9.71 Functional MRI of High-Level Vision

Fall 2007

Lecture 8B
Number: A Candidate "Special" Domain of Cognition

I. Understanding approximate number
- Adults
- Infants
- Animals

II. Brain basis of number:
- neuropsychological patients
- fMRI nderstanding approximate number

Understanding Number

- “animals, young infants, and adult humans possess a biologically determined, domain-specific representation of number”

- “a specific neural substrate, located in the left and right intraparietal area, is associated with knowledge of numbers and their relations (‘number sense’). The number domain is a prime example where strong evidence points to an evolutionary endowment of abstract domain-specific knowledge in the brain because there are parallels between number processing in animals and humans.”

–Dehaene, Dehaene-Lambertz & Cohen, TINS, 1998

What does “number sense” mean?

• Adults can represent large numerical magnitudes without verbal counting.

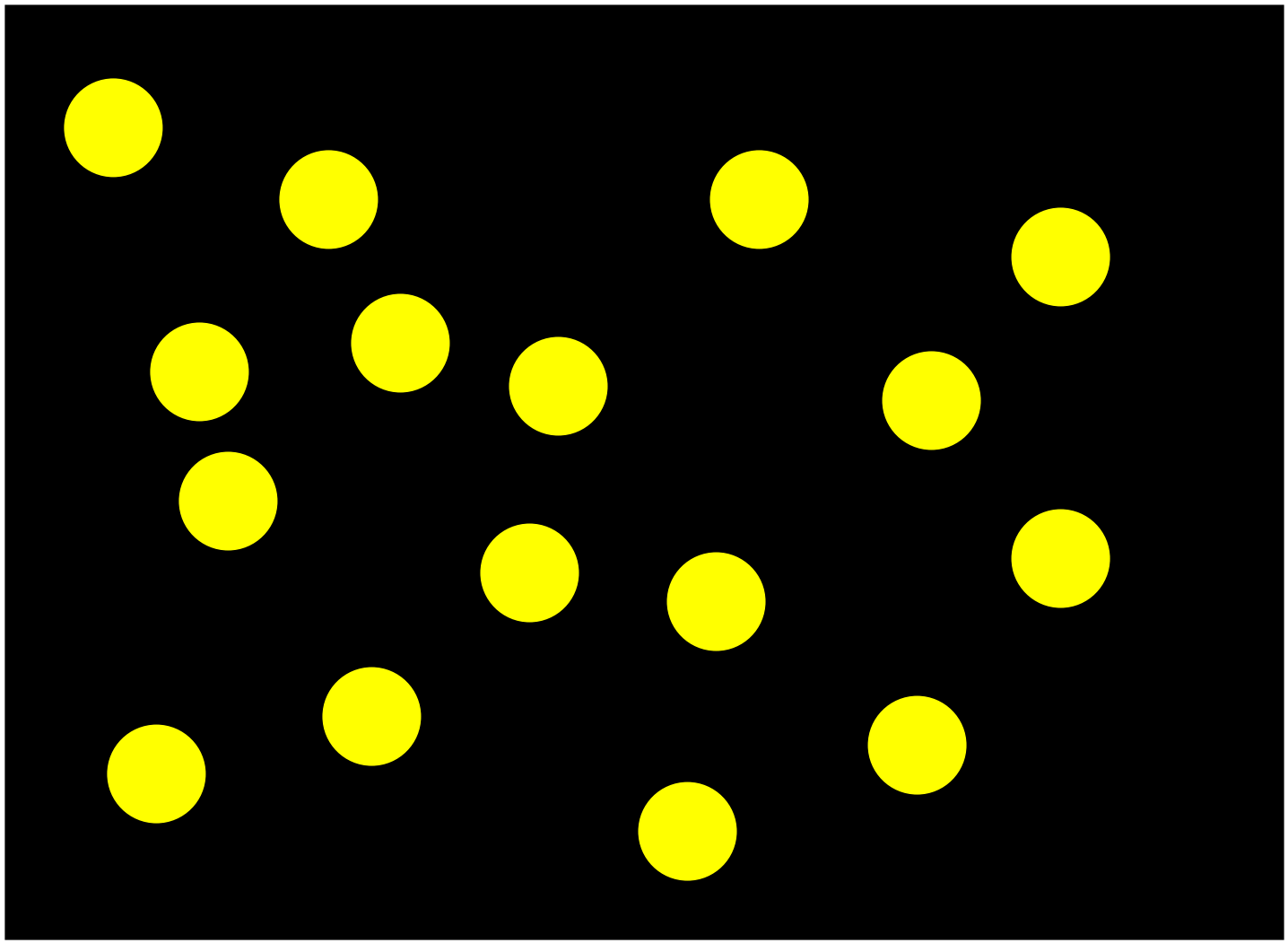
• The representations are approximate; discriminability of two numerosities depends on their ratio.

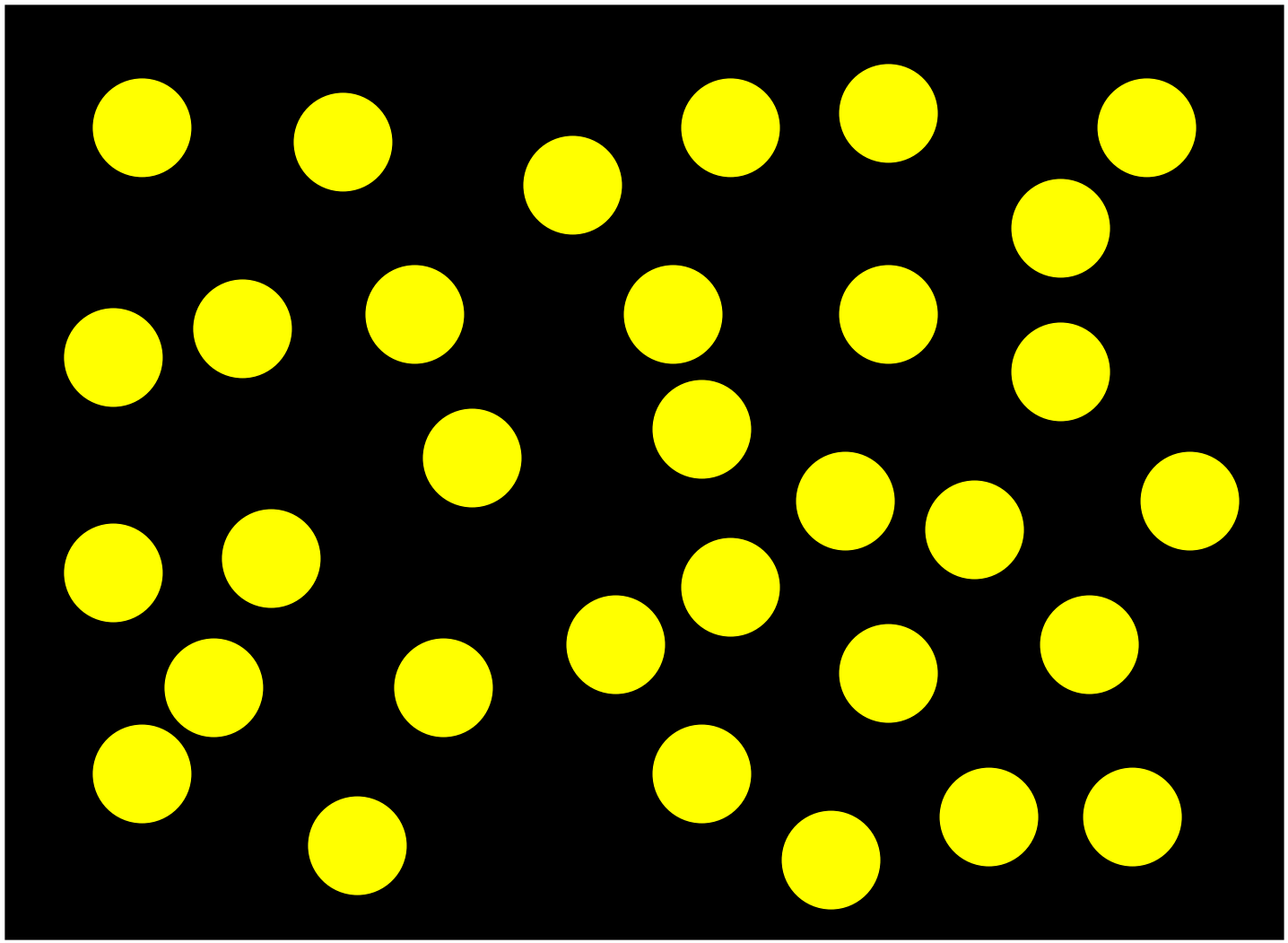
• The representations are abstract.

• The representations enter into arithmetic computations (addition).

For example……

Which has more dots?





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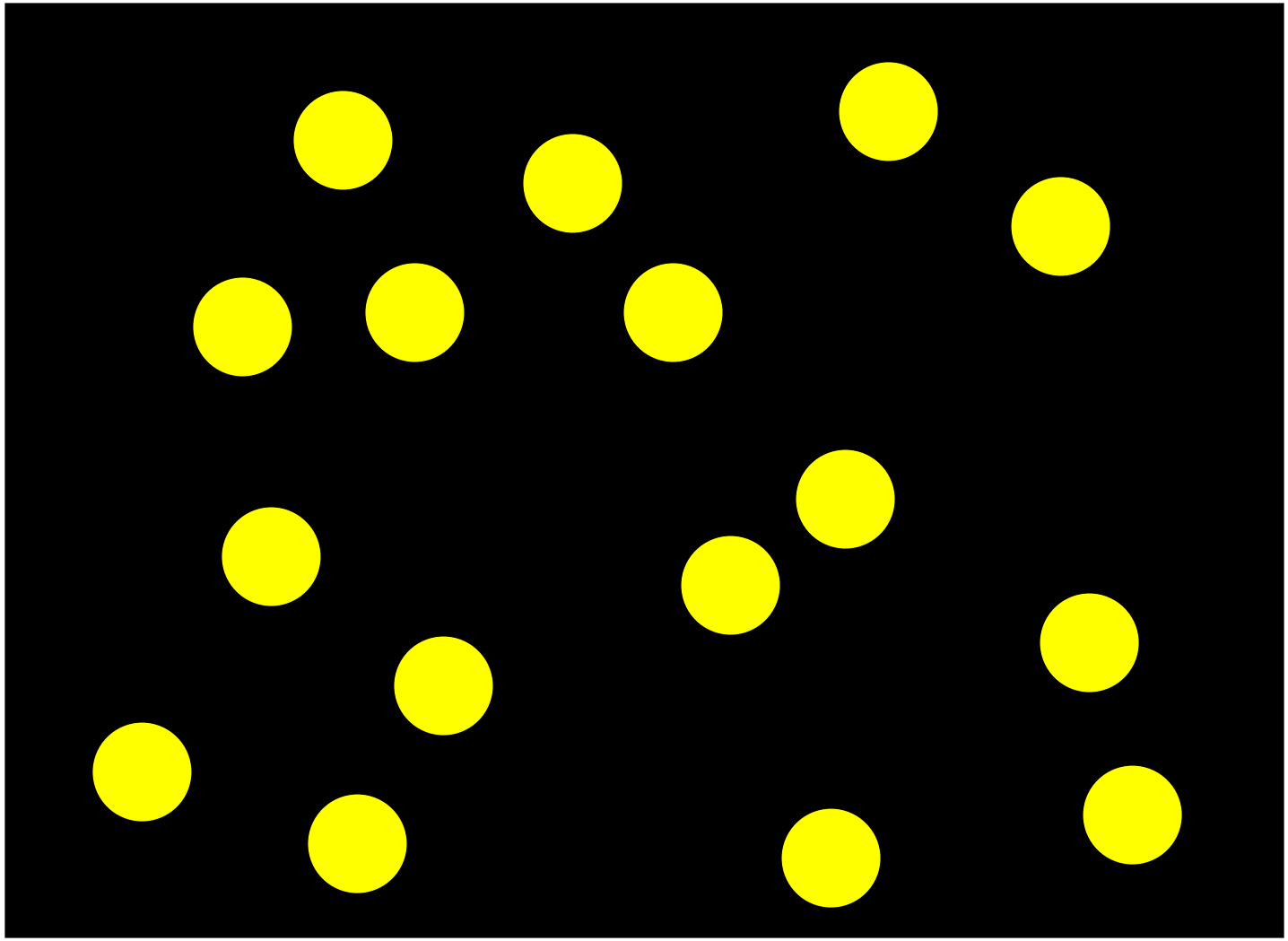

