Université catholique de Louvain UCL

Dyscalculia: from brain to education

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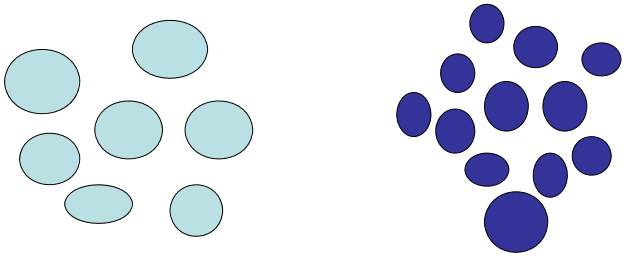
London

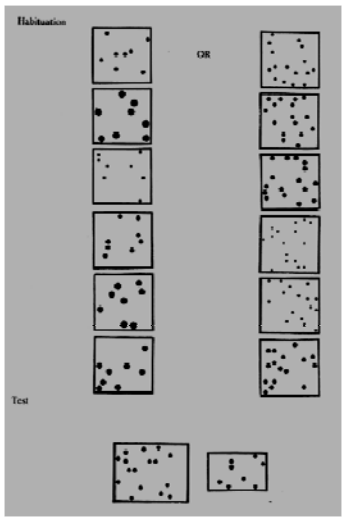
A brain made for numbers ?

- Which collection is larger ?

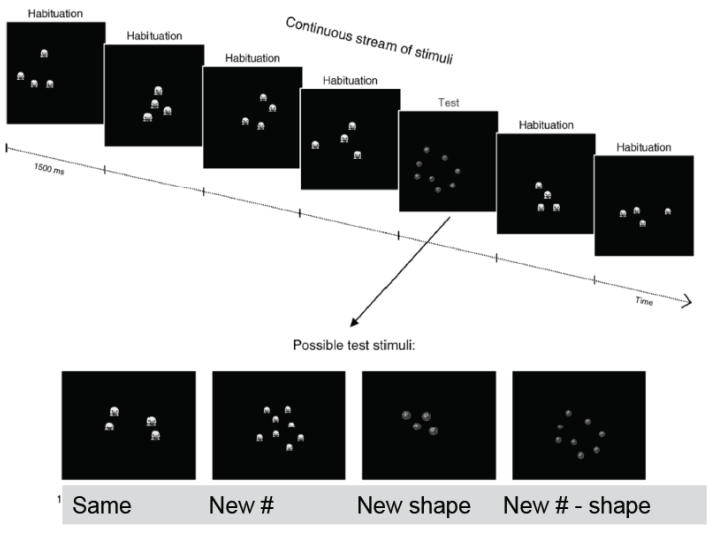


Babies

- 6 month-old babies
  - Discriminate 8 vs. 16,
  - but not 8 vs. 12,
  - Can discriminate 16 vs. 32
  - But Ratio of 1:2
- 9 month-old babies
  - 16 vs. 24
  - Ratio 2:3

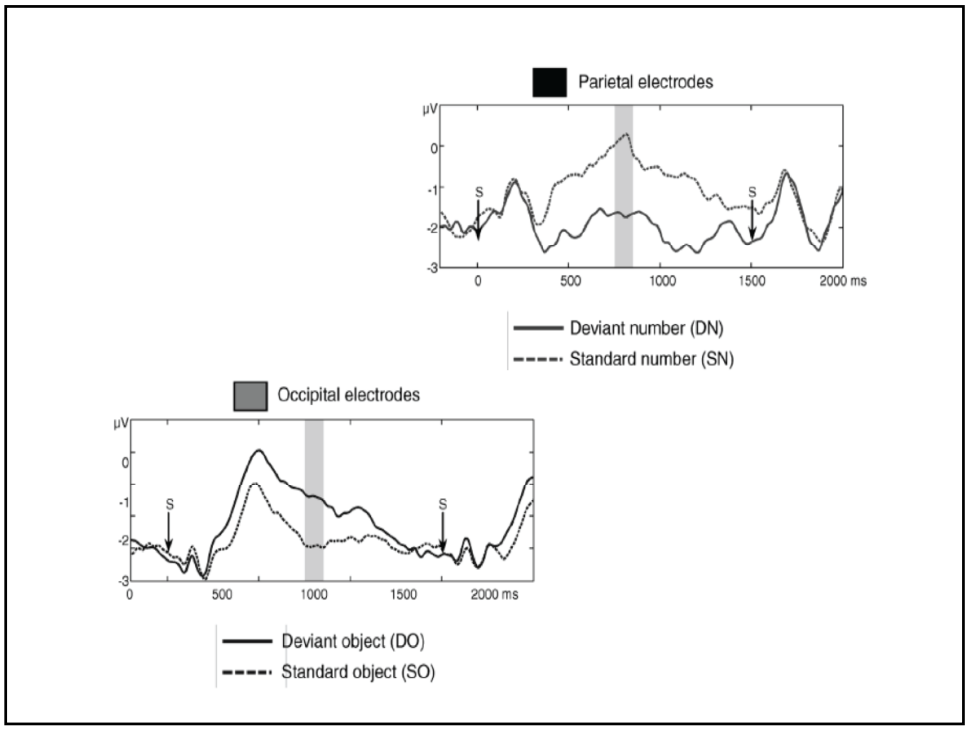


Xu & Spelke, 2000; Xu & Ariaga, 2007



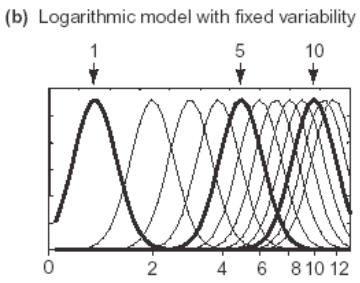
- 3 months-old babies
- evoked potentials

