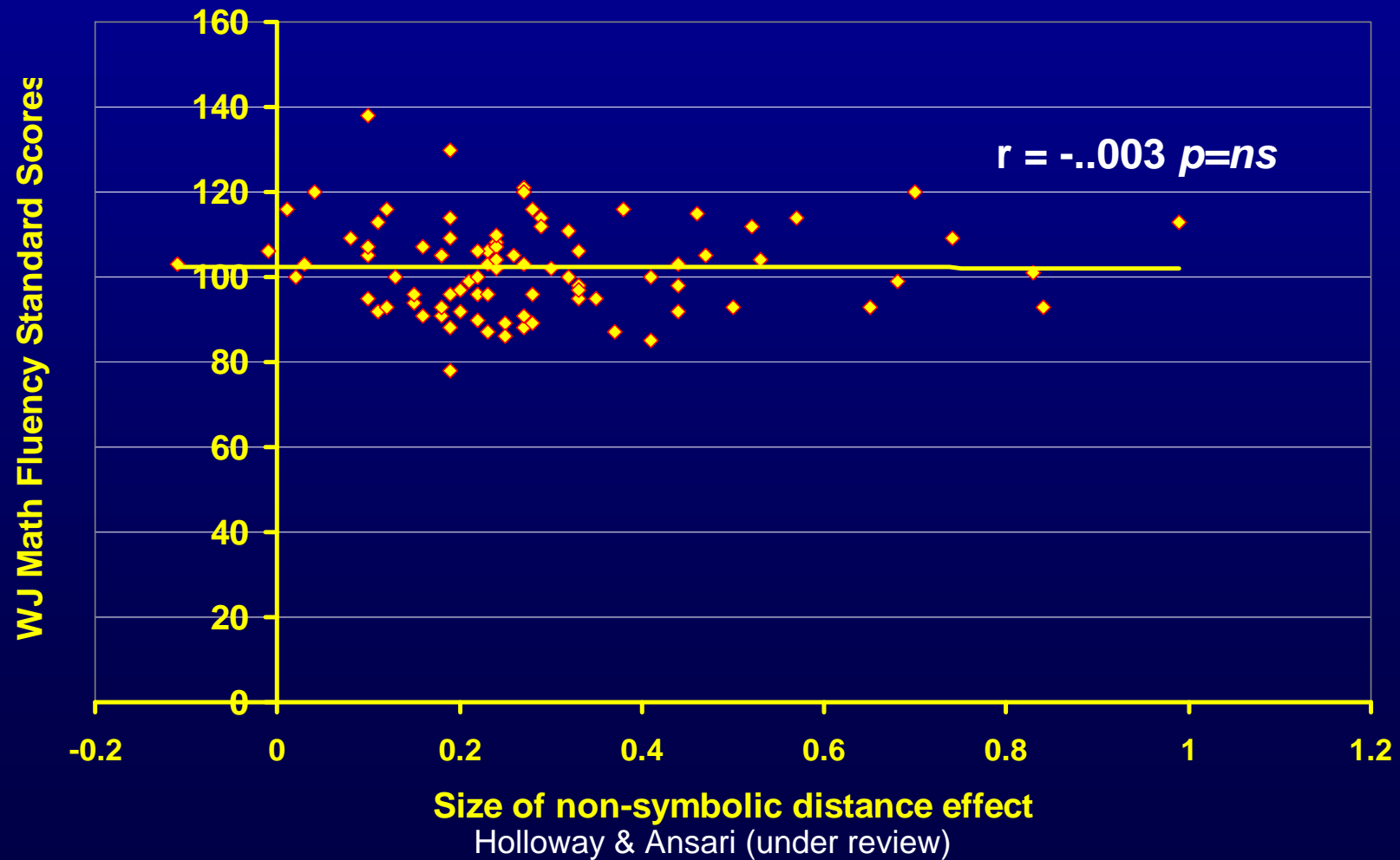
Holloway & Ansari (under review)



Distance effect

Predictive measure?