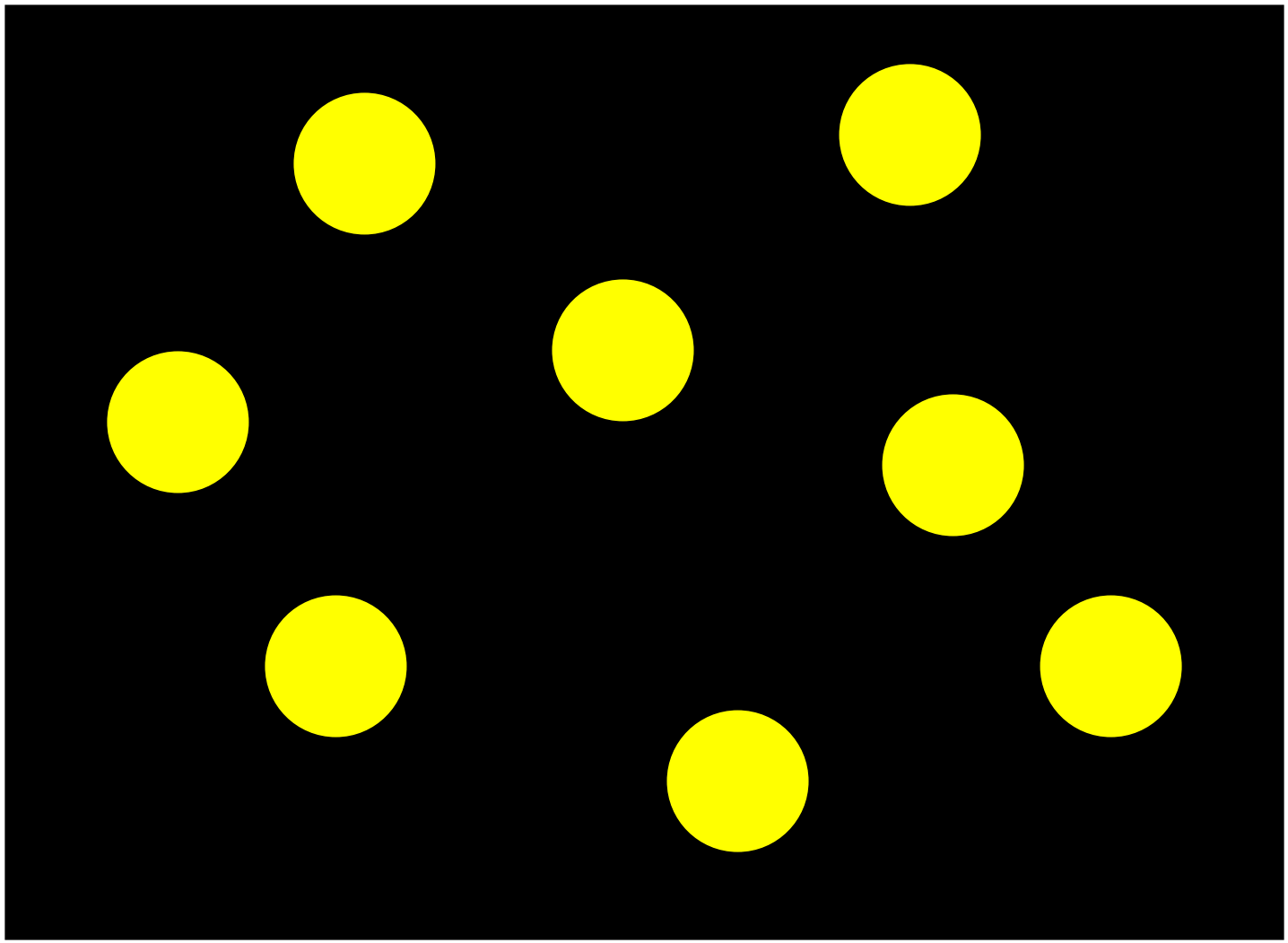

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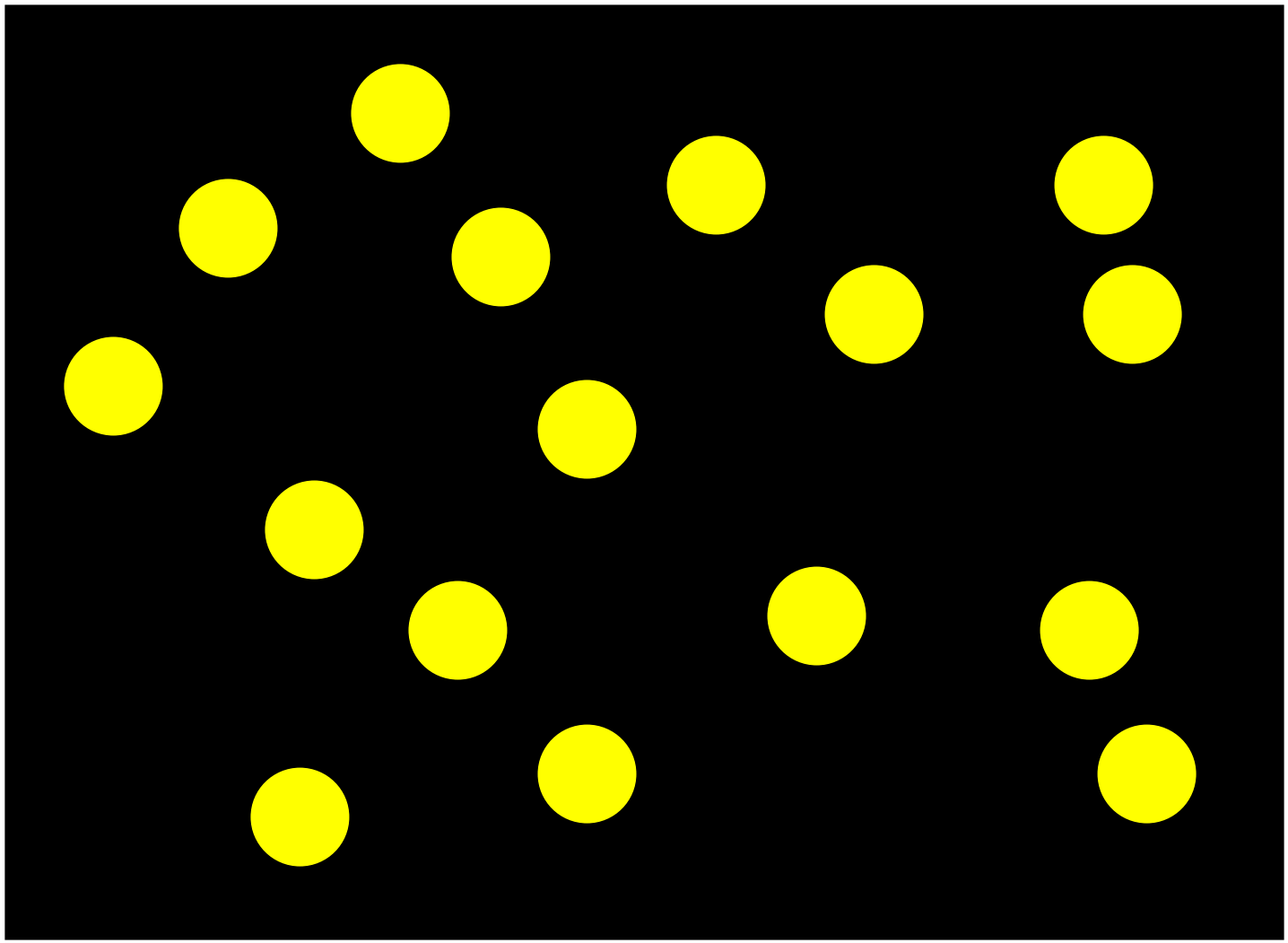

