Approaching the core numerical deficit of developmental dyscalculia

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Typical and atypical neurocognitive aspects of numerical processing
Haïfa, April 13

Definition (DSM)

- *Developmental dyscalculia is a specific learning difficulty manifested by failure to achieve adequate proficiency in arithmetic despite*
  - *normal intelligence,*
  - *scholastic opportunities,*
  - *emotional stability, and*
  - *sufficient motivation.*
- *These difficulties do not result from a sensorial deficit*
- *These difficulties interfere significantly with daily life and/or school success*

prevalence

- In Israel, 3029 children 10 y.o. (Gross-Tsur, et al. 1996)
  - 6.5 % (score < two grade below mean & IQ > 80)
- 6 years follow-up (Shalev & al. 2005).
  - Among the 104 DC children
    - 40 % : score < pc 5 standardised test
    - 5% : score < pc 25

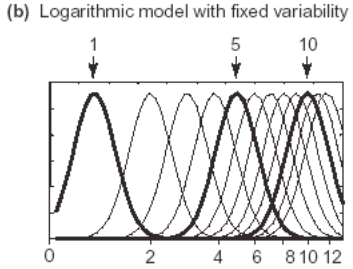
Core deficit

General cognitive factor: WM

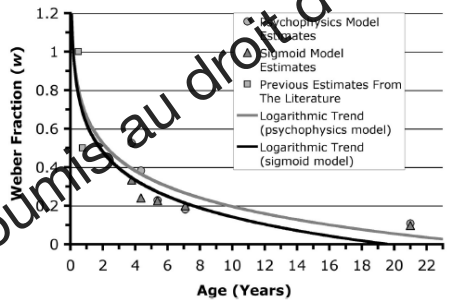
Basic numerical factor: the number sense

A simple story

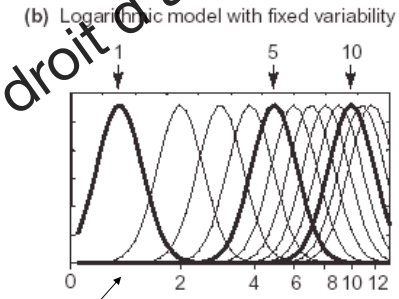
- Babies
  - Parallel individuation system: models of small sets (<4) in WM (or more if chunking: Feigenson & Halberda, 2008)
  - Language-independent system for representing numerosity
    - Analog magnitude system: ANS
    - Weber ratio limit



- Acuity of the ANS increases through development



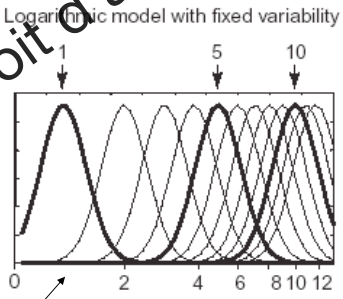
- Around 3 y.o
  - Learn the counting list
  - Map this counting list to the ANS to build meaning of these words



One, two, three, four, five, six, seven ....

Gallistel & Gelman, 1992

- Math learning builts on this ANS representation



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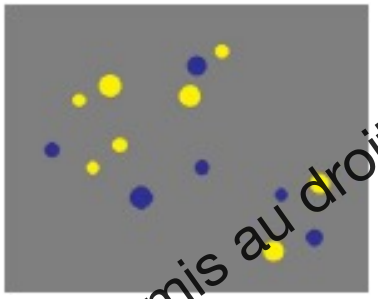
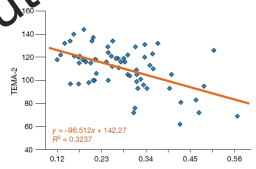
In unselected population





- 64 teenagers of 14 y.o.
- Measure of the acuity of ANS correlated with past school performance in math

Halberda, Mazzocco & Feigenson (2008)

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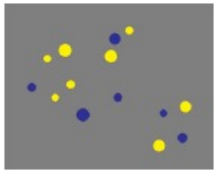

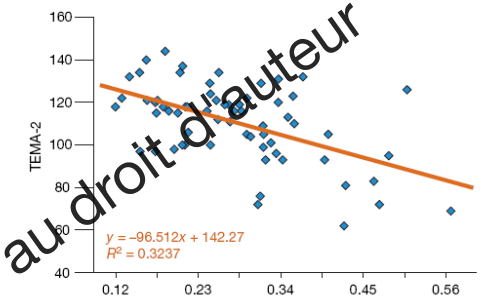

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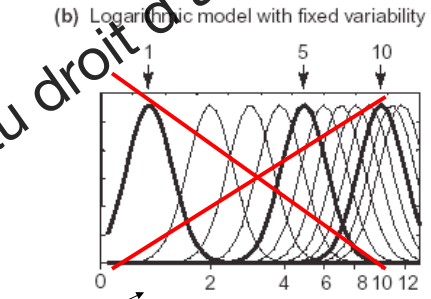
Developmental dyscalculia