Izard, Dehaene & al., 2008

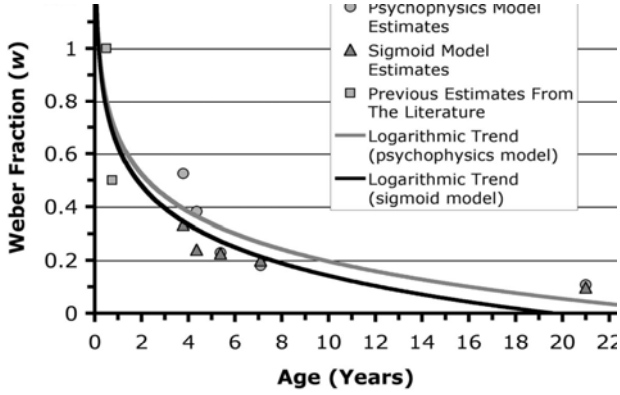


Children & adults

- Also a performance that varies with the ratio between the 2 collections
- => an approximate representation of number magnitude



Number acuity (w) or the smallest discriminable ratio
Ratio n1/n2 => w = n2-n1/n1



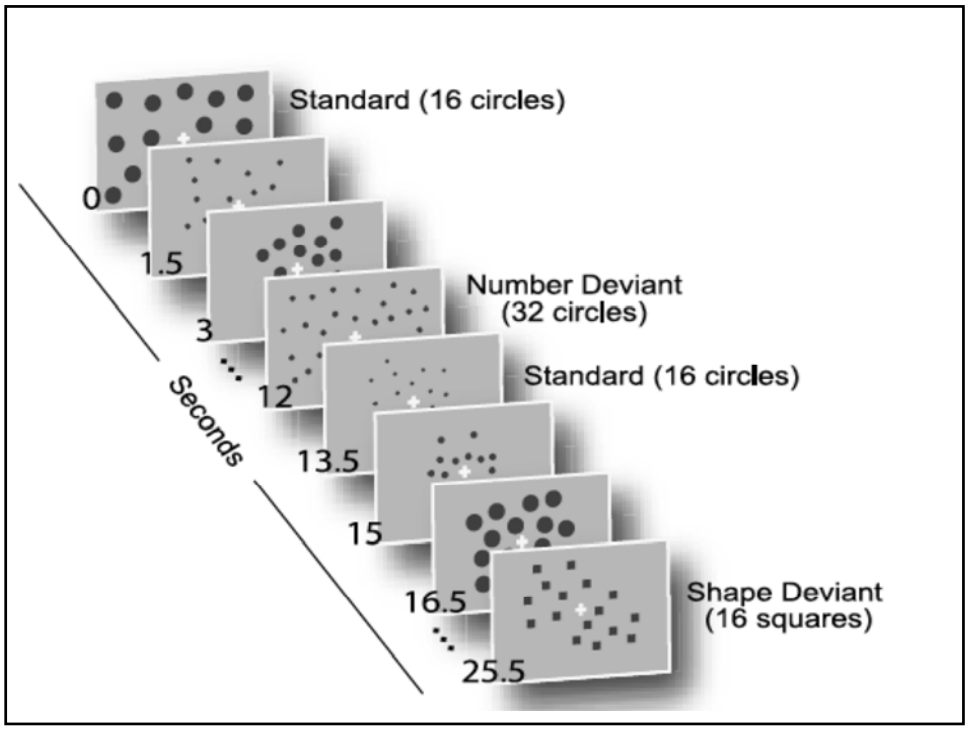
increasing precision over development

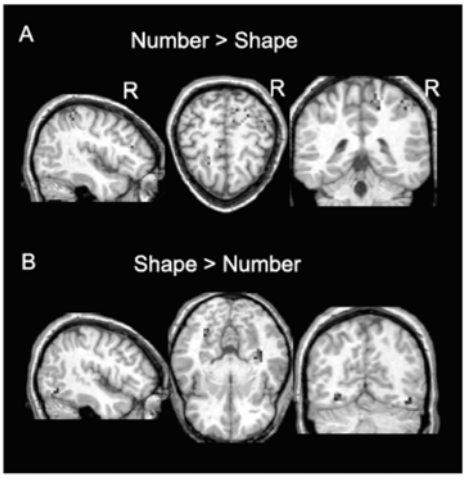
Halberda, Feigneson, 2008, Devlp Psych

Cerebral bases in children

- Habituation paradigm with deviant stimulus, either
  - numerically deviant or
  - shape deviant
- 4 y.o. children
- IRMf

Cantlon, Branon, 2006





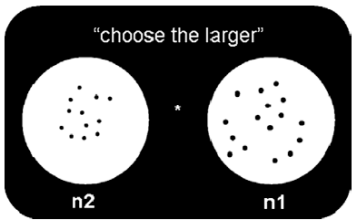
- Right intraparietal sulcus reacts to numerical change
- Similar regions as those observed in adults

Developmental dyscalculia

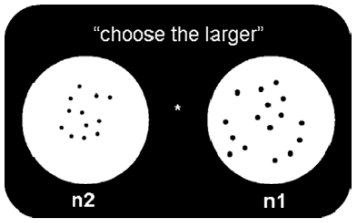
- Persistent and specific disorder of numerical development and mathematical learning
  - In the context of normal intelligence, normal schooling
  - Not due to sensory deficit
- Gross-Tsur et al. (1996):
  - 3029 4th grade children in Israel
  - Normal intelligence but two years behind in math
  - 6.5 % of the children are dyscalculics

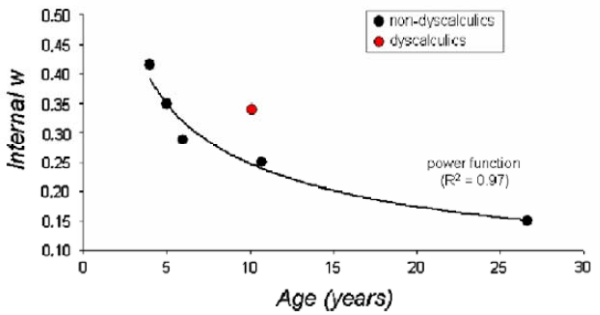
Dyscalculia: a problem in the approximate magnitude representation ?