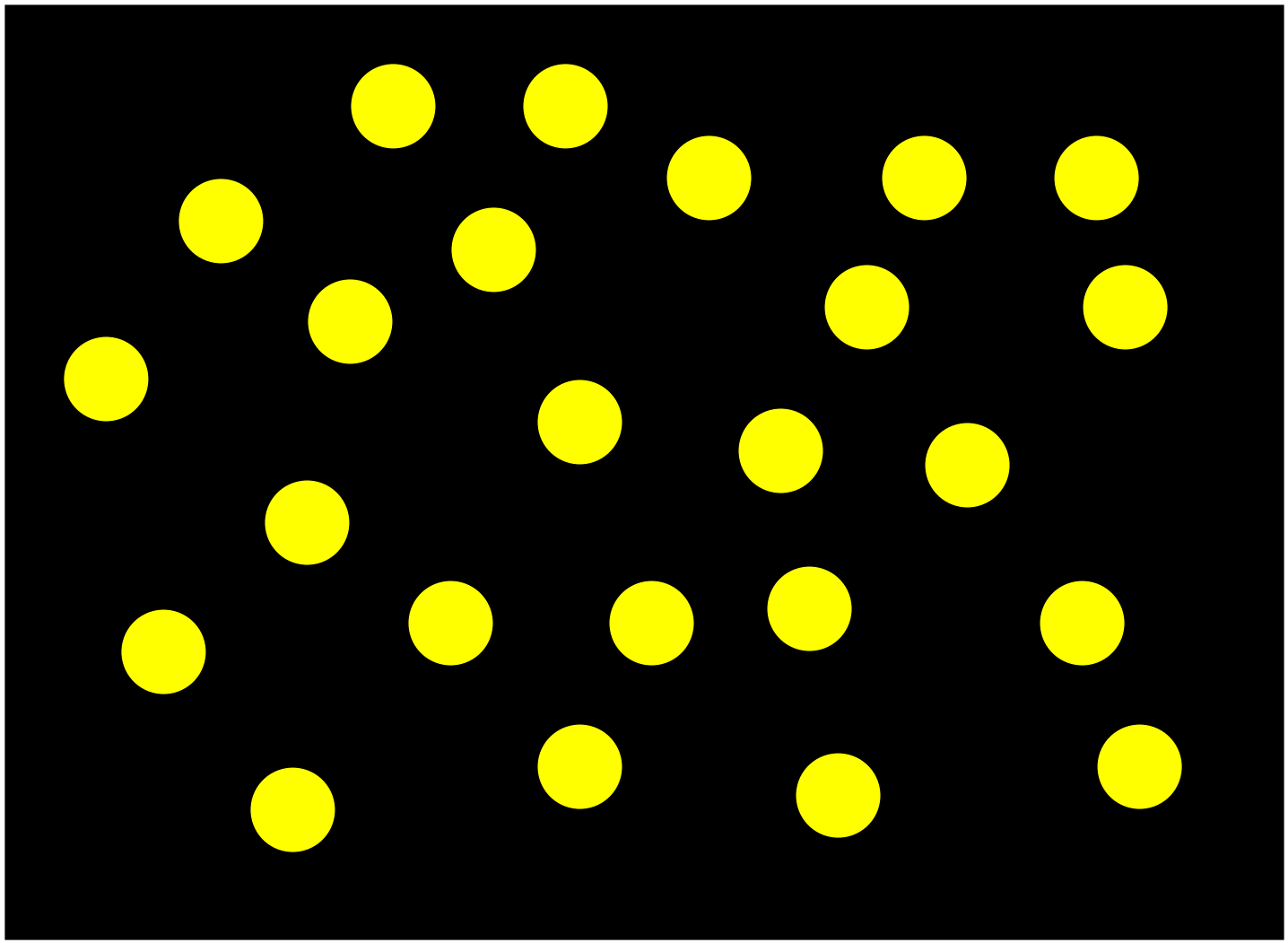

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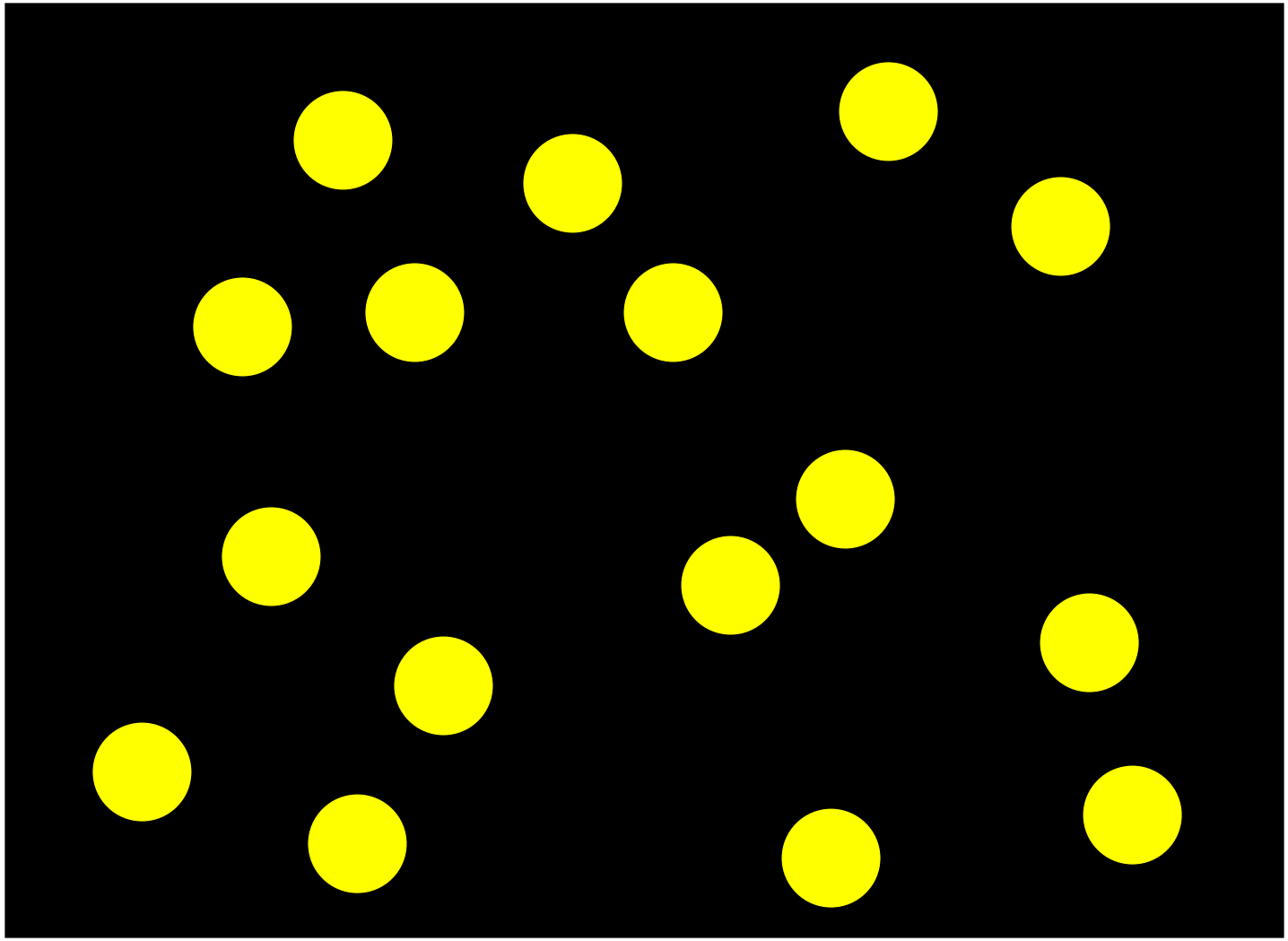
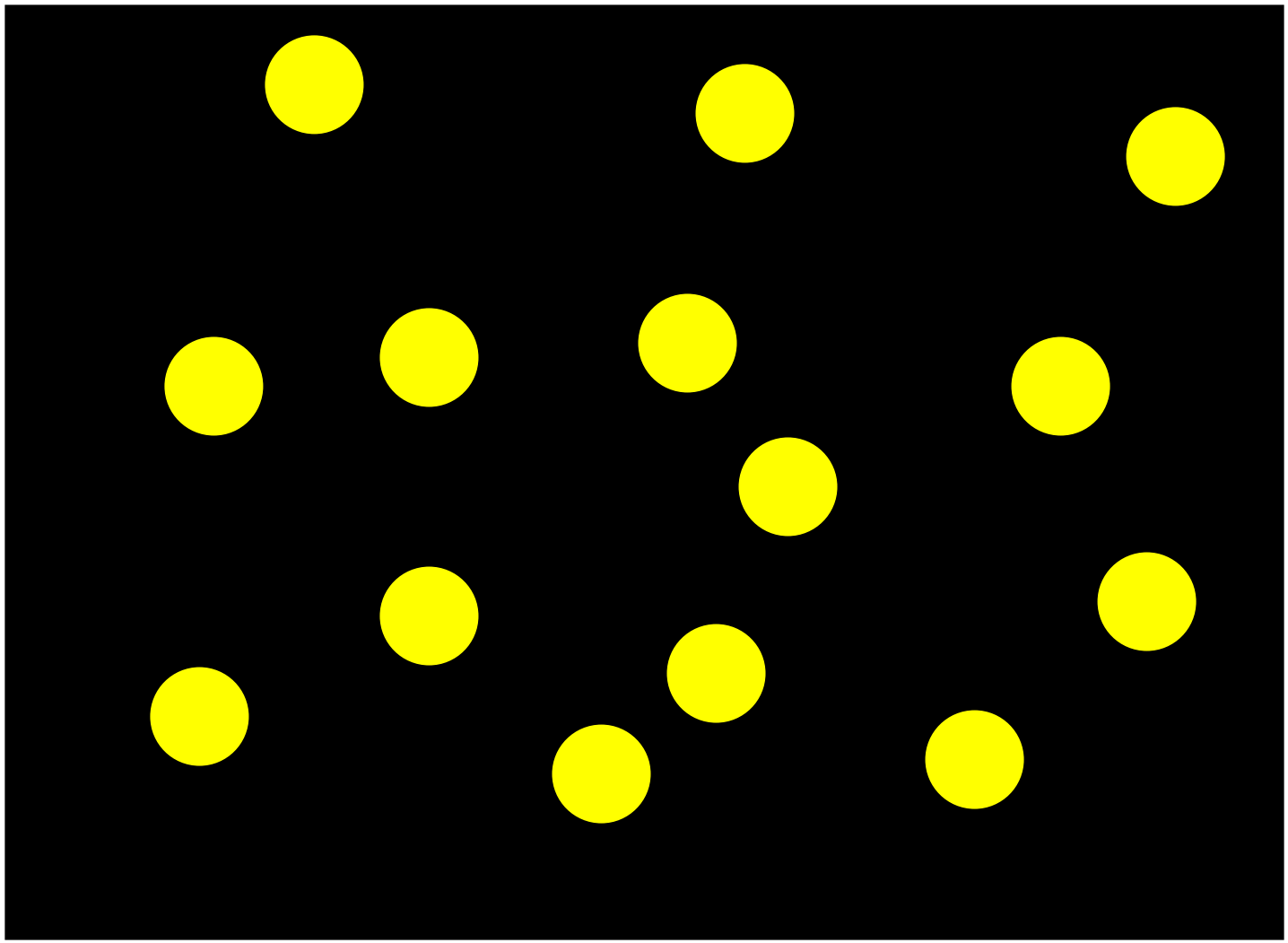
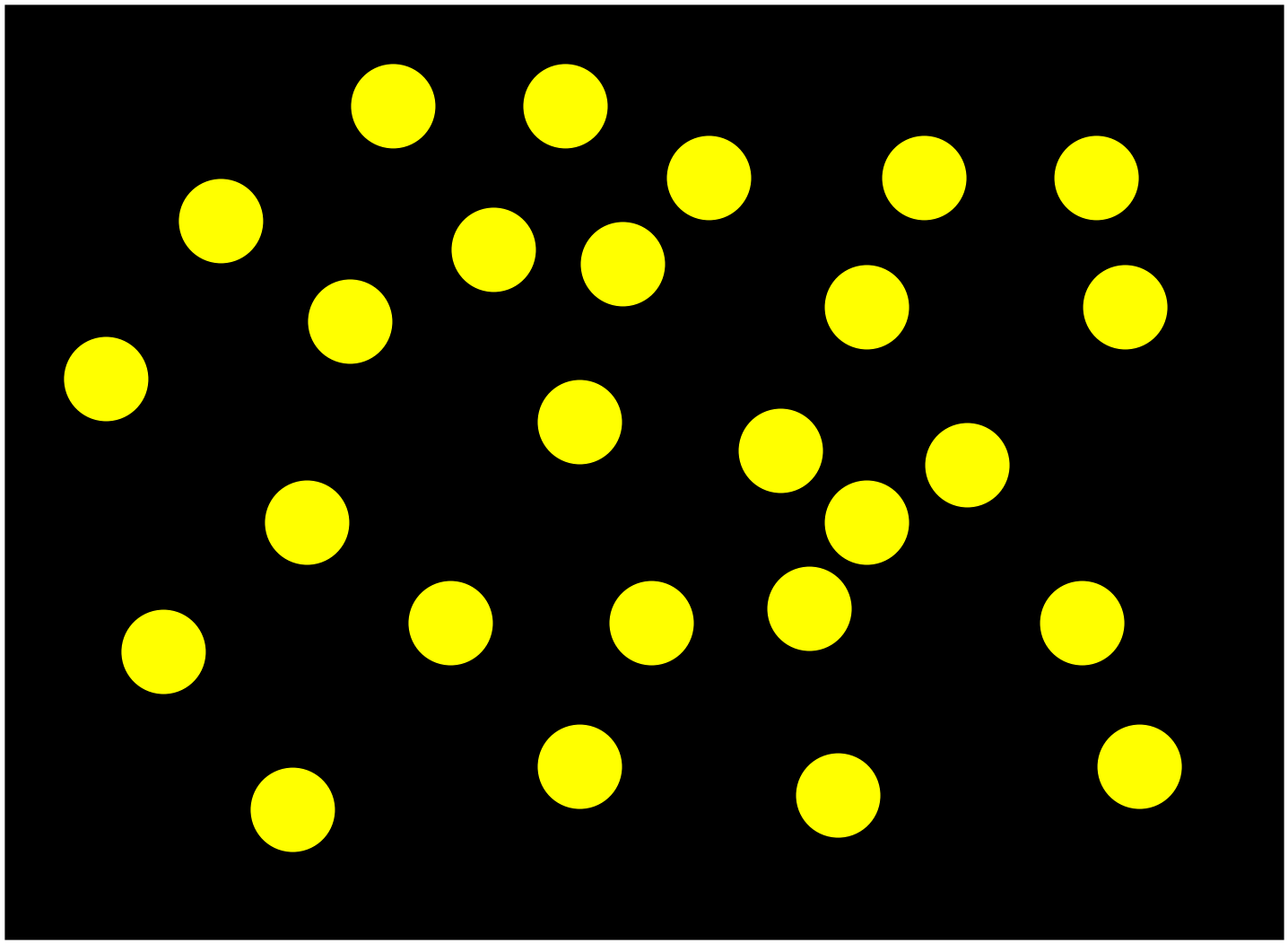
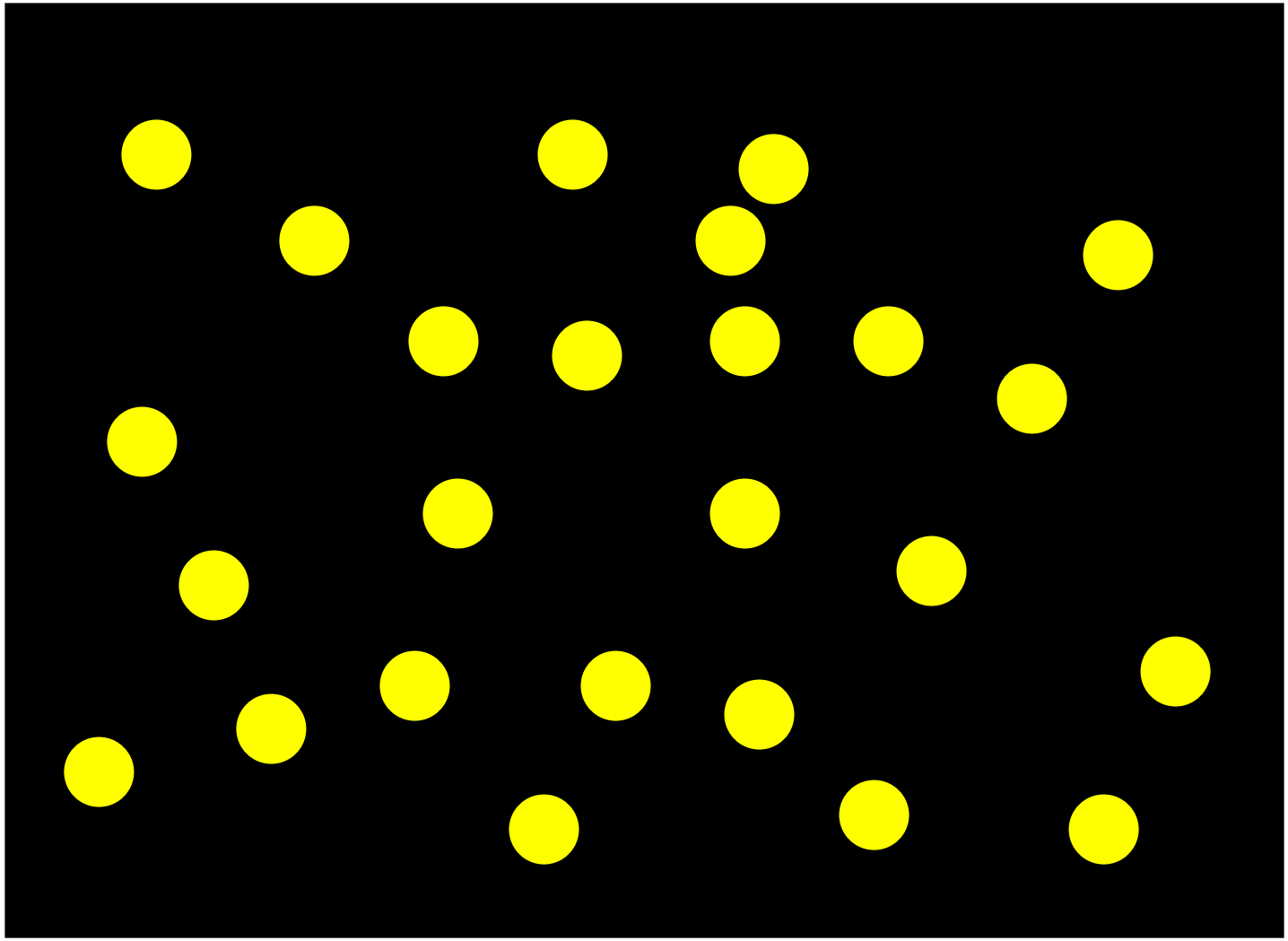




Which has more dots?



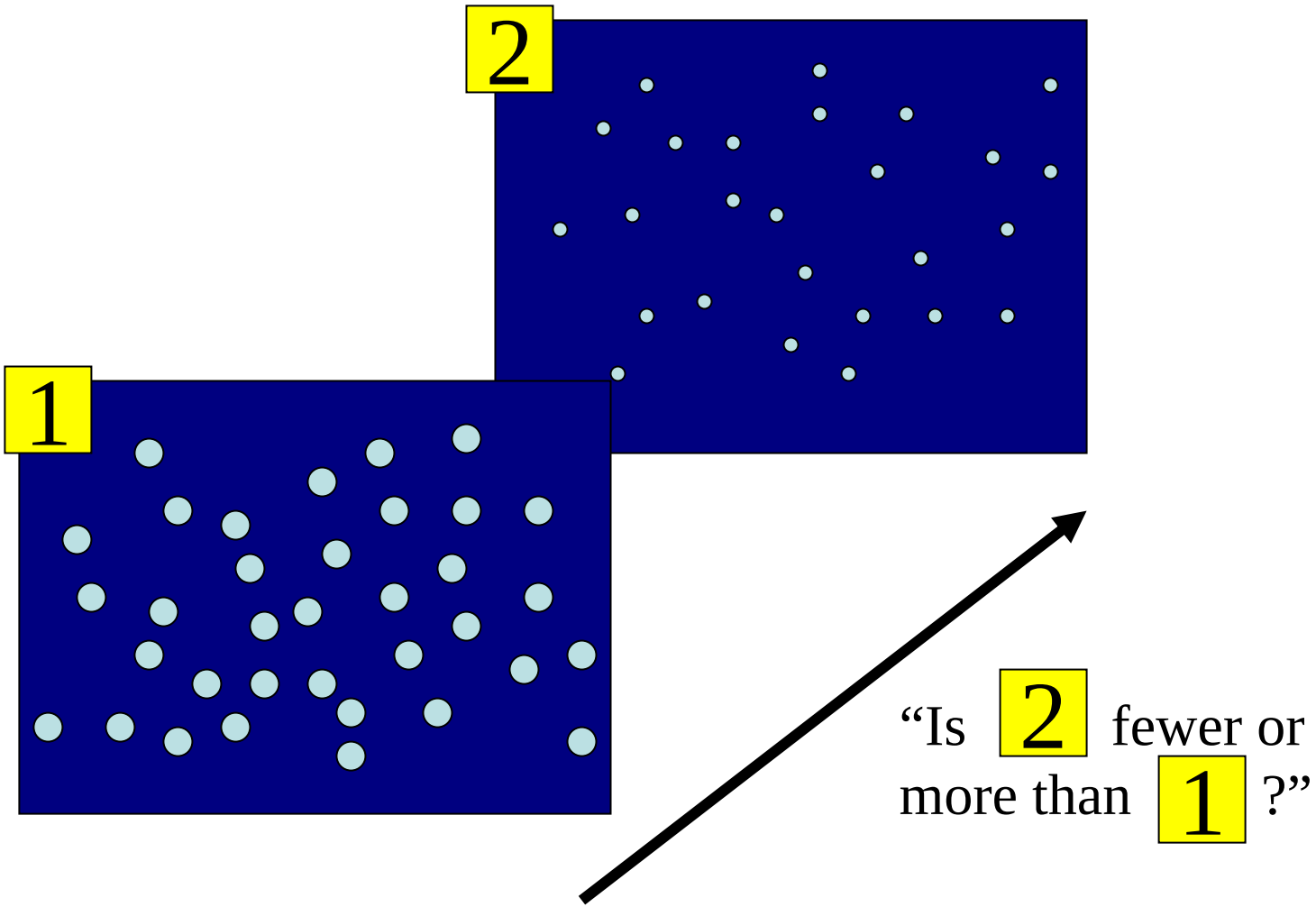


How did you do this?

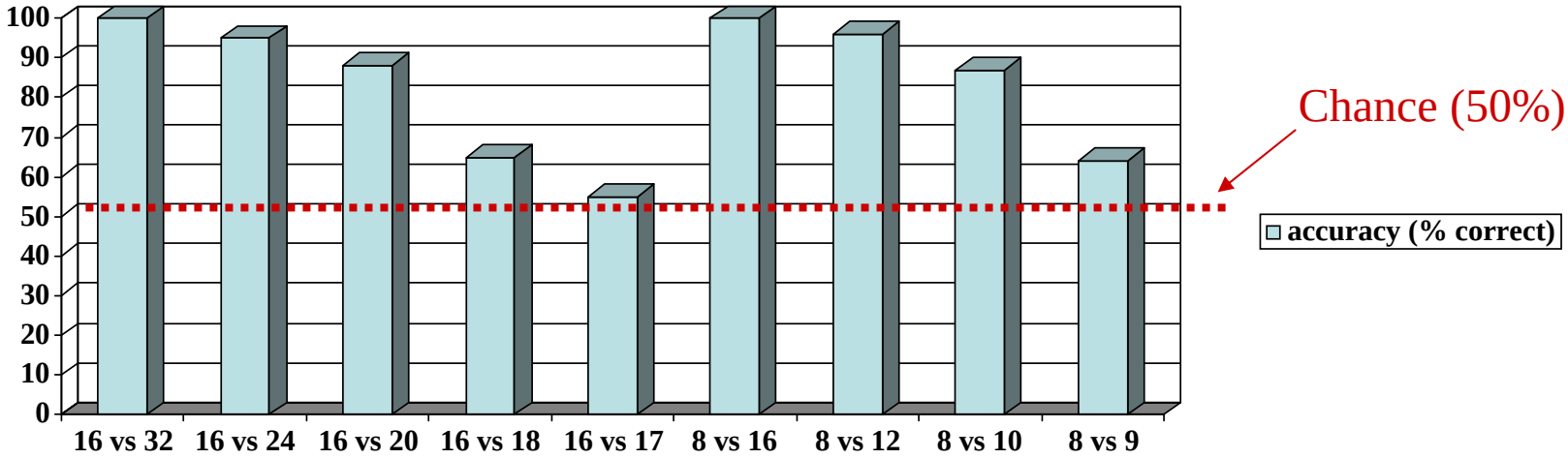
Did you count verbally?

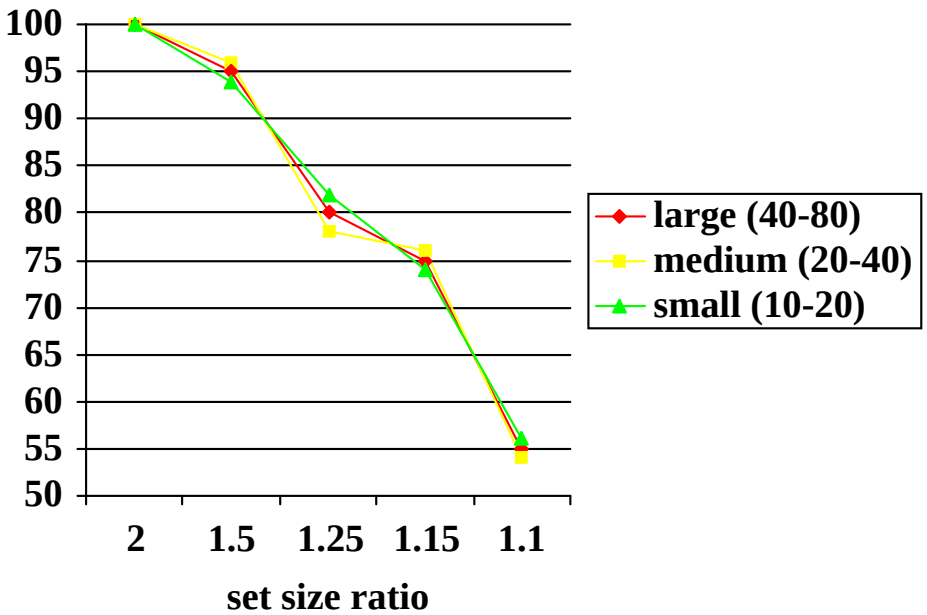
Which ones were harder?