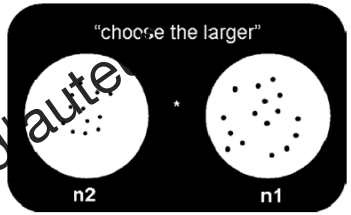
- Deficit of the ANS
  - deficit in learning and processing numerical symbols
  - Deficit in math

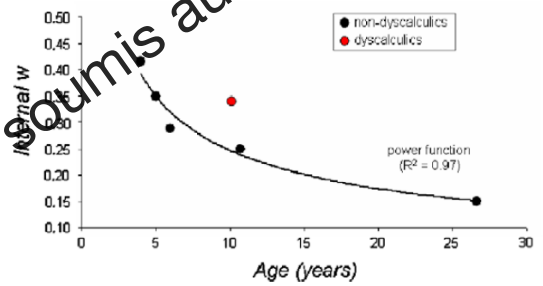


One, ~~two~~, three, four, five, ~~six~~, seven ....

Reduced acuity of the ANS in developmental dyscalculia

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

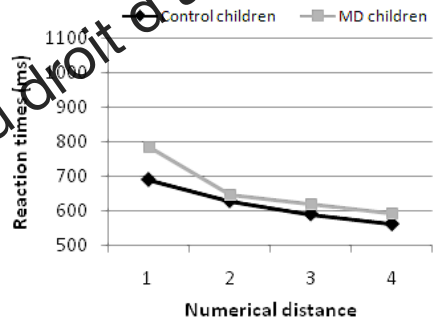




Piazza, M., Facoetti, A., & al, *Cognition*, 2010

- 15 MLD (10-11 y.o.), < pc 15 in X° fluency
- 15 controls (10-11 y.o.)
- Normal reading and IQ

Non canonical dot patterns



Mussolin, Mejias & Noël, 2010, *Cognition*

Yet

In unselected populations

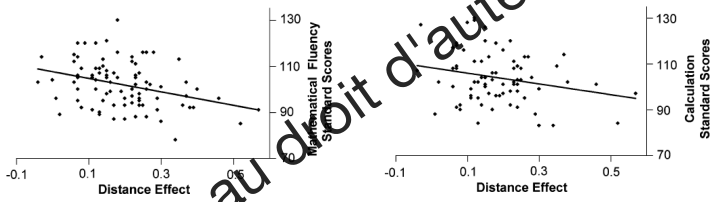
- Population
  - 6 y.o. (n=26), 7 y.o. (n=31), 8 y.o. (n=27)
  - Magnitude comparison
    - Comparison of two symbols (1 - 9)
    - Comparison of two sets (1 - 9 items)
  - Math performance
    - Calculation score (Woodcock Johnson Math)
    - Math fluency (+,-,x in 3')

3 - 7

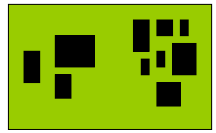
Holloway & Ansari, 2009, *JECP*

Symbolic task correlates with
- Calculation score: $r_{(85)}$=-.222*
- Math fluency:$r_{(86)}$=-.339**

3 - 7



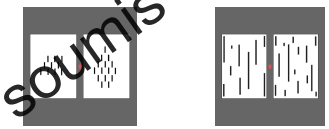
Non-symbolic task does not correlate with
- Calculation score: $r_{(85)}$=-.07
- Math fluency: $r_{(86)}$=.037



=> Not related to the approximate number sense

In clinical samples

- Population
  - 45 children with MLD (7 y.o.)
  - 45 control children (7 y.o.)
- Tasks
  - Non-symbolic