- Weaker number acuity ?



- Population
  - children from age 3 to 6
  - MLD children (10 y.o.)
  - control children (10 y.o.)
  - 20 adults

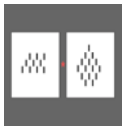




Piazza, M., Facoetti, A., & al, Cognition, 2010

But divergent results

- Population
  - 45 children with Math Learning Disability (7 y.o.)
  - 45 control children (7 y.o.)
- Tasks
  - Non-symbolic



Easy condition

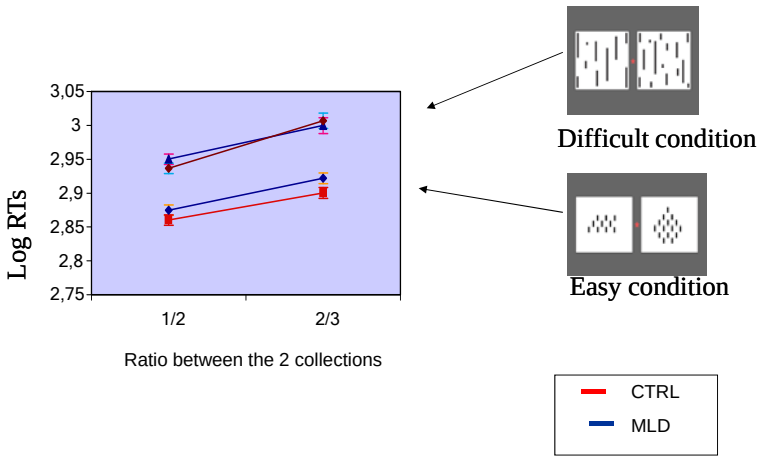
Difficult condition

symbolic

2 5

Rousselle & Noël, 2007, *Cognition*

collections comparaison



Divergent results

	age	Non-symbolic
De Smedt & Gilmore (2011)	6 years old	DC=C
Rousselle & Noël (2007)	7 years old	DC=C
Landerl & al. (2004)	8-9 years old	-
Iuculano et al. (2008)	8-9 years old	DC=C
Piazza & al. (2010)	10 years old	DC<C
Mussolin, Mejias & Noel (2010)	10-11 years old	DC<C
Price & Ansari (2007)	12 years old	DC<C

Weaker performance only in older DC
We should look for a more primitive deficit

What is specific to human numerical cognition ?

- Not the detection of / discrimination between numerosities (monkeys, rats, dolphin can do it)
- The use of symbols to refer to numbers
  - Number words: *one, two, three, four ...*
  - Arabic numbers: *1, 2, 3, ...*

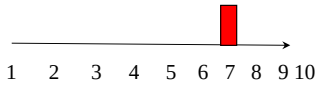
Learning numerical symbols

- 1/ learn the sequence of verbal numbers
- 2/ discover the cardinal meaning of each number words
  - The “give me task”
    - Slow process
    - Sequential

- For children who can count *one, two, three, four, five, six, seven, eight* ...
- Give me
  - *One*: ± 36 months old
  - *One, two*: ± 38 months old
  - *One, two, three*: ±42 months old
  - *One, two, three, four* and all the other numbers of their counting list: ±44 months old

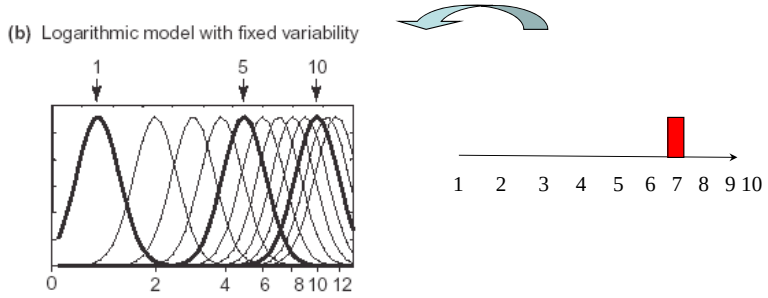
Wynn, 1992; Sarnecka & Carey, 2008

- Slow process because the child needs to build a new representation
  - exact
  - based on the successive function
    - The cardinal meaning of *n* = the cardinal of the preceding number in the counting list + 1



Sarnecka & Carey, 2008

- Then connect the cardinal meaning of number words to the approximate magnitude representation of sets



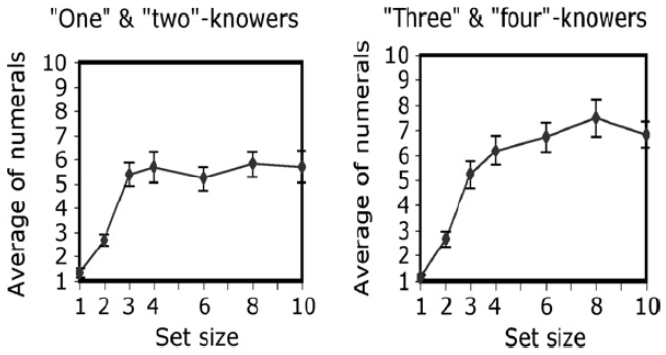
Mapping symbols to approximate magnitude of sets

- Estimate without counting (1 s.) the number of dots (1 to 15)
- 116 children from 3 to 5 y.o.
- All accurate in counting a list of 10 items
- give me task
  - 42 **Subset knowers**
    - 6 one-knowers
    - 14 two-knowers
    - 18 three-knowers
    - 4 four-konwers
  - 71 **CP knowers**

Le Corre & Carey, 2007, *Cognition*

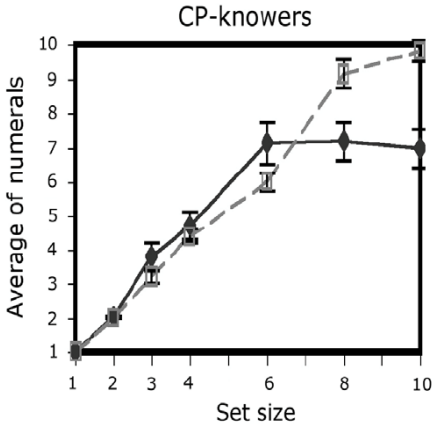
Mapping symbols to approximate magnitude of sets