How accurate are adults' large number representations? (Barth, Kanwisher & Spelke, 2003)



Numerosity discrimination by adults (Barth)





Weber's Law:
The discriminability of two numerosities depends on their *ratio* (not absolute diff).

What does “number sense” mean?

✓ • Adults can represent large numerical magnitudes without verbal counting.

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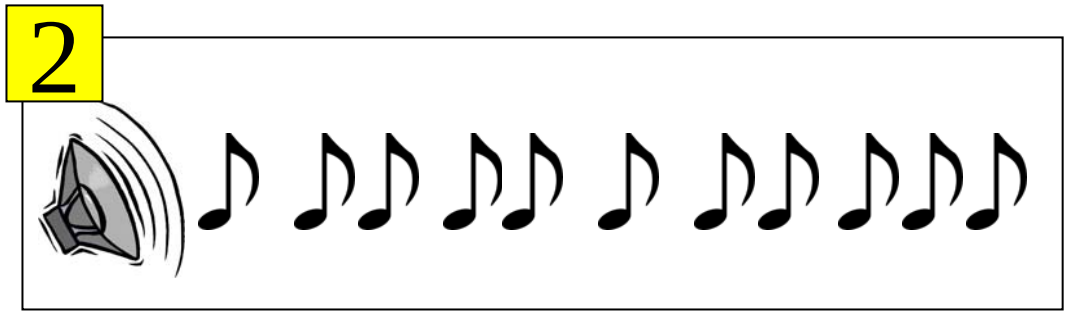
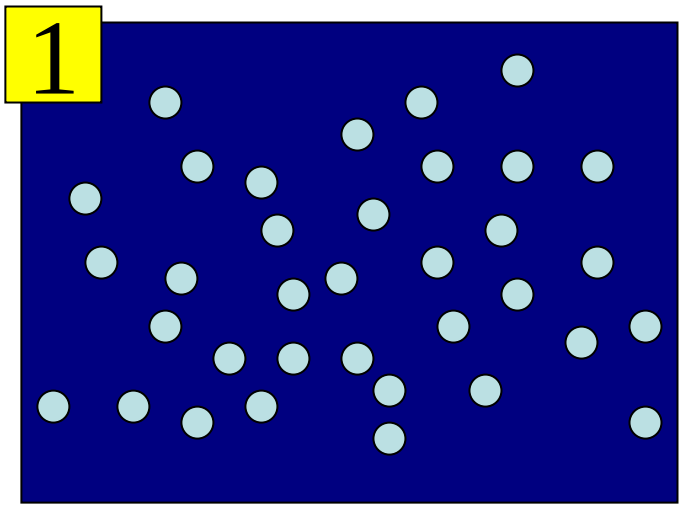
✓ • The representations are not based on continuous quantities like *area*, but rather on discrete *number*.

? • The representations are abstract.

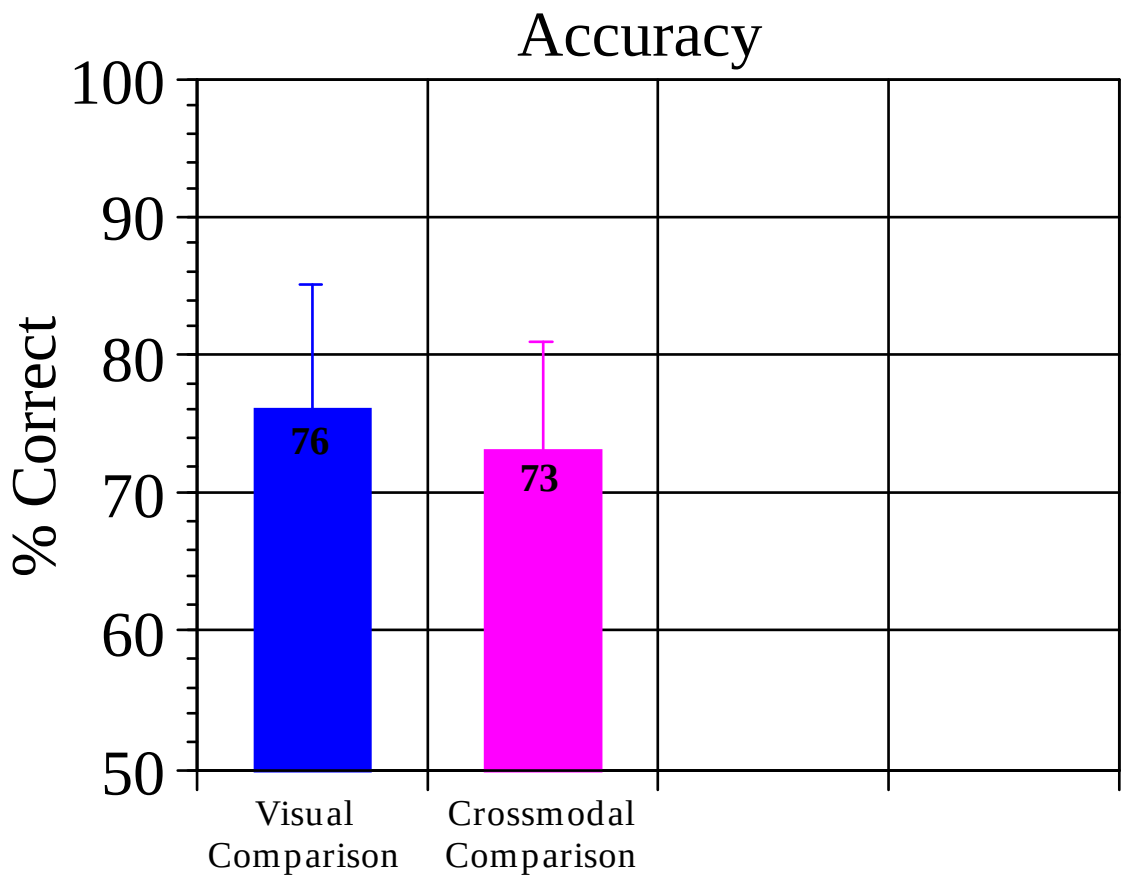
? • The representations enter into arithmetic computations (addition).

How abstract are adults' large number representations?





"Is 2 fewer or more than 1 ?"



Cross-modal comparisons are almost as accurate as comparisons within the visual modality alone.

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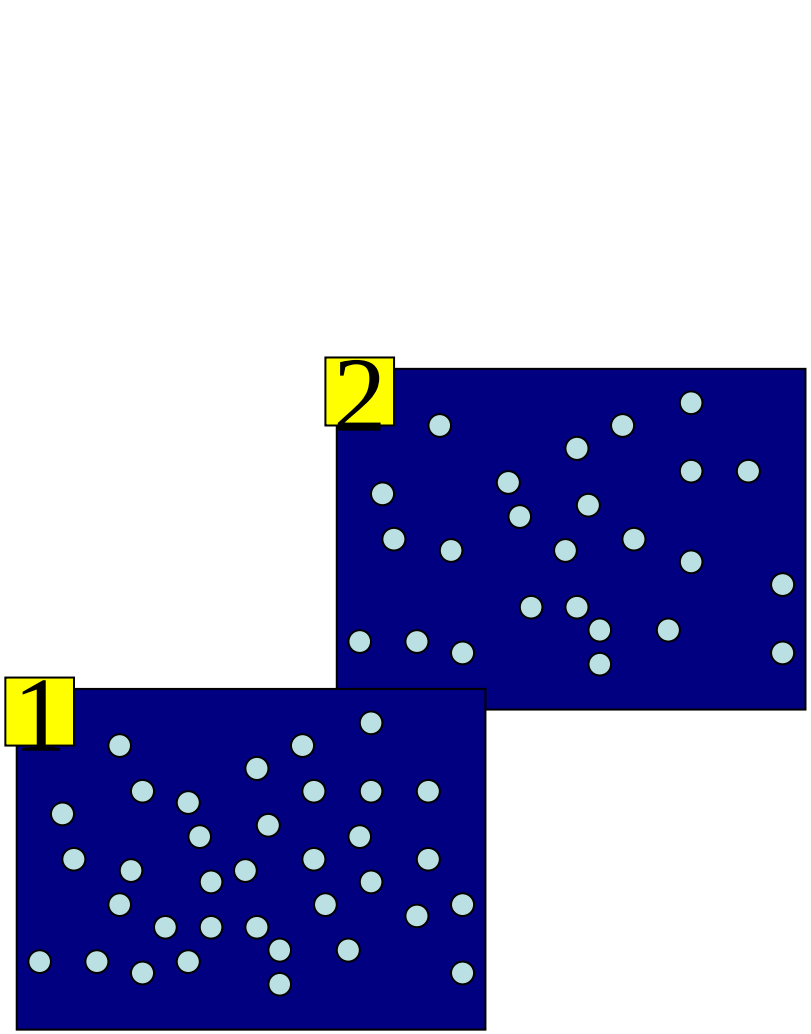
What can adults do with these large number representations?
Addition of visual arrays



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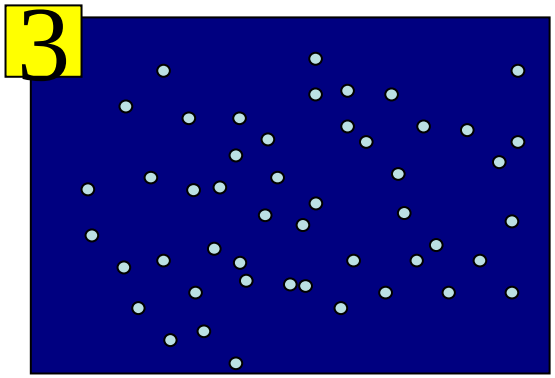
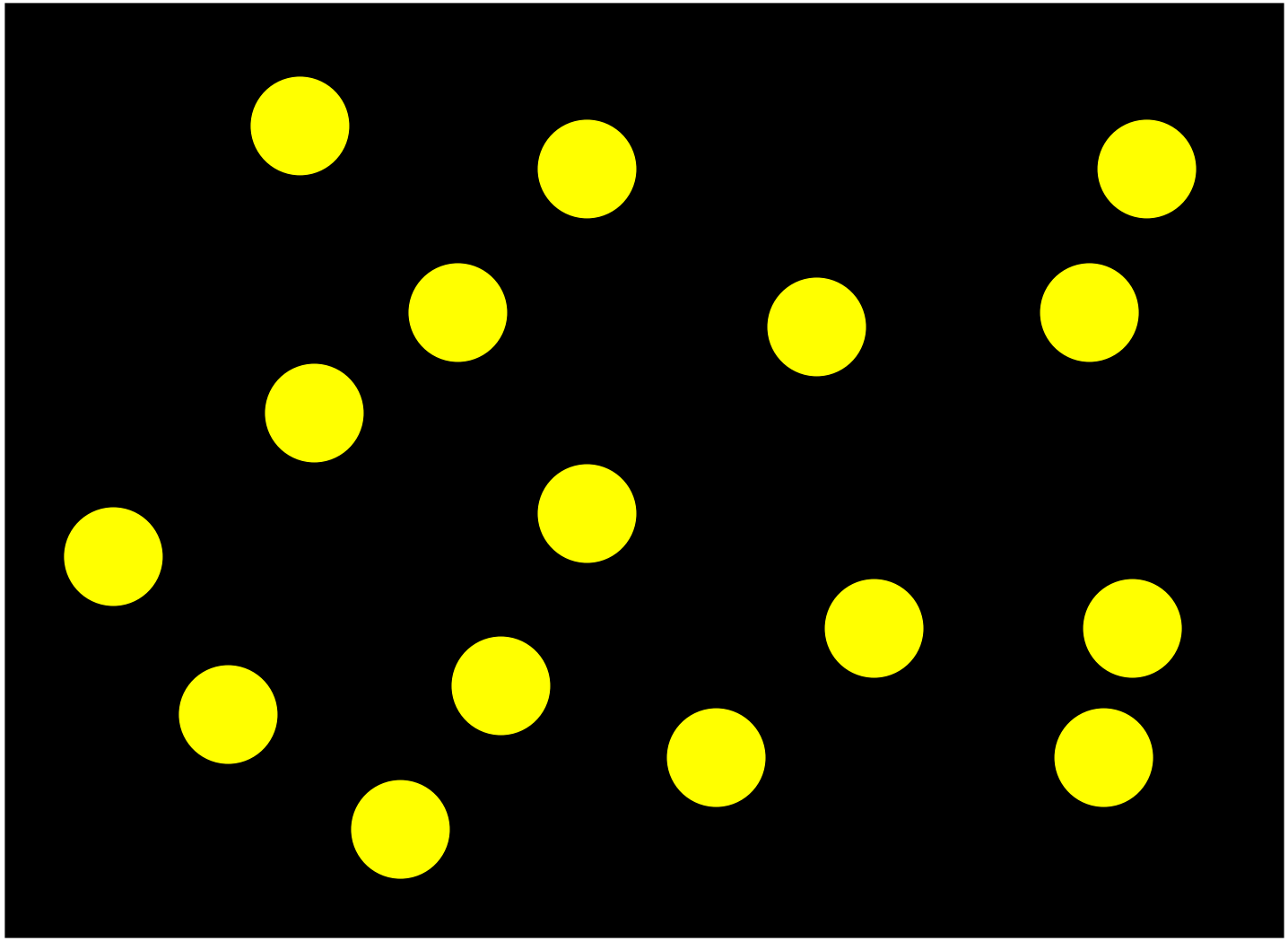
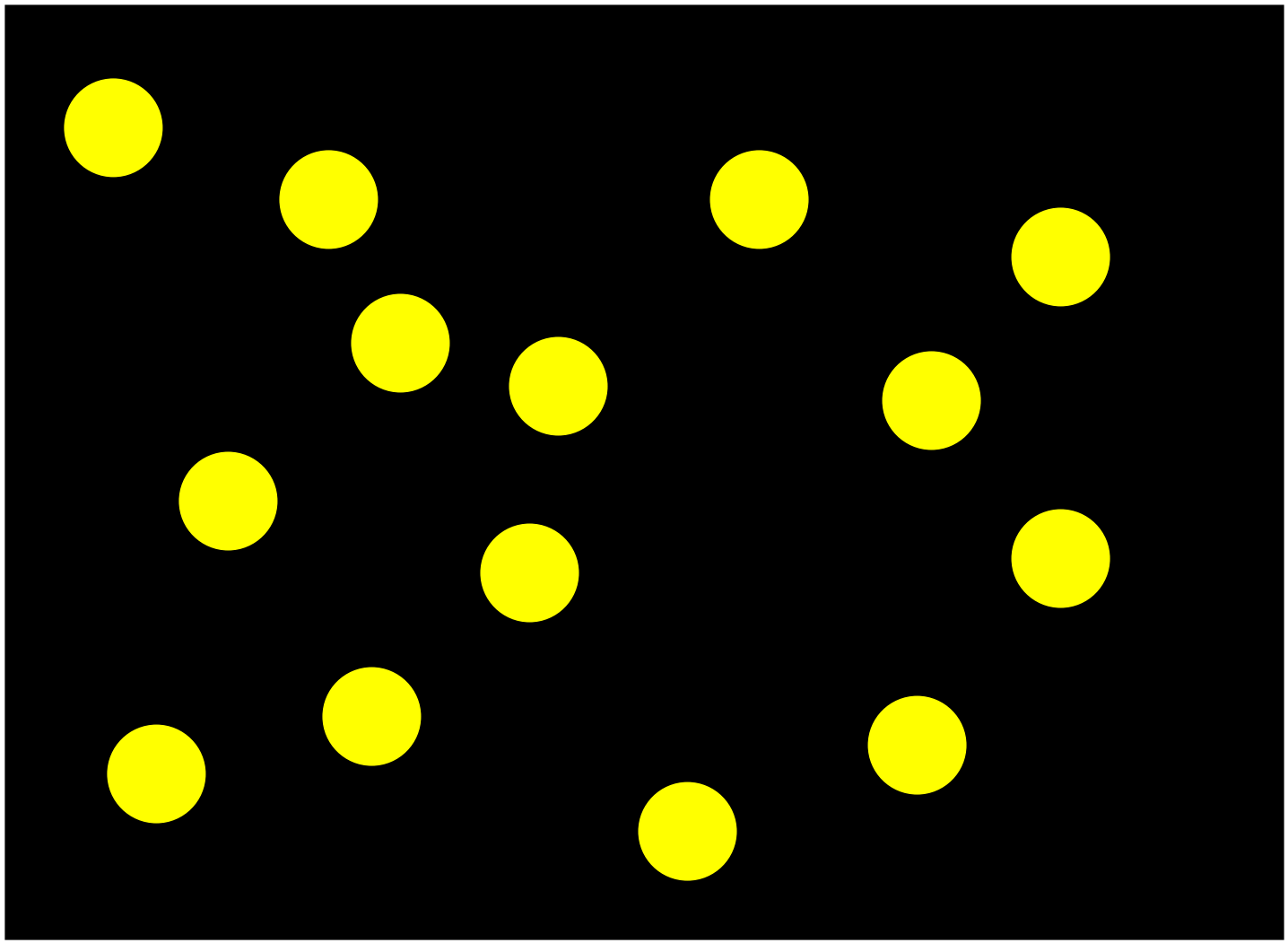