Correlation of WJ Math Fluency Scores
with Non-symbolic Distance Effect



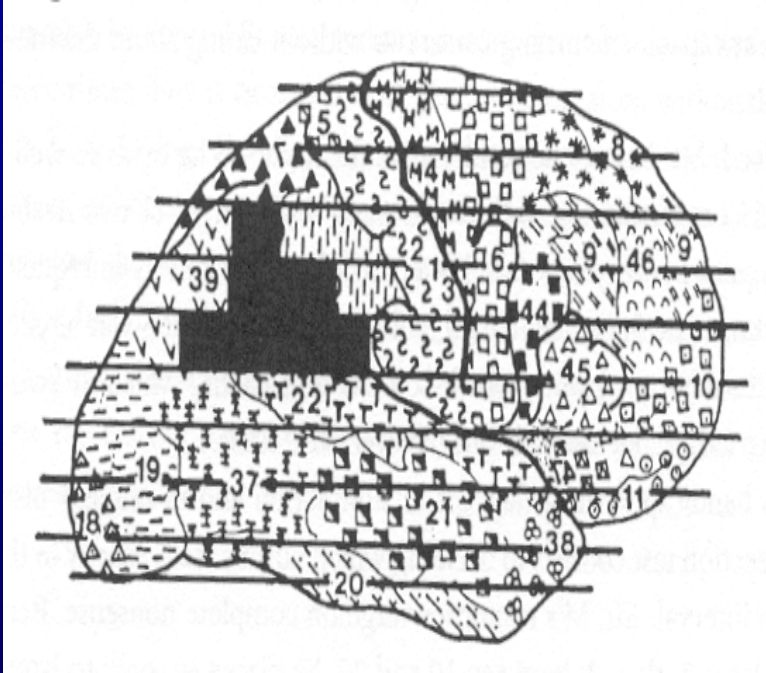
Distance effect

Predictive measure?

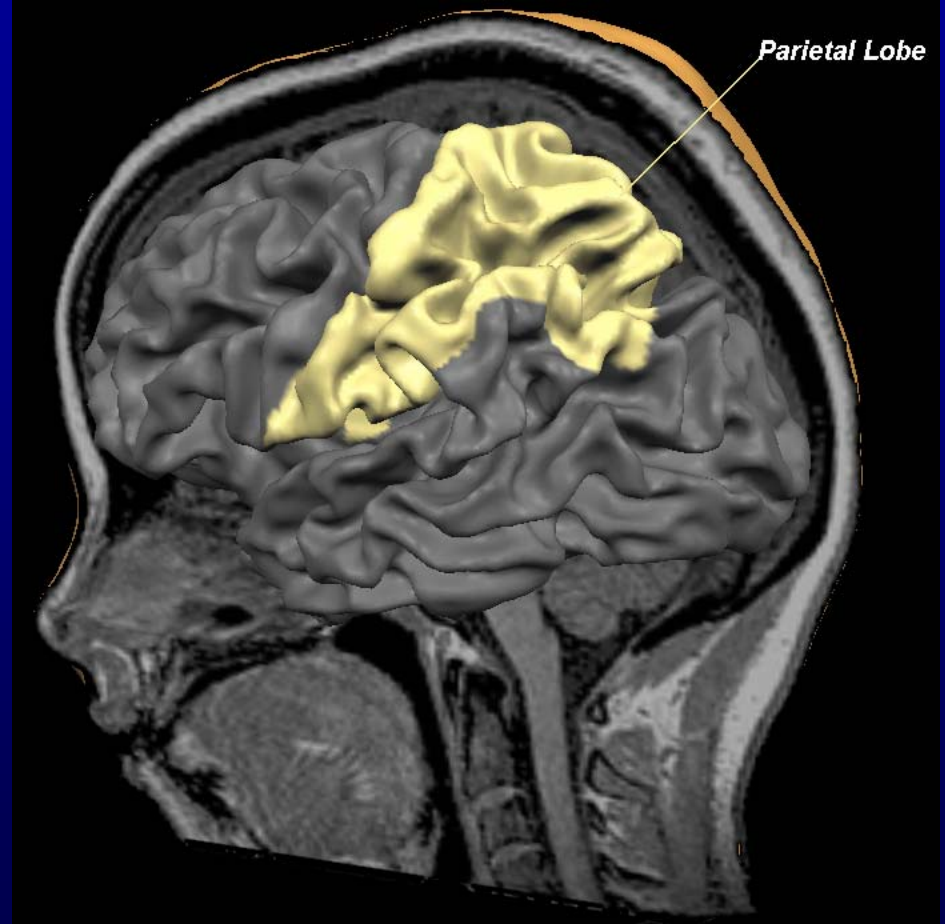
- Individual differences in symbolic BUT NOT non-symbolic distance effect correlate with math scores
- **Also: no correlation with reading scores**
- ***Basic understanding of the quantities that symbols represent is crucial for math development***