– For the subset knowers, beyond the # they know, the curve is flat



Le Corre & Carey, 2007, *Cognition*

- For the CP knowers, two groups emerge:
  - flat curve : **CP knowers non-mappers**
  - curve increasing with the size of the target: **CP knowers non-mappers**



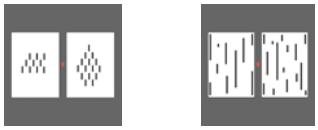
Le Corre & Carey, 2007, *Cognition*

- First learning the cardinal meaning of number words
- Then, mapping number words to approximate magnitude of sets

Dyscalculia: a problem with the magnitude representation of symbolic numbers ?

- No one studied the fate of the young children who are slow in learning the cardinal meaning of number words
- But several studies used magnitude comparisons of Arabic numbers

- Population
  - 45 children with Math Learning Disability (7 y.o.)
  - 45 control children (7 y.o.)
- Tasks
  - Non-symbolic symbolic

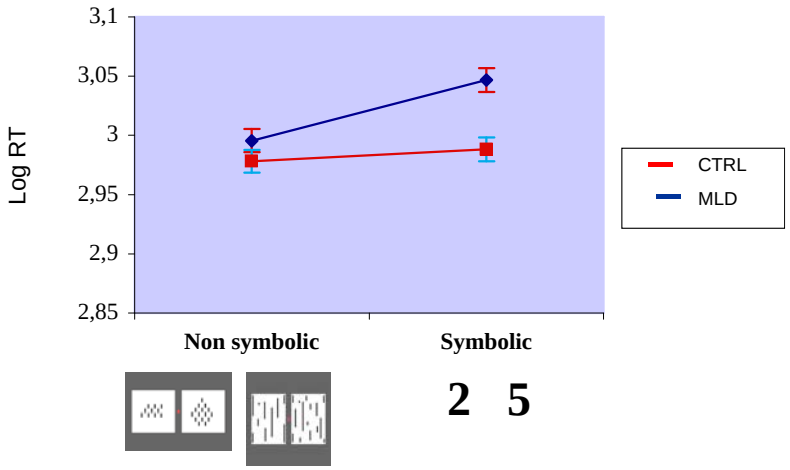


Easy condition

Difficult condition

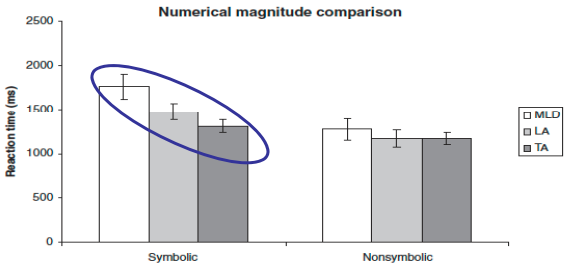
2 5

Rousselle & Noël, 2007, *Cognition*



Replication of the results

- First grade children
  - 41 who are typical achievers (TA)
  - 21 low in math (pc 16-25: LA)
  - 20 with math learning disability (< pc 16: MLD)



Arabic digits (1-9) collections

De Smedt & Gilmore, 2011, JECP

An early and stable deficit of processing magnitude of symbolic numbers

	age	symbolic	Non-symbolic
De Smedt & Gilmore (2011)	6 y.o.	MLD<C	MLD=C
Rousselle & Noël (2007)	7 y.o.	MLD<C	MLD=C
Landerl & al. (2004)	8-9 y.o.	MLD<C	-
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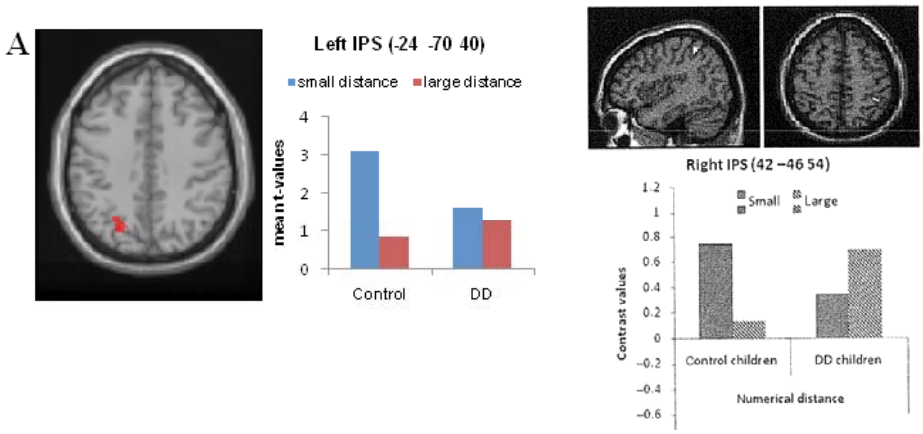
Piazza	10 y.o.	-	MLD<C
Mussolin, Mejias & Noel (2010)	10-11 y.o.	MLD<C	MLD<C
Price & Ansari (2007)	12 y.o.	-	MLD<C

Brain activity of dyscalculic children

- 15 dyscalculic children (mean age of 10 y.o.) and 18 control children (same age)
- Compare the magnitude of 2 Arabic digits: select the bigger
  - 5-6: small distance: harder
  - 2-7: large distance: easier

Mussolin, De Volder, . & Noël, 2010, J of Cog Neurosc



Higher activation of the left and right intraparietal sulci for close pairs than for distant pairs in control children but not in DC children