For example…

"Is the sum of 1 and 2 fewer or more than 3 ?"





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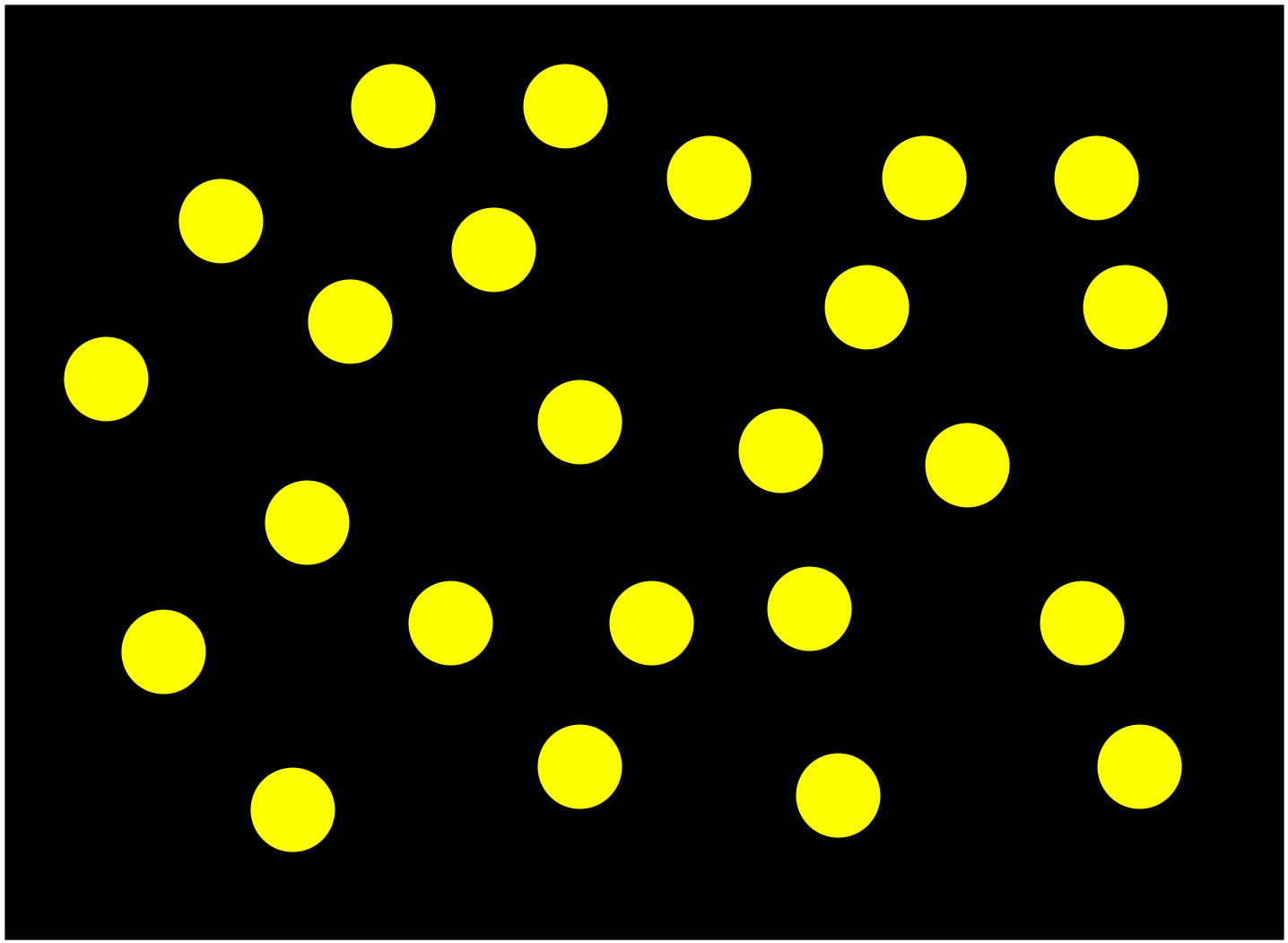
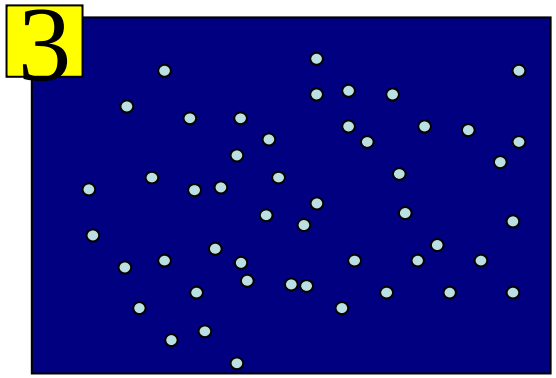


What can adults do with these large number representations?
Cross-modal addition



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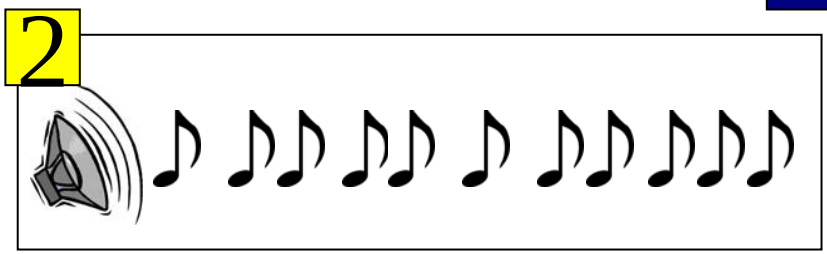
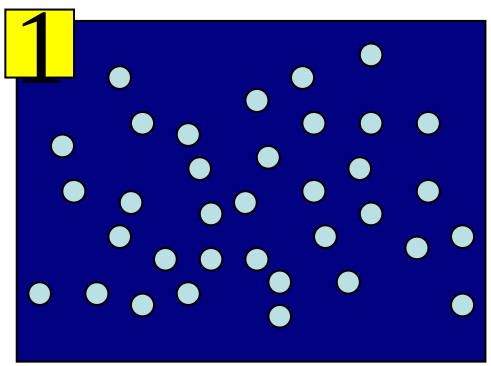
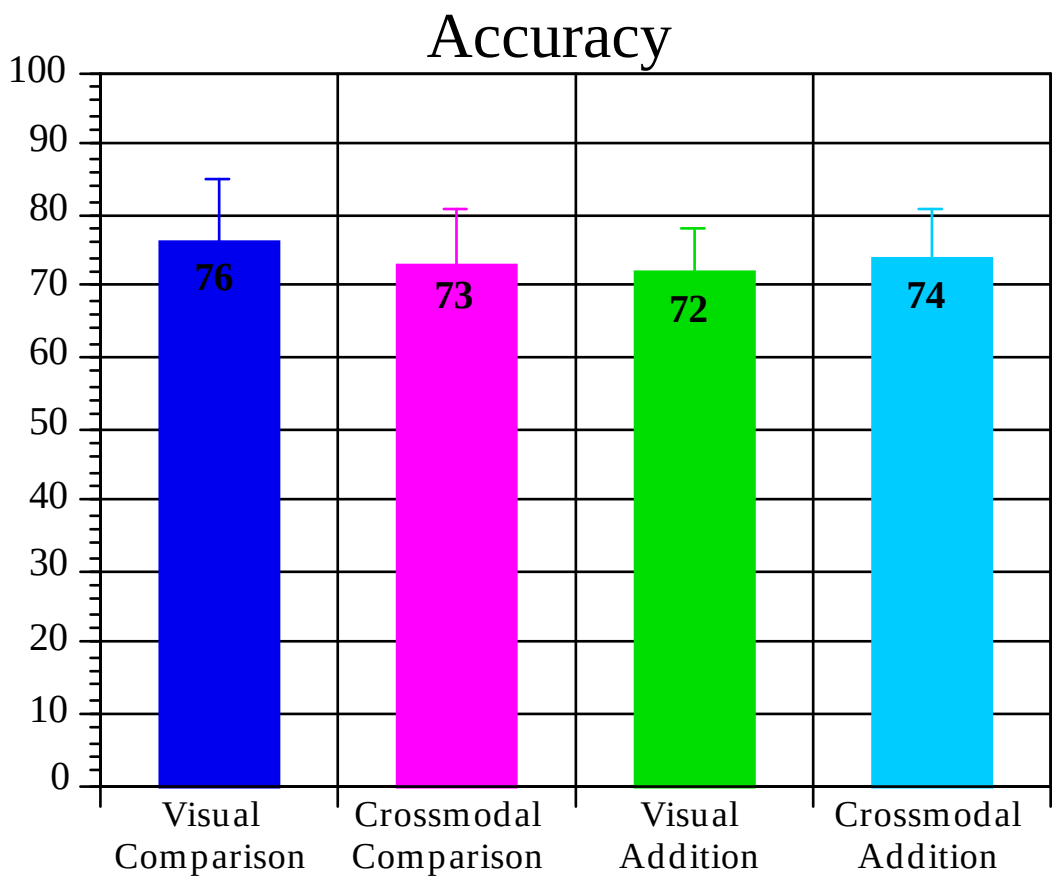




"Is the sum of 1 and 2 fewer or more than 3 ?"

Nonsymbolic Comparison and Addition



Barth (2001)

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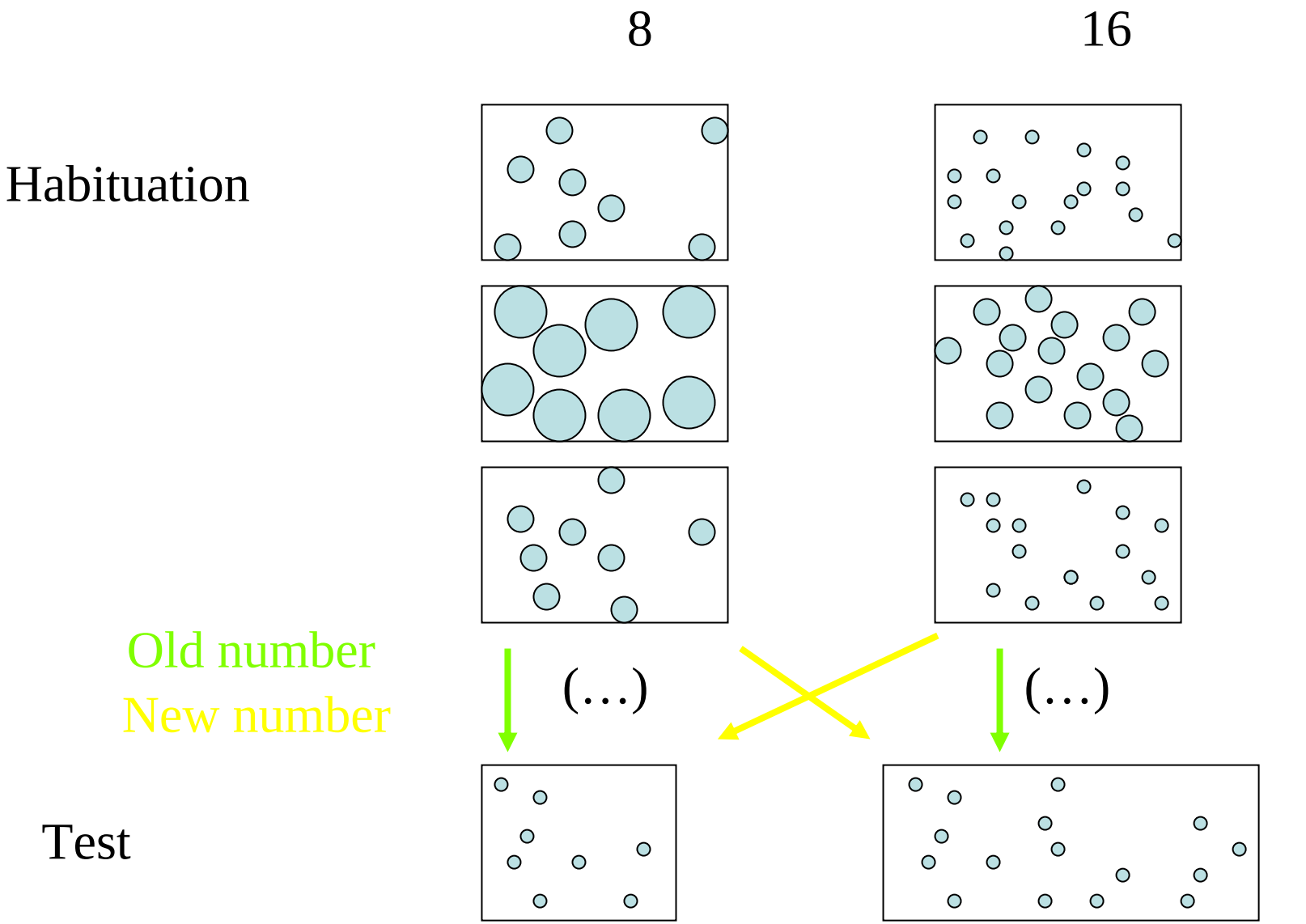
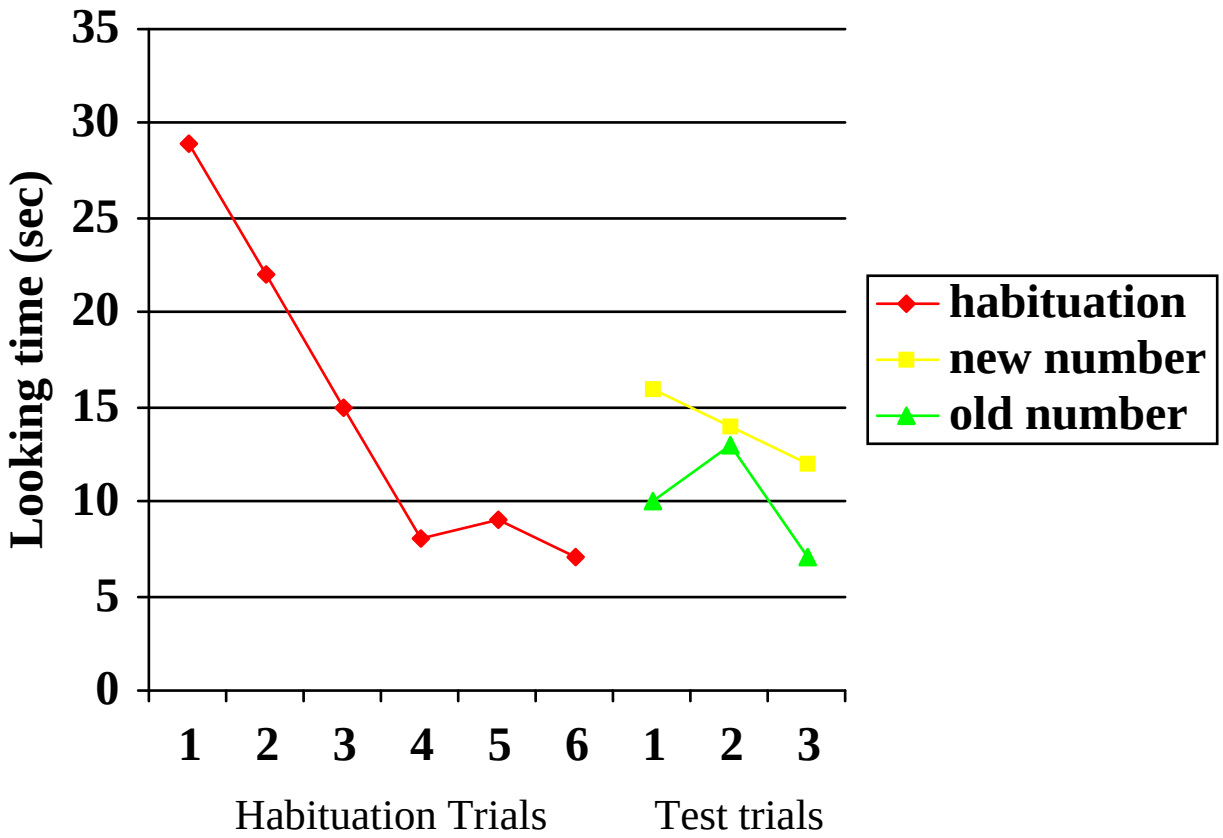
But: the people in these studies have spent years learning and using formal arithmetic. Do these abilities exist in infants? Animals?