Evidence from Brain-Imaging

Neural systems

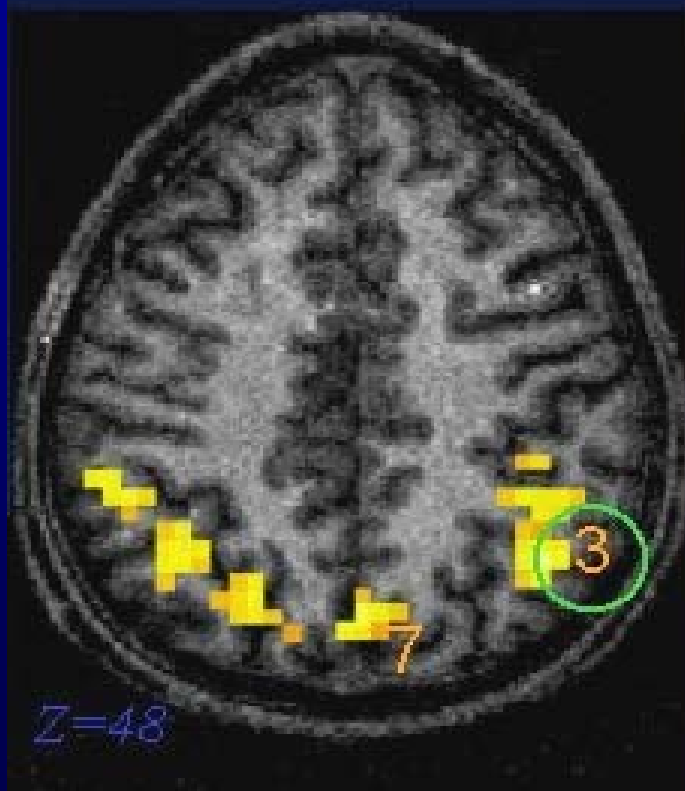


Patient N
(Dehaene & Cohen 1995)