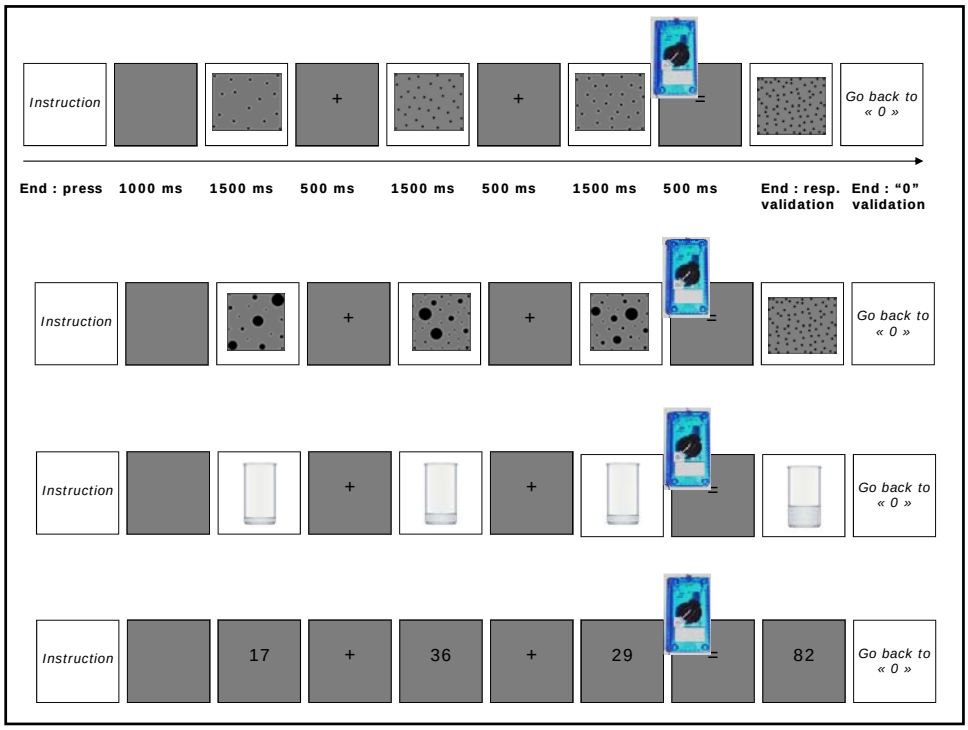
Mussolin, De Volder, . & Noël, 2010, J of Cog Neurosc

What is the fate of MLD children ?

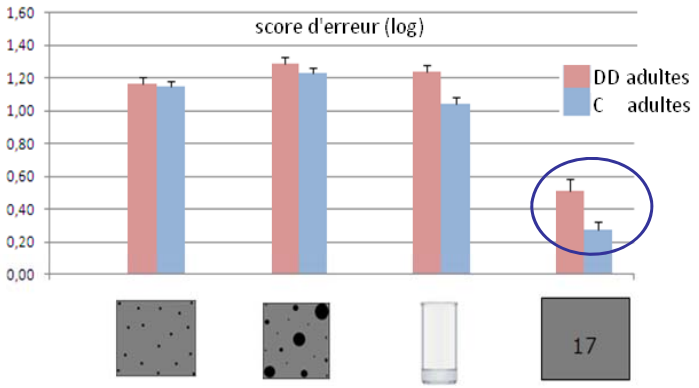
- Many difficulties in exact calculation
- Just a difficulty in doing the calculation procedure or in accessing the magnitude of the calculation ?
- A global problem or only when symbolic numbers are used ?

- 17 adults who were MLD (25±10 y.o.)
- 17 adults control, same age, same studies or profession
  - Global math battery
    - Error rate: MLD (20±11) > CTR (6±5): t(32)=4.95**
    - RT: MLD (1235±370 s) > CTR (755±284s): t(32)=4.24**

Mejias, Gregoire & Noël, *submitted*



Score of imprecision
Log AES = log | estimate - target |



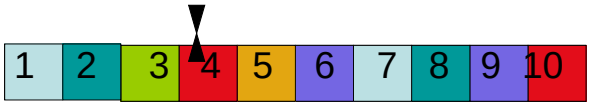
Mejias, Gregoire & Noël, *submitted*

How can we improve the magnitude representation of symbolic numbers ?

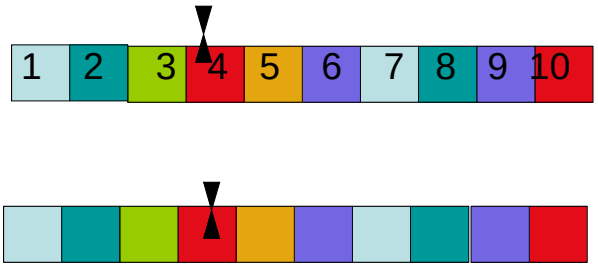
- Use of the space metaphor: the number line

For small numbers: the number board game

- Number board game
  - 4 y.o. Children (unselected)
  - 5 sessions of 15-20 minutes

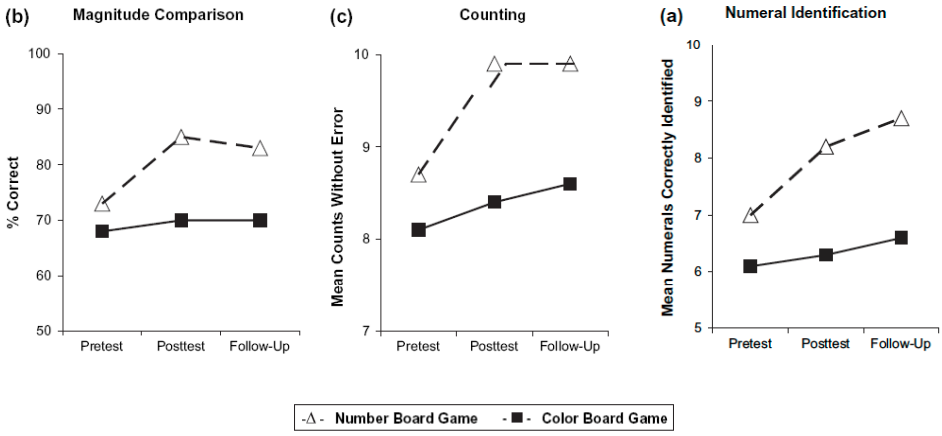


Ramani & Siegler, 2008



- Comparing the number board game & the colour game
- Baseline:
  - comparing the magnitude of two digits (1-9)
  - Counting from 1 to 10
  - Naming Arabic digits