Large number representations in infants



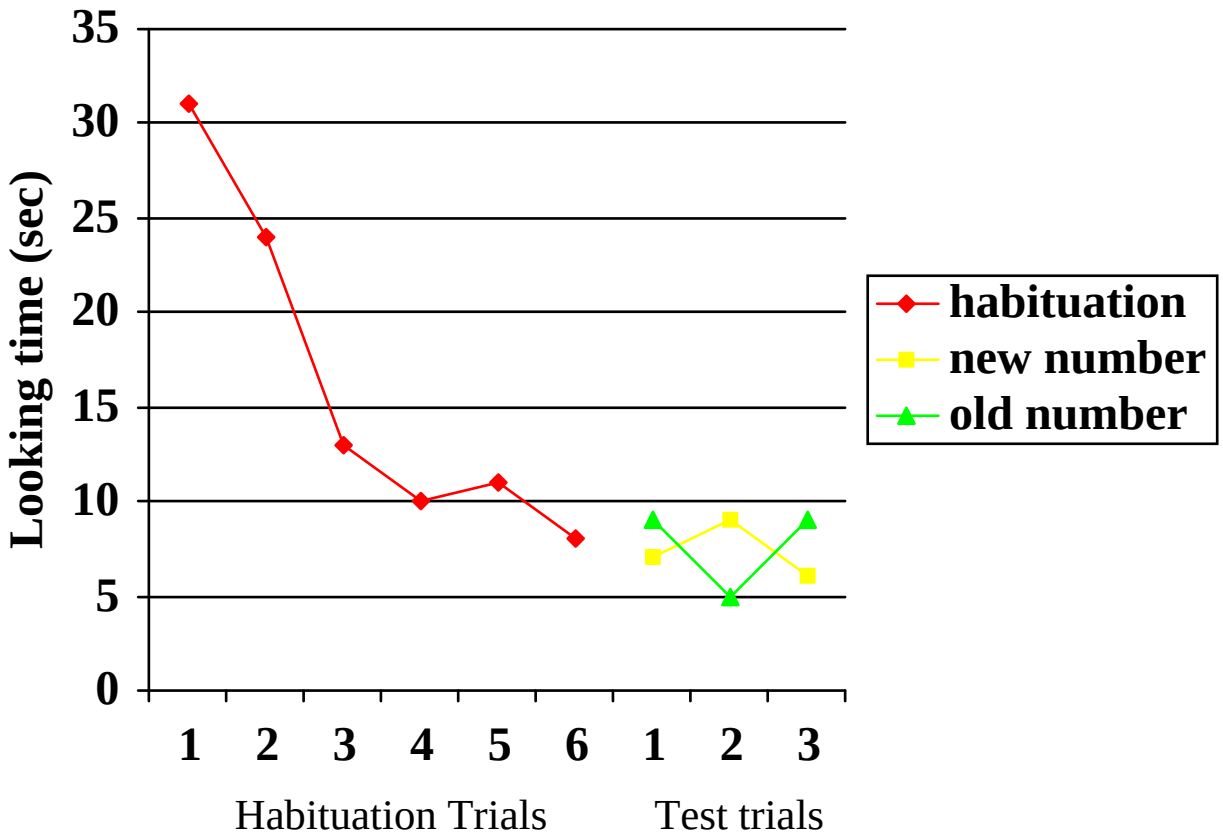
Xu & Spelke (2000)

Discriminating 8 vs. 16 dots at 6 months



Infants discriminate between large numerosities in dot arrays.

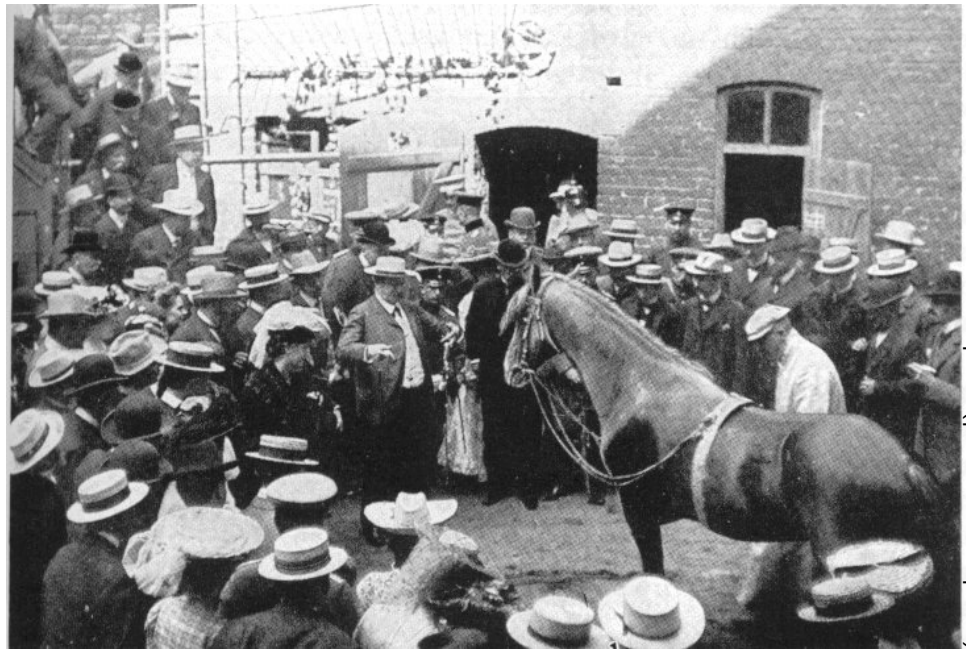
Discriminating 8 vs. 12 dots at 6 months



Infants' number representations are imprecise.

Large number representations in non-human animals

The case of Clever Hans

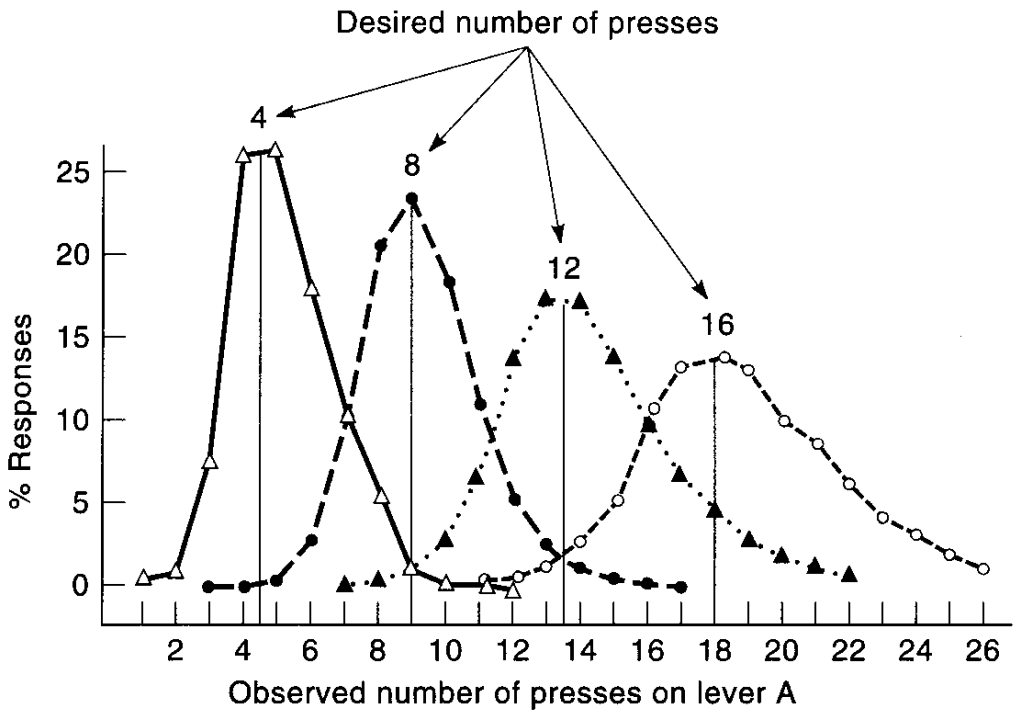


Source: Wikipedia (public domain photo).

Arguments against number representations in animals: what good is number?

- foraging? (continuous amount, not number)
- keeping track of offspring? (individual recognition, not number)

Large number representations in non-human animals: Evidence from rats (Mechner expts.)



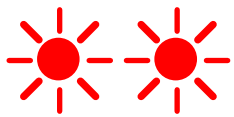
Rats represent the approximate number of presses.
Their representation of number accords with Weber's Law.

Mechner, F. "Probability relations within response sequences under ratio reinforcement." *Journal of the Experimental Analysis of Behavior* 16 (1958): 109-121.

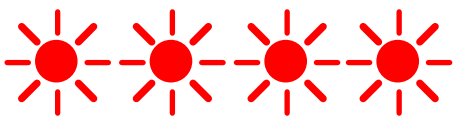
Church & Meck: abstract number in rats

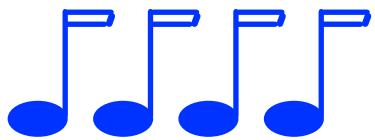
Training phase:

If 2 lights or 2 sounds press "2" lever



If 4 lights or 4 sounds press "4" lever

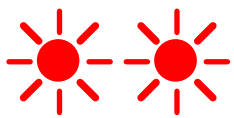


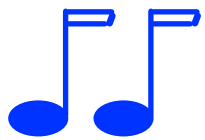


Church & Meck: abstract number in rats

Testing phase:

Present 2 lights AND 2 sounds





Rats press the "4" lever: spontaneous abstraction across modalities!

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But: the people in these studies have spent years learning and using formal arithmetic. Do these abilities exist in infants? Animals? *YES!*

They are part of our basic cognitive machinery.

I. Understanding approximate number

- Adults
- Infants
- Animals

II. Brain basis of number:

- neuropsychological patients
- fMRI: understanding approximate number

HUMAN PARIETAL CORTEX

Neuroanatomy

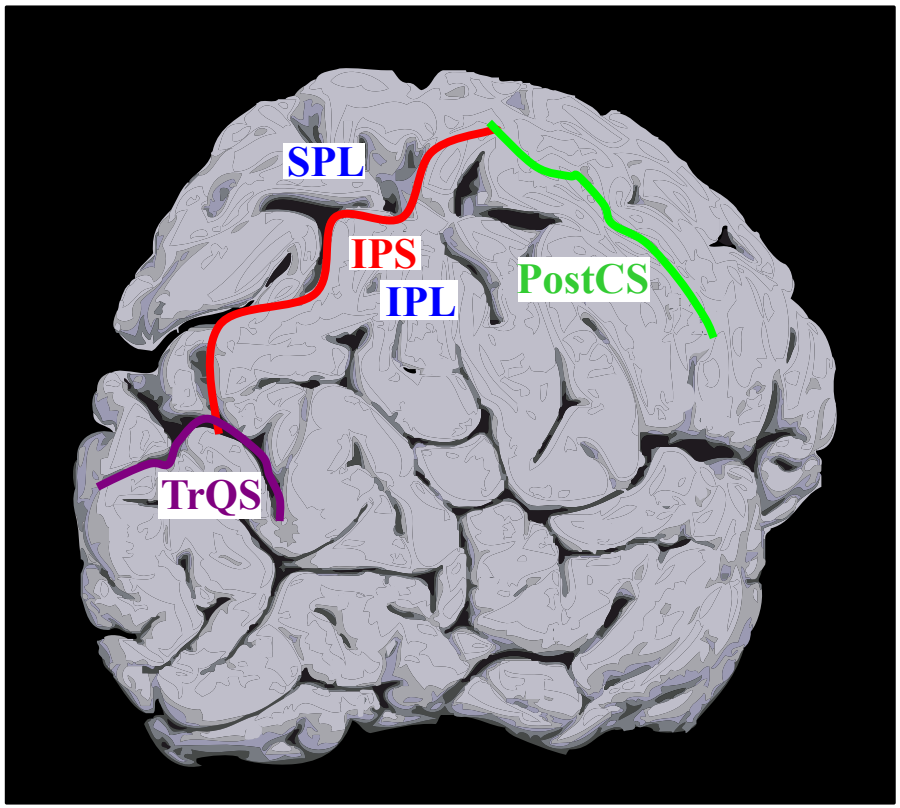


Figure by MIT OpenCourseWare.