Evidence from human adults

- Distance modulates a network of brain areas

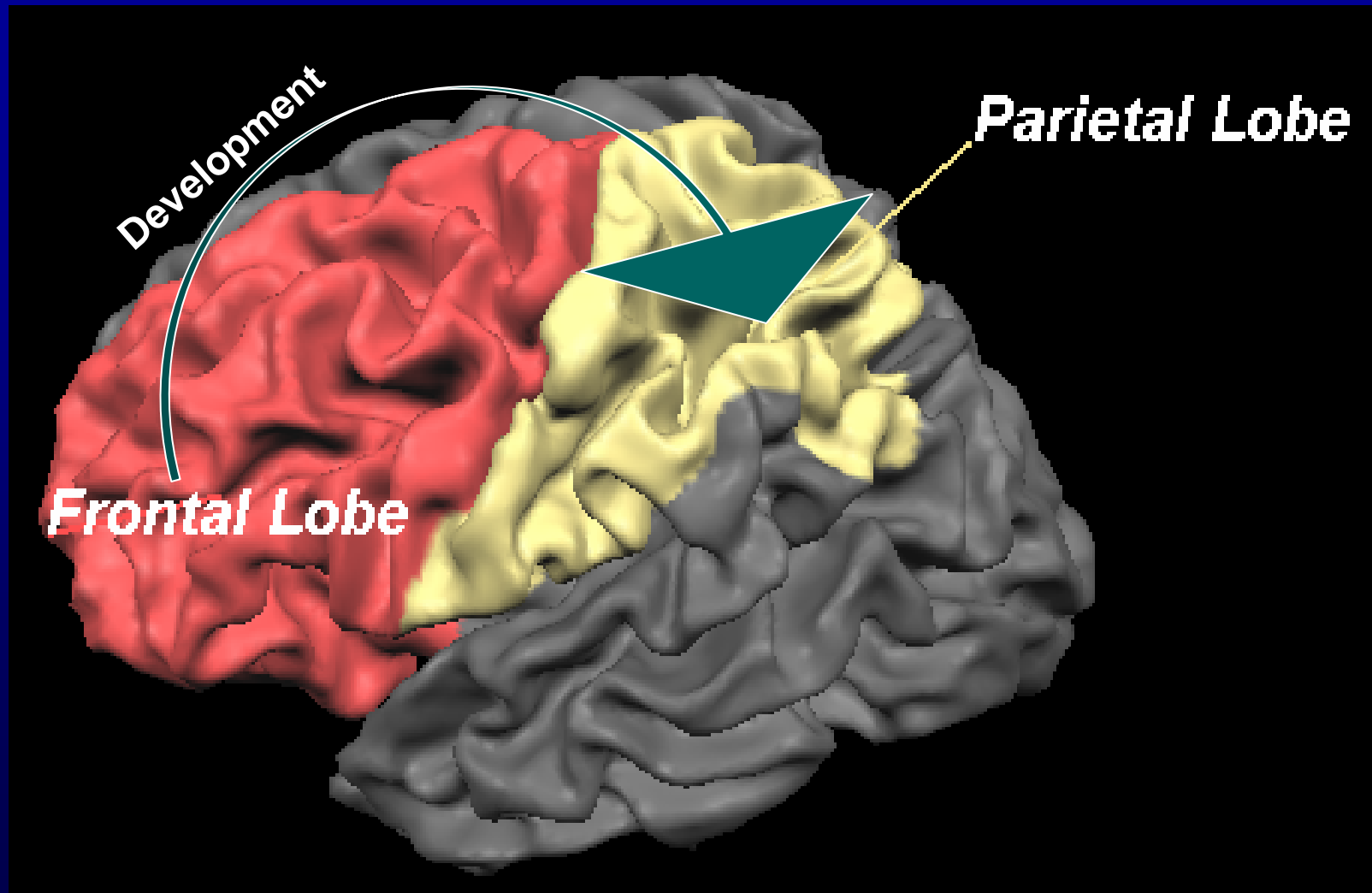


Pinel et al. 2003

Development of neural system

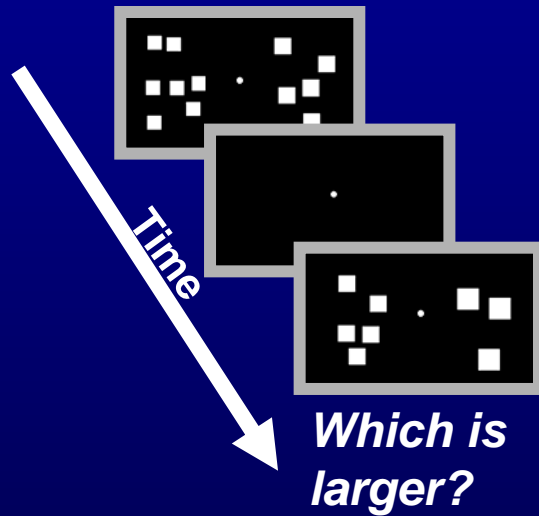
- Do brain systems underlying numerical and mathematical cognition change over developmental time?