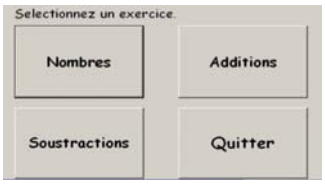
Ramani & Siegler, 2008

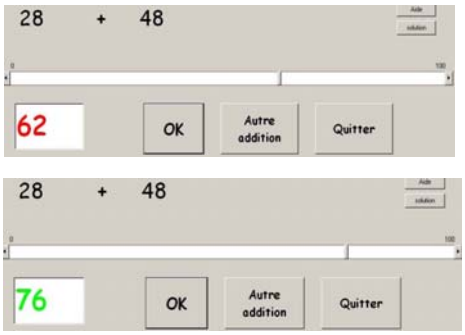


Ramani & Siegler, 2008

For larger numbers in the context of arithmetical operations

The estimator

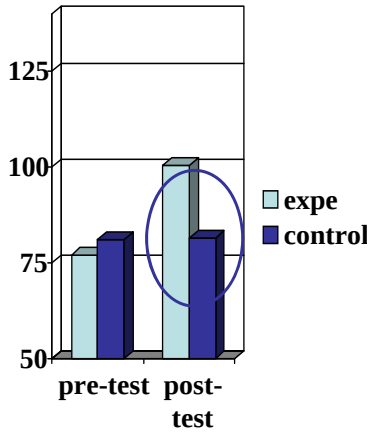




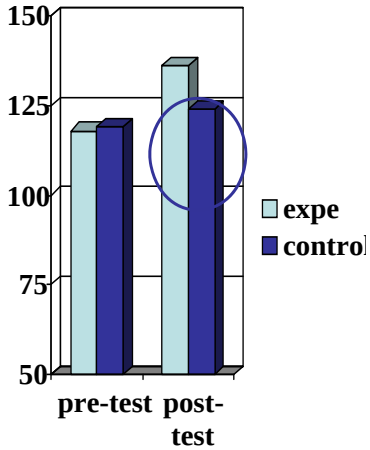
Vilette, Mawart & Rusinek, 2010

- Method
  - 20 children, 11 y.o., 2 years behind in math
  - 2 groups
    - Expe group: uses the estimator + and -
    - Control group: uses another computer program on the same calculations but which only requires exact answers
  - 7 sessions of 30'
  - Baseline: Zareki-R

Vilette, Mawart & Rusinek, 2010

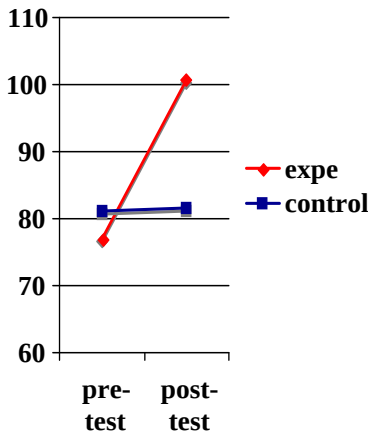


SN on Additions-subtractions



Total SN score on the Zareki battery

Vilette, Mawart & Rusinek, 2010



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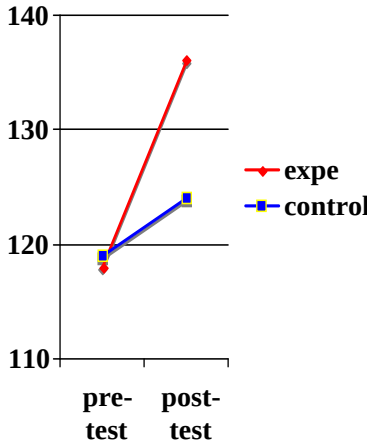
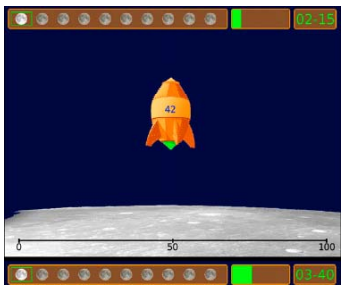


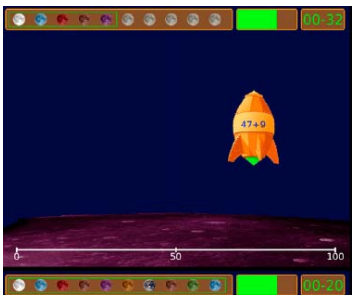
Total SN score on the Zareki battery

Vilette, Mawart & Rusinek, 2010

Rescue calcularis

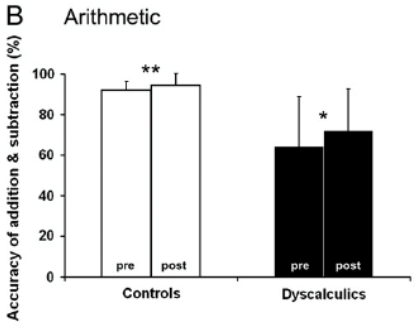
- estimate the position of a number, or of the result of an addition or a subtraction, on a number line marked 0 to 100 at the extremities.
- If estimation is within a range of ±10 of the correct position, the exact position is given as feedback.





Kucian et al., 2011, NeuroImage

- 16 control and 16 MLD children (± 9 y.o.)
- 25 times for 15' within a 5-week period.
- Increase performance in both groups in arithmetic



- And in positionning numbers on a number line

What about fractions?