Intraparietal sulcus (IPS)
divides superior (SPL) and inferior (IPL) parietal lobules

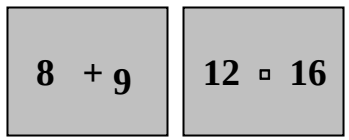
Neuropsychological Studies

- Lemer, Dehaene, Spelke, Cohen (2003):
  - One “acalculic” patient :
    - Left parietal lobe damage
    - Bad at approximation
    - More impaired on subtraction than multiplication
  - Another “acalculic” patient :
    - left temporal
    - Intact approximation
    - More imparied at multiplication than subtraction

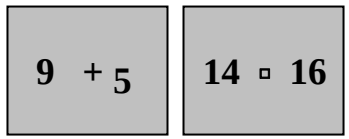
•Taken together, these two patients are a……..???

fMRI: Comparing “Approximate Vs. Exact” calculation (Dehaene et al, 1999)

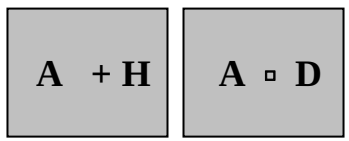
- Addition of Arabic Numerals
- Two versions:
- One control task:



Approximate



Exact



Letters

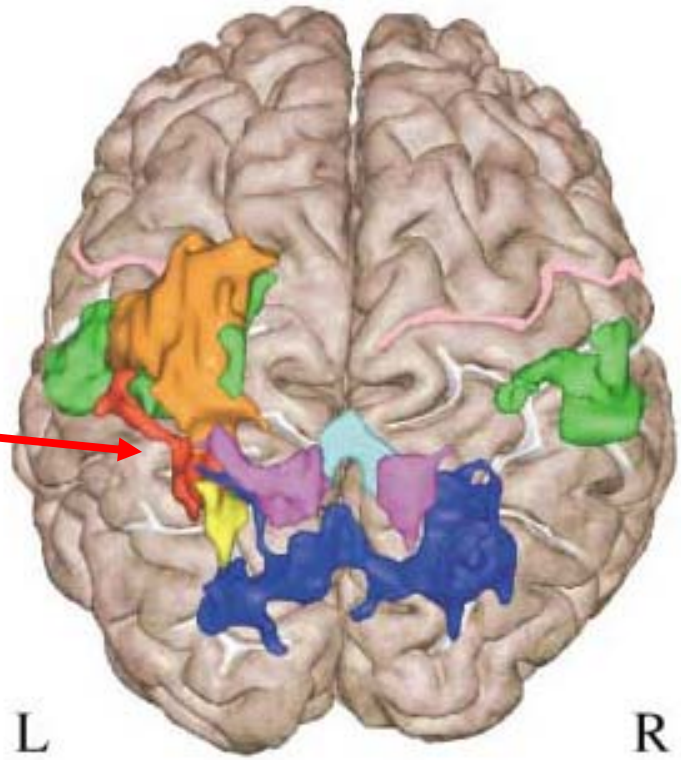
Image removed due to copyright restrictions.
Two MRI images from Fig. 3 in Dehane, S., et al. “Sources of Mathematical Thinking: Behavioral and Brain-Imaging Evidence.” *Science* 284, no. 5416 (1999): 970-974.

Dehaene-Spelke Results

- Approximate > exact activations (in yellow) in the intaparietal sulci, extending anteriorily to the depth of the postcentral sulcus and laterally into the inferior parietal lobule

Simon, Mangin, Cohen, Le Bihan & Dehaene, *Neuron*, 2002

"HIPS"



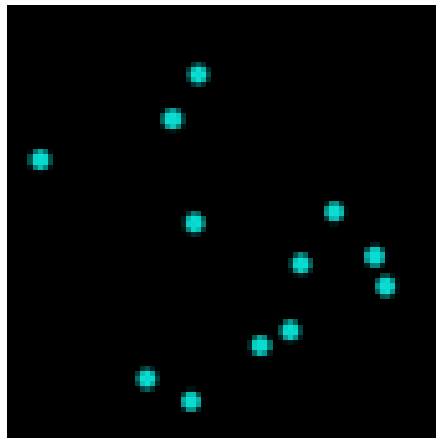
Claim: this parietal region is the approximate number system that has been characterized behaviorally.

But only tested with symbolic number.

Grasping only
Saccades only
Calculation only
Attention only
Manual tasks
Visuo-spatial tasks
Calculation, Saccades and Language

Shuman & Kanwisher (2004)

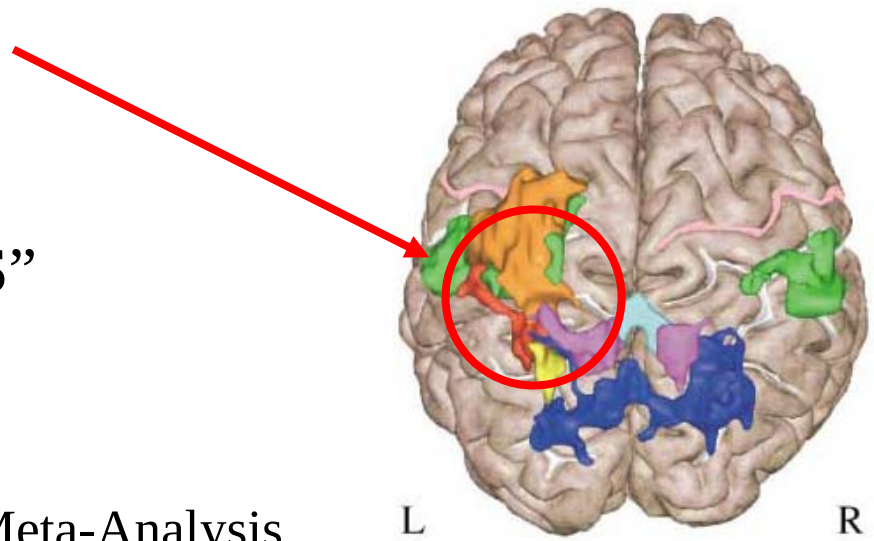
- Are these parietal regions engaged in processing abstract numerical magnitude?
  - Test using *non-symbolic* number:



- Are these parietal regions *selectively* engaged in processing numerical magnitude?

Design

- fMRI using 2 methods:
  - Task Manipulation
  - Adaptation
- ROI method: Look in “HIPS”

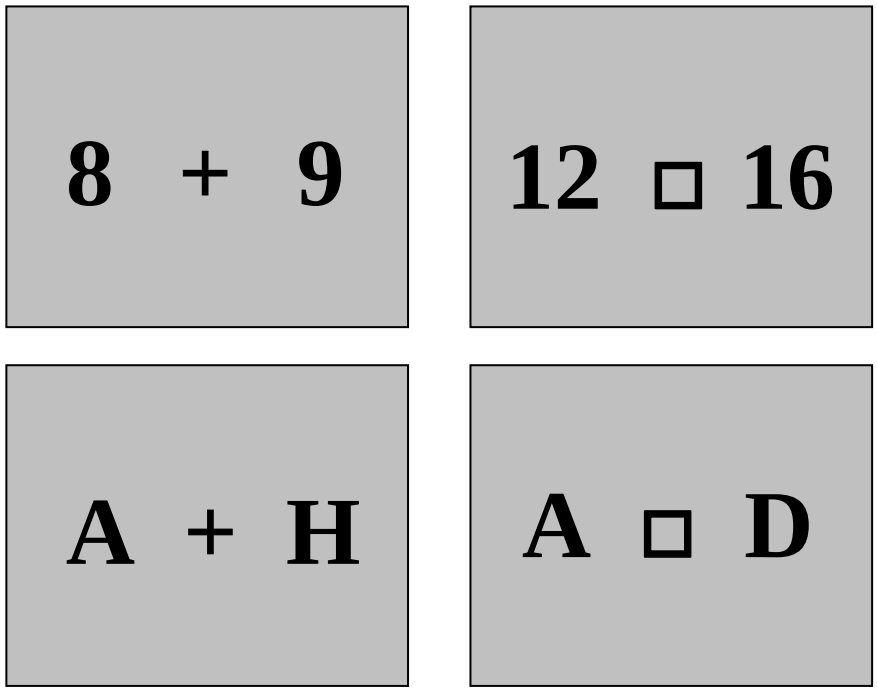


–Mean Coordinates from Meta-Analysis

–Individual, Functionally Defined ROIs

using Dehaene’s letter approximation task as a localizer

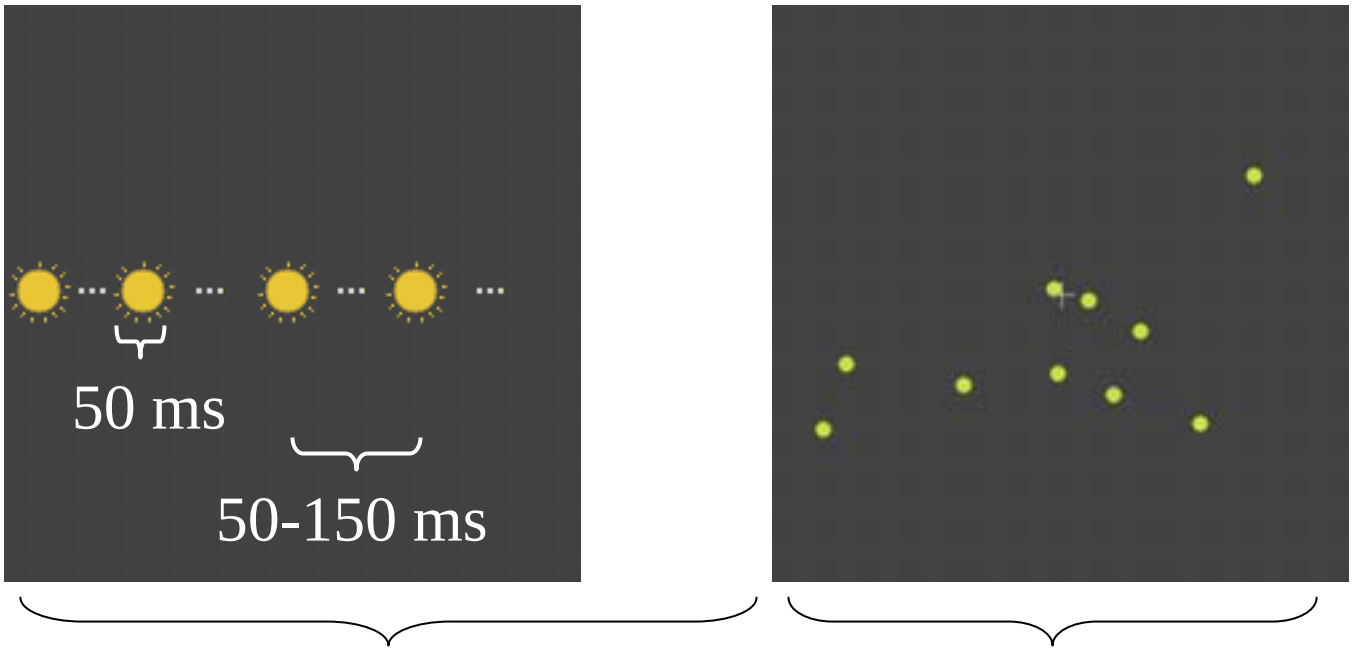
Localizer task: Dehaene et al, 1999, *Science*



Approximate Addition

Letter Comparison

Experiment 1: Task Manipulation

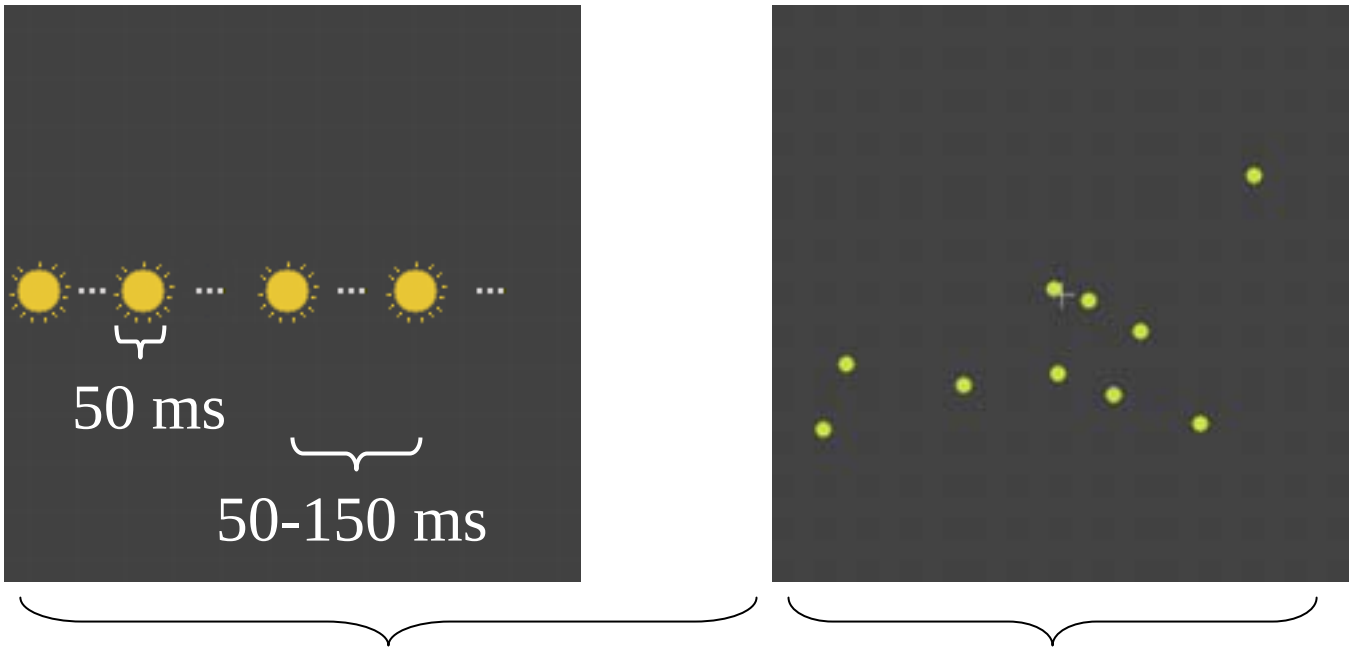


Number:
More Flashes or Dots?

OR

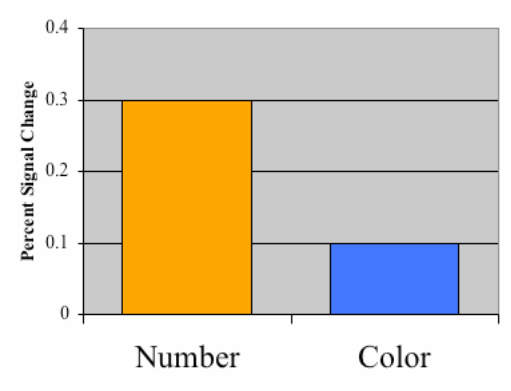
Color:
Same or different?