Age-related shift

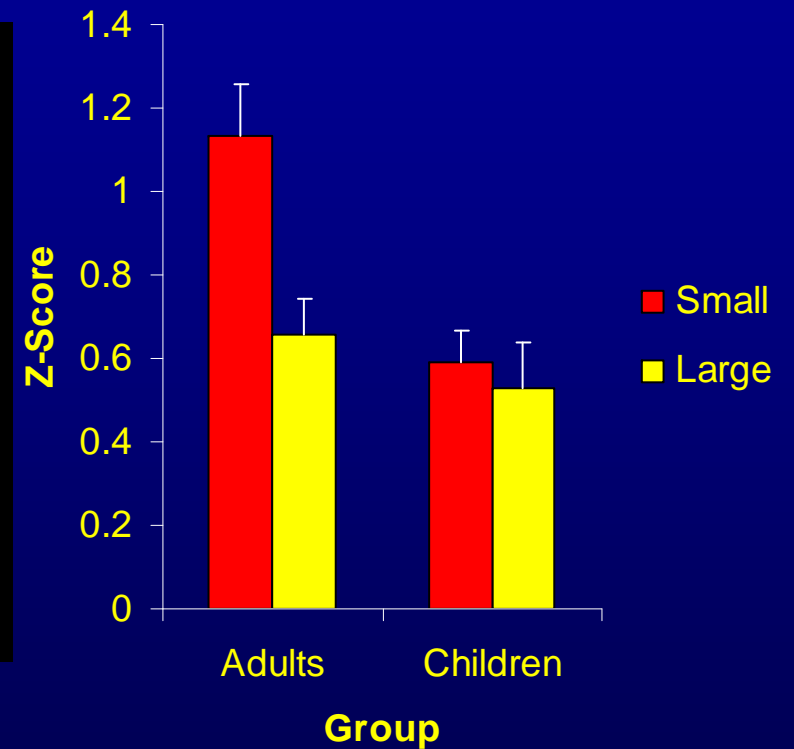


Rivera et al. (2005); Ansari et al. (2005); Ansari & Dhital (2006)