- Fractions are difficult to learn
- Typical errors: "natural number bias"
  - 4/9 > 3/4 because 4 > 3 and 9 > 4 or because 4 & 9 > 3 & 4
  - in calculation

$$\frac{1}{4}+\frac{1}{3}=\frac{2}{7}$$

$$\frac{3}{7}-1=\frac{2}{7}$$

First studies in adults

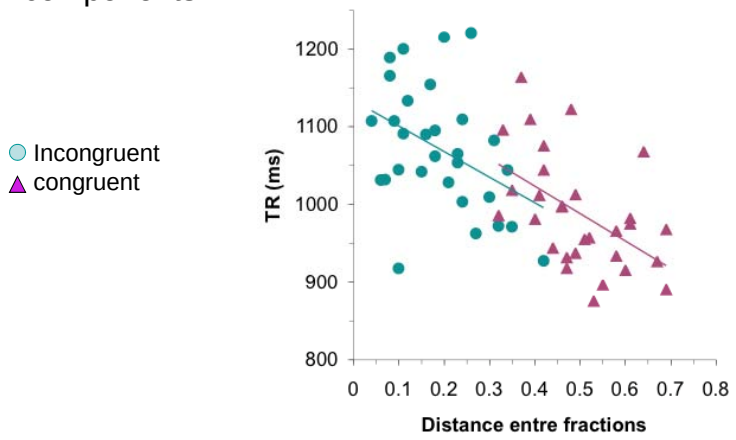
- University students
- Comparing 1/1, 1/2, 1/3, ...1/9 to 1/5
- RTs are a function of the distance between denominators and not between the magnitude of the fractions
- => they do not process the magnitude of the whole fraction!

Bonato & al., 2007

- Lets' use a task that do less encourage strategies based on components
  - Bonato: 1/1, 1/2, 1/3, ...1/9 to 1/5
  - Here: fractions without common components (5/7 - 3/8)
    - Congruent pairs: the larger fraction is made of the larger components (3/8 - 1/6)
    - Incongruent pairs: 4/5 - 5/9
  - Adult participants

Meert, Grégoire, Noël (2010). Acta Psych

- RT are faster for congruent than incongruent fractions
- RTs are globally correlated with the distance between the two fractions rather than between their components

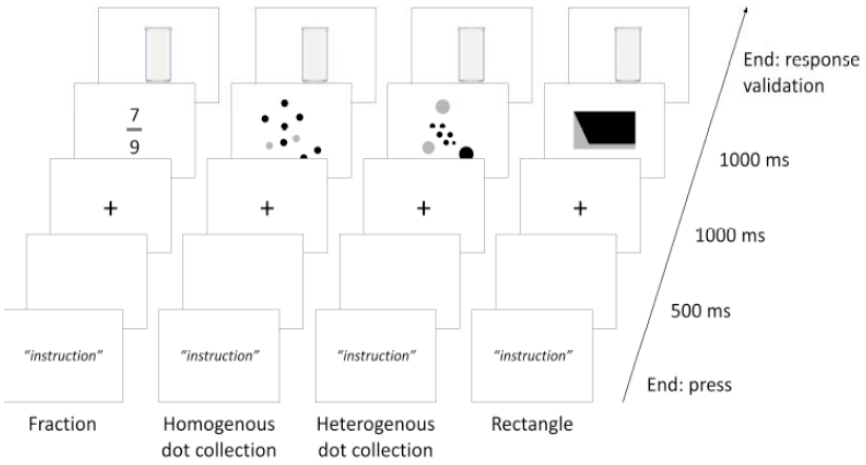


Meert, Grégoire, Noël (2010). Acta Psych

Difficulty in processing ratios or fractions?

- Adult participants
- Task: estimating the magnitude represented by
  - Fractions
  - The ratio between the orange surface area relative to the whole rectangle
  - Number of orange dots relative to the total number of dots

Meert, Grégoire, Seron & Noël (in press). Q J. Of Exp Psyc



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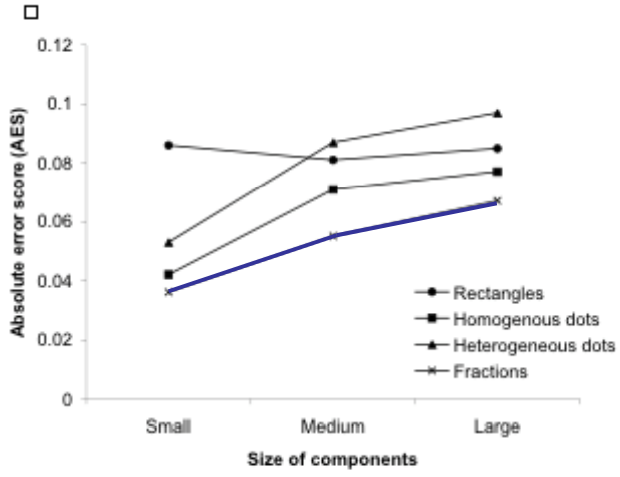
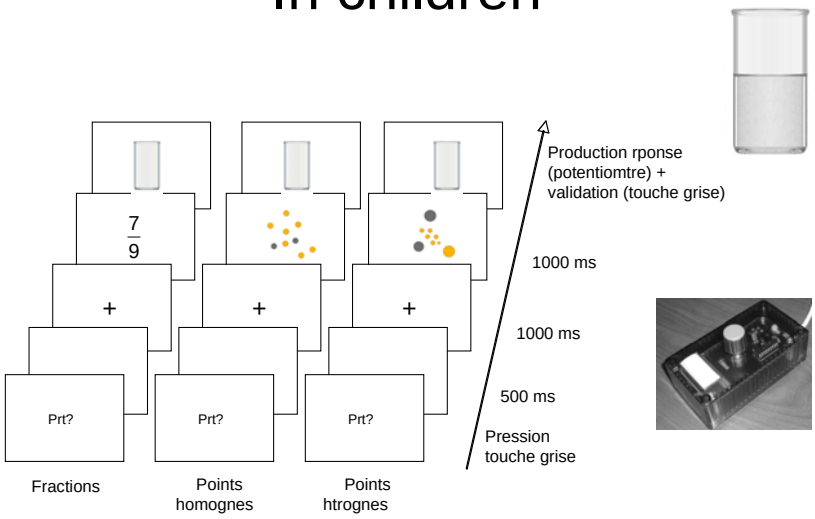