Experiment 1: Task Manipulation

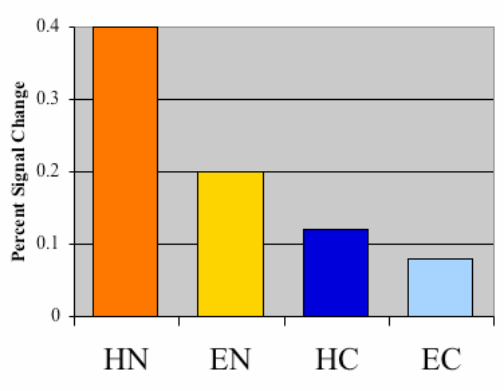


2 x 2 Design:
Difficulty (Hard / Easy) x Task (Number / Color)

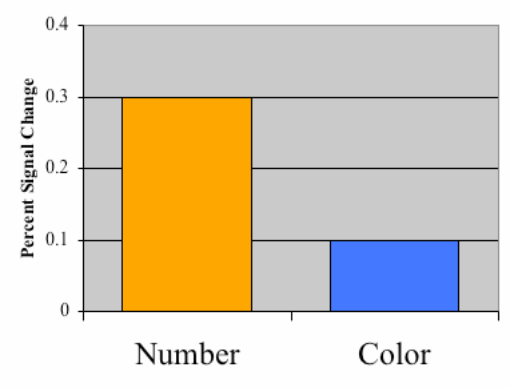
Predictions for a “number” region:

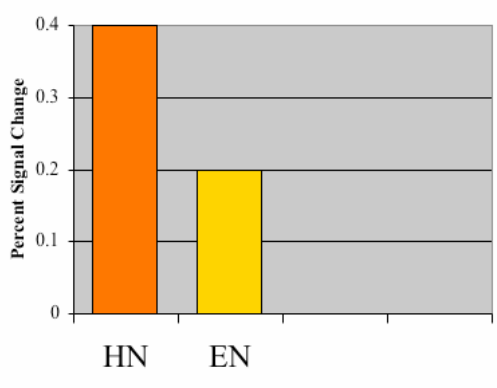


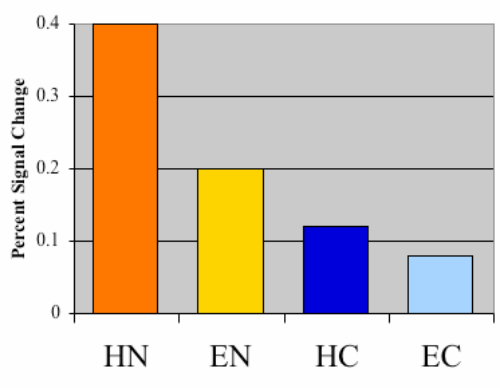
and



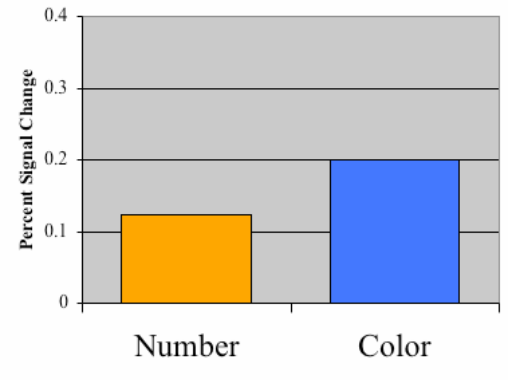
Predictions for a “number” region: :

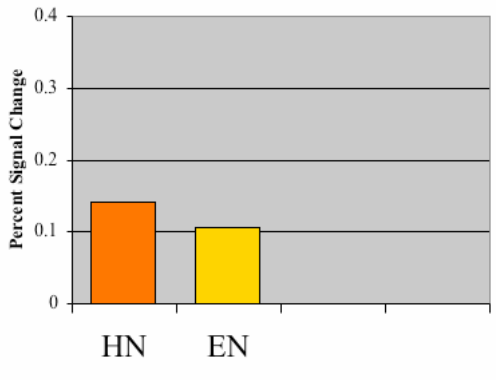


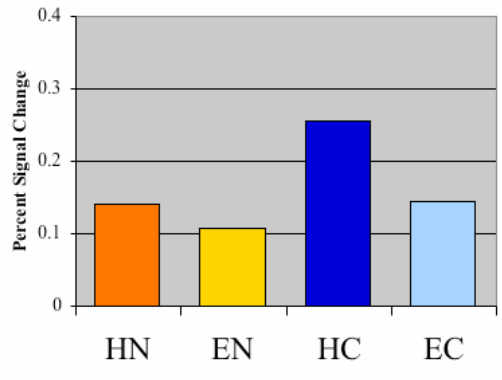




Results in HIPS:



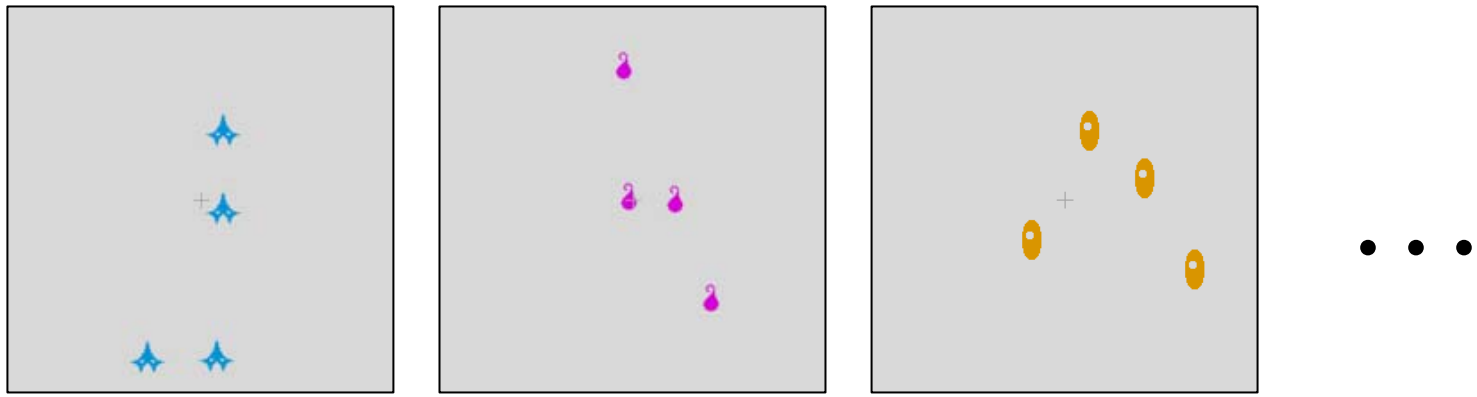




Doesn’t look like a number region.

Experiment 2: fMRI Adaptation

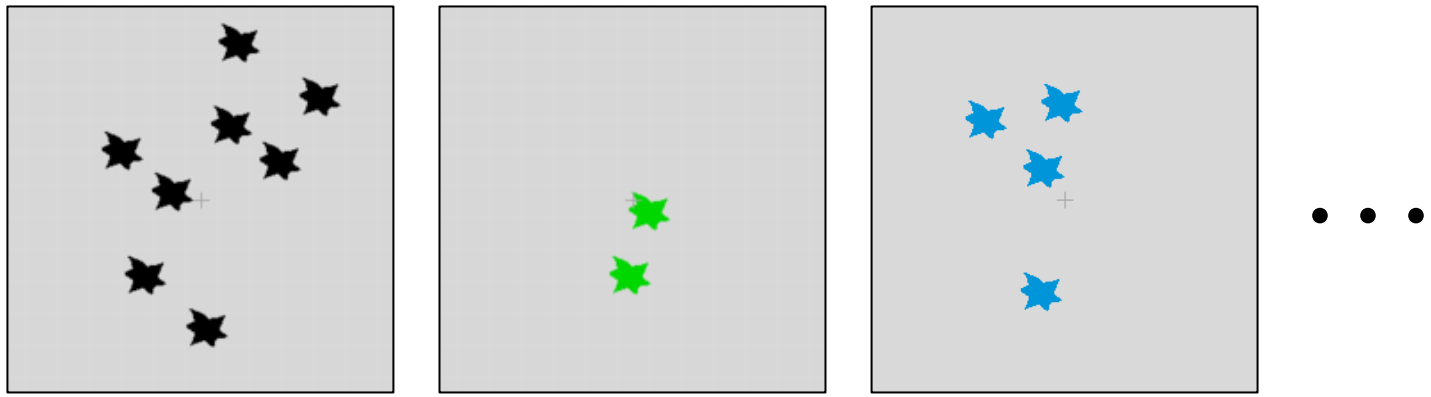
Experiment 2: fMRI Adaptation



Sequence of 16 different shape arrays
Blocked; task = Passive viewing or color ‘1-back’

	Shape Const	Shape Varies
Number Const		
Numb. Varies		

Experiment 2: fMRI Adaptation

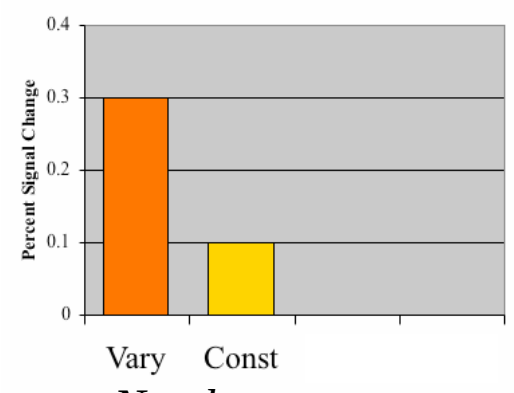


Sequence of 16 different shape arrays

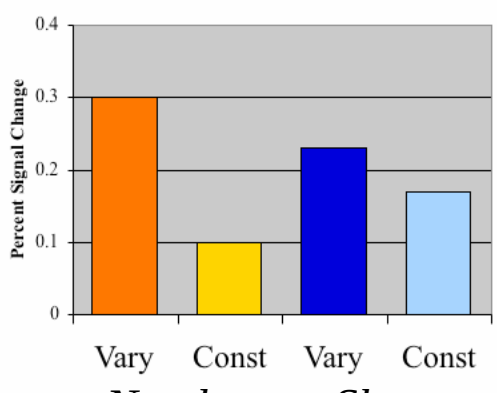
	Shape Const	Shape Varies
Number Const		
Numb. Varies		

Passive viewing or color ‘1-back’

Predictions:

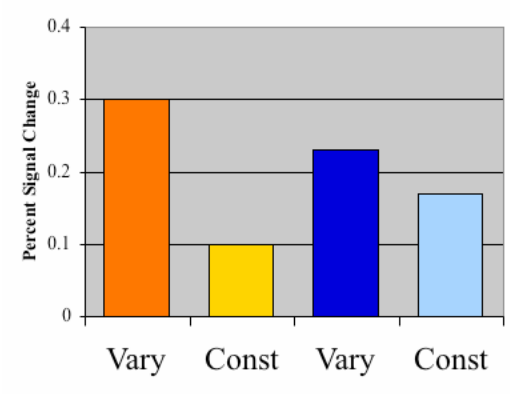


Number



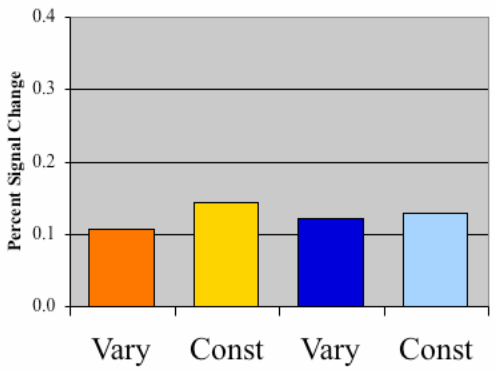
Number *Shape*

Predictions:



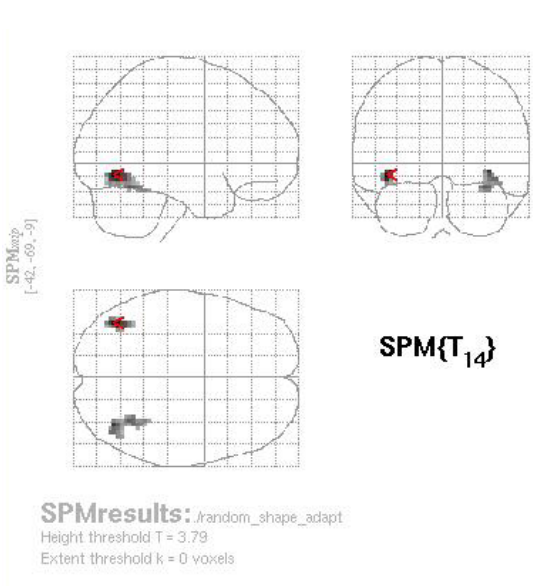
Number *Shape*

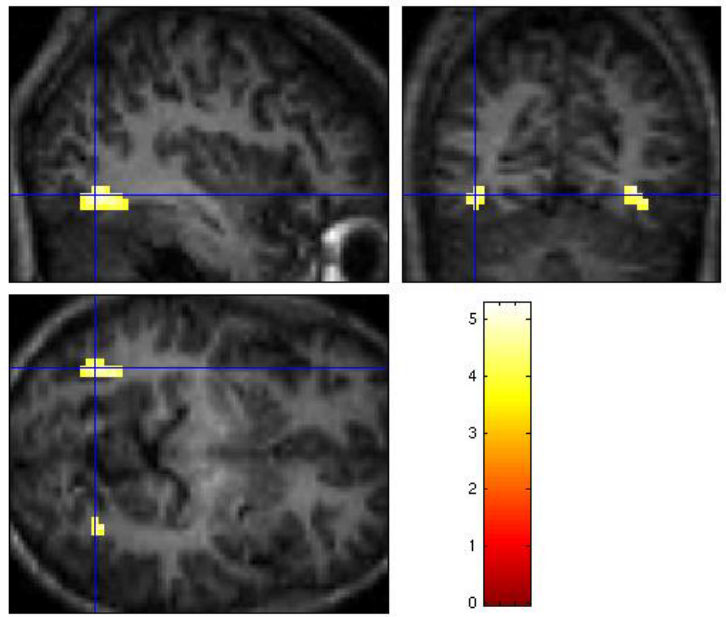
Results in HIPS:



Number *Shape*

Shape Adaptation in LO

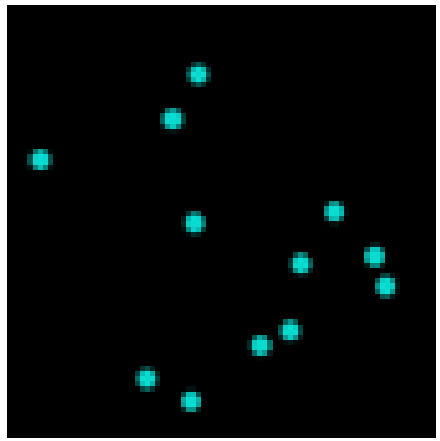




Courtesy of Susan Whitfield-Gabrieli. Used with permission.

Shuman & Kanwisher (2004)

- Are these parietal regions engaged in processing abstract numerical magnitude?
  - Test using *non-symbolic* number:



- Are these parietal regions *selectively* engaged in processing numerical magnitude?

No evidence in our data for parietal regions selectively engaged in processing number. But this debate goes on…..

Understanding Number: What is the evidence for these Claims?

- "animals, young infants, and adult humans possess a biologically determined, domain-specific representation of number"

- "a specific neural substrate, located in the left and right intraparietal area, is associated with knowledge of numbers and their relations ('number sense'). The number domain is a prime example where strong evidence points to an evolutionary endowment of abstract domain-specific knowledge in the brain because there are parallels between number processing in animals and humans."

–Dehaene, Dehaene-Lambertz & Cohen, TINS, 1998