Non-symbolic distance effect

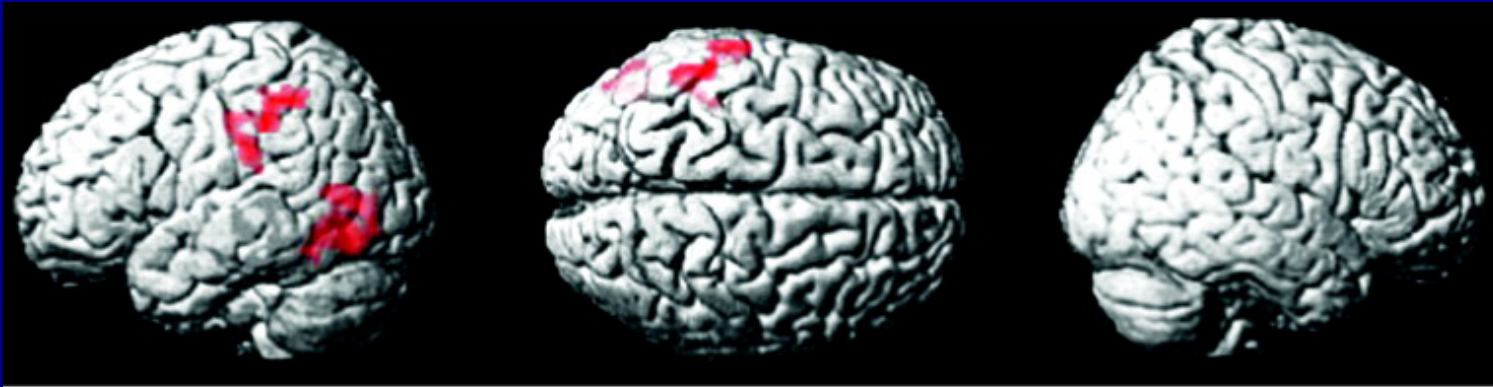


Left IPS (-35, -48, 38)

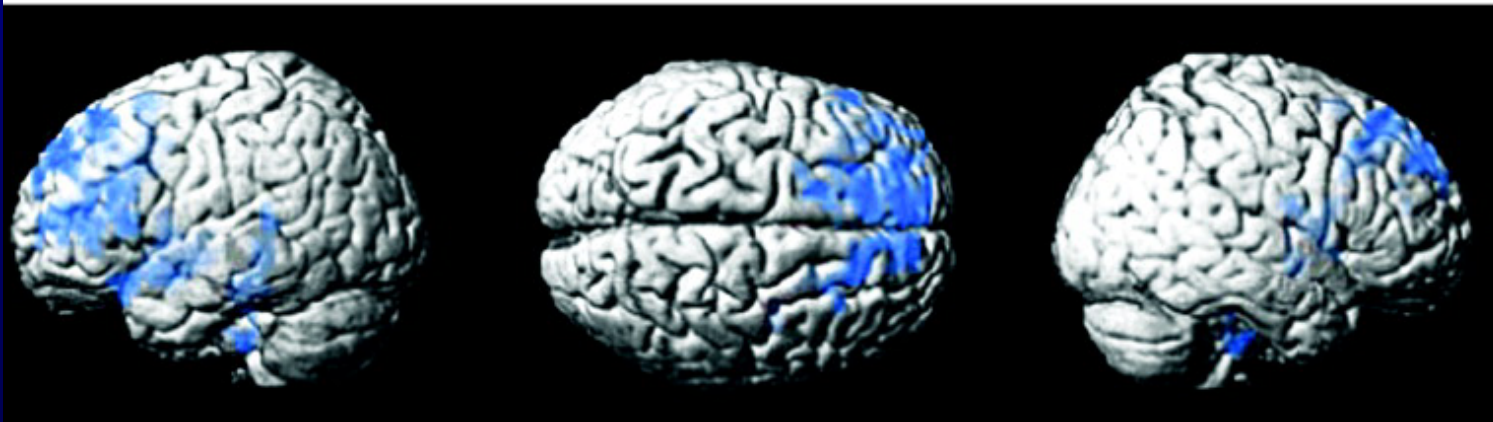


Ansari & Dhital (2006, *JoCN*)