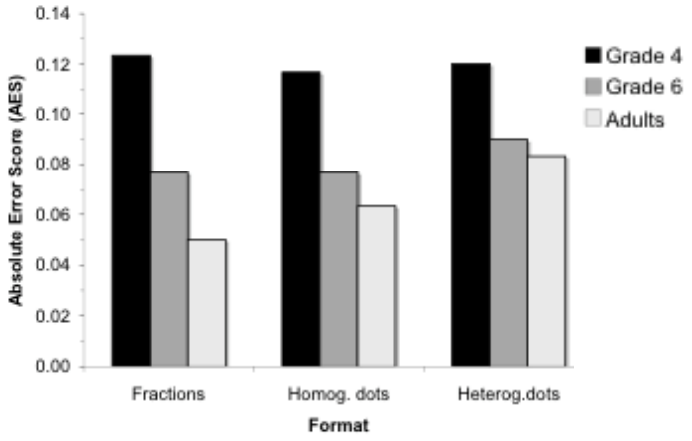
- The estimation error is smaller for fractions than for dots or rectangles

Meert, Grégoire, Seron & Noël (in press). Q J. Of Exp Psyc

In children



Meert, Grégoire & Noël, submitted



- Estimation error decreases over development

Meert, Grégoire & Noël, submitted

- Better estimation for homogeneous dot ratio than heterogeneous dot ratio (help of the non-numerical ratio such as surface area)
- Ratio with small (2-5), medium (7-9) or large (21-29) denominators
  - 3/4, 7/9 or 16/21

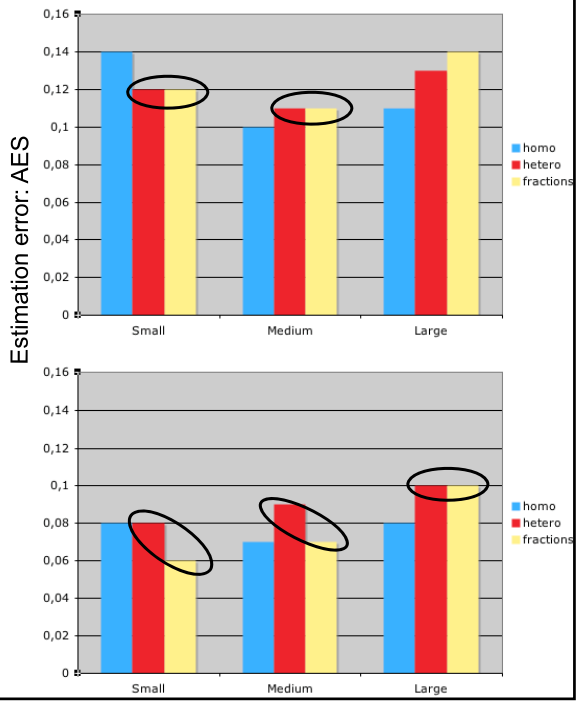
Meert, Grégoire & Noël, submitted

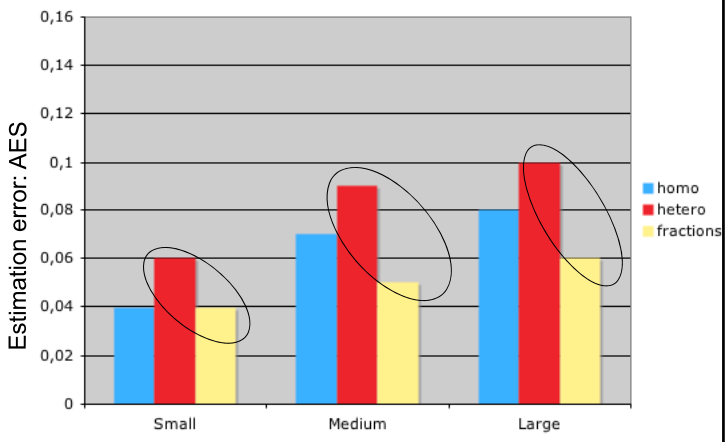
4th grade

- Estimation error
  - Equal for fractions and hetero for small and medium components

6th grade

- Estimation error
  - Smaller for fractions than hetero for small and medium denominators
  - Equal for fractions and hetero for large denominators





- Adults
- Estimation error is smaller for fractions than for hetero in all cases

Meert, Grégoire & Noël, submitted

- Some tasks induce the « natural number bias » and the child has to process the fraction and inhibit the tendency to work on the components
  - Comparing fractions
  - Calculation on fractions
- This tasks favours the access to the magnitude of the whole fraction and might be very interesting for educational purpose

Fractions on number lines

- 11 and 13 y.o. Teenagers
- Task
  - Estimate the position of fractions on a line 0-1 or 0-5
  - Comparing the magnitude of fractions
  - Calculation with fractions
  - Global math test

Siegler & al. (2011). Cog Psych

At both ages, significant correlations between the positionning on the number line and the other tests

	11 ans		13 ans	
	[0-1]	[0-5]	[0-1]	[0-5]
[0-5]	0,56**		0,61**	
Compa fractions	-0,48*	-0,33	-0,70**	-0,67**
Calcul fractions	-0,56**	-0,55**	-0,64**	-0,70**
Math	-0,67**	-0,54**	-0,63**	-0,86**

- Future works
  - Test whether MLD children have more problem with the magnitude of fractions than of non-symbolic ratios
  - Test whether training them on accessing the magnitude of fractions (e.g., on a number line) would help their comprehension of fractions and their ability to compare fractions and calculate with fractions

Take-home message

- Newborns have an approximate representation of number magnitude
- But they need to build a representation of exact numbers, thanks to symbolic numbers
- Processing the magnitude of symbolic numbers is an early and persistent deficit in persons with dyscalculia
- Using number line games can help
  - For learning numbers
  - For calculation
  - Maybe for fractions as well

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Thank you !

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