Easy condition

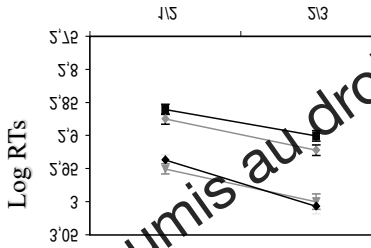
Difficult condition

symbolic

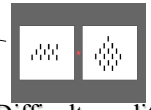
2 5

Rousselle & Noël, 2007, *Cognition*

collections comparaison

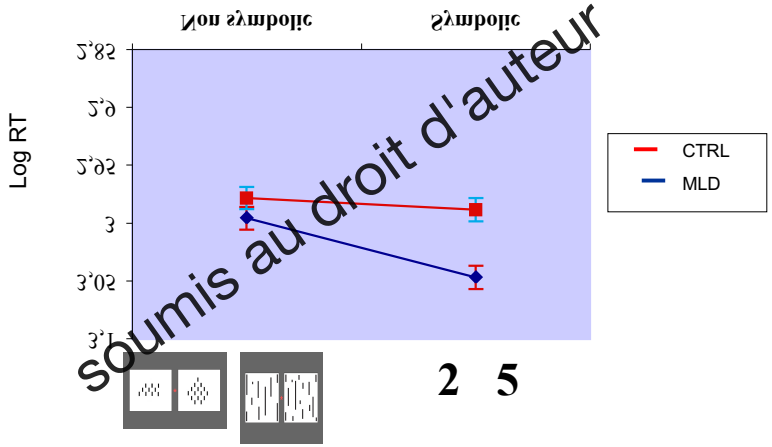


Easy condition



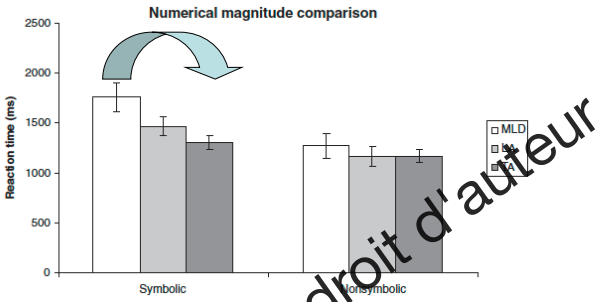
Difficult condition

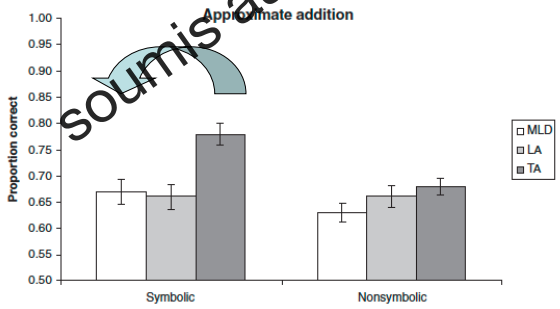
CTRL
MLD



- First grande children
  - 20 Learning difficuties in math (<pc 16)
  - 21 Weak in math math (entre pc 16 et pc 25)
  - 41 Controls (> pc 35)
- Magnitude comparison (1-9)
  - Arabic digits
  - Collections
- Approximate additions
  - Arabic digits
  - Collections

De Smedt & Gilmore (2011), *Cognition*





De Smedt & Gilmore (2011), *Cognition*

How can we account for these results ?

A developmental account of MLD ?

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

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Price & Ansari (2007)	12 y.o.	-	MLD<C

X

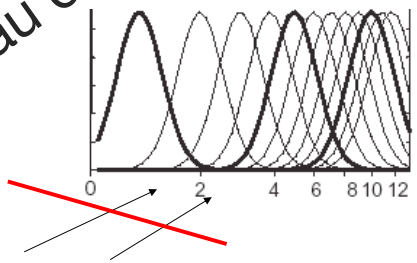
A developmental account

- First deficits are not seen in non-symbolic numerical tasks
  - not due to a deficit of the ANS
- First deficits are seen in symbolic numerical tasks

=> How do children learn the meaning of number symbols (words) ?

X

- Around 3 y.o
  - Learn the counting list
  - Children must develop a representation of exact natural numbers
    - Seven does not mean "about seven"
  - Meaning of number words are not learned by simple mapping with the ANS.



One, two, three, four, five, six, seven ....

X

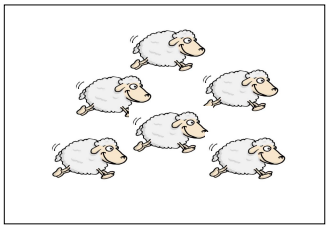
- Around 3 y.o
  - Learning the meaning of number words is very slow and sequential :
    - One: "one-konwers" (± 36 months)
    - Two: "two-knowers" (±6 months later),
    - Three: "three knowers" (±3 months later)
    - **subset knowers**

Sarnecka & Carey, Cognition, 2008

X

Mapping number words to the ANS in subset knowers

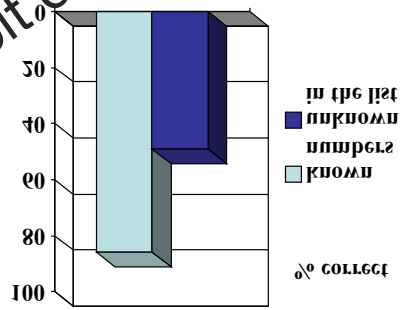
- Subset knowers with a counting least at 10 or more
- Two arrays, ratio of 2:1 (e.g., 3-6, 10-5)
- "*can you point to the card with six sheep?*"



Condry & Spelke, 2008 JEP:G

Mapping number words to the ANS

=> **Subset knowers map known numbers to the ANS but not unknown words which are in their counting list** (chance level)



Condry & Spelke, 