Neural correlates of mental arithmetic development



**Increases
with age**



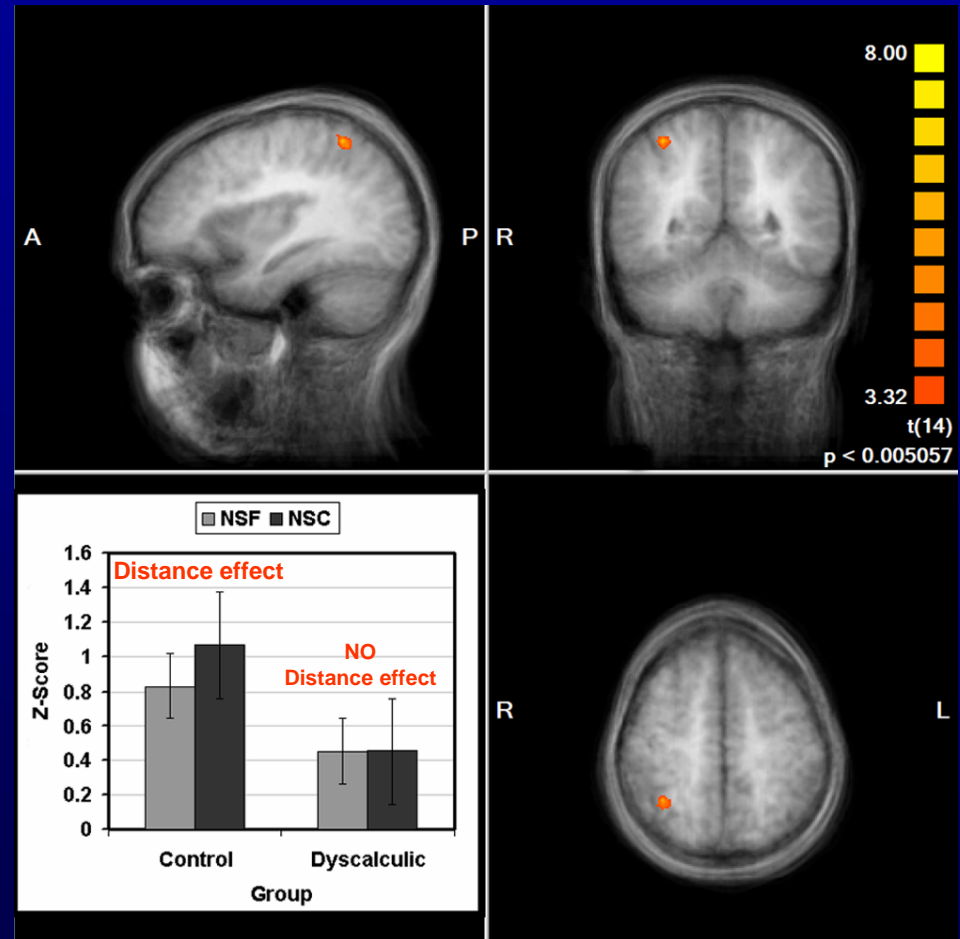
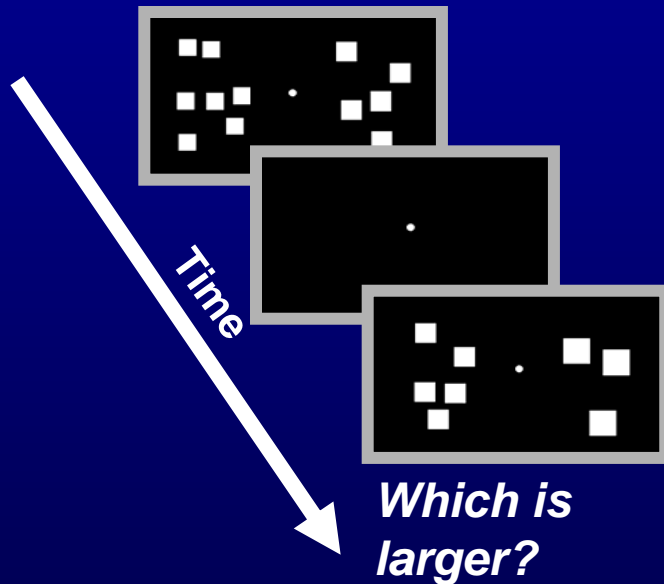
**Decreases
with age**

Rivera et al. (2005)

Development of neural system

- Is the development of neural systems disrupted in children with mathematical difficulties?

Evidence from Developmental Dyscalculia



Price, Holloway, Vesterinen, Rasanen & Ansari (*Current Biology*)

Conclusions

- Evolutionary and developmental evidence for basic magnitude system
- Important scaffold for development of math skills
- Disrupted in children with dyscalculia
- Interacts with the acquisition of symbolic representation of number

Thank you for your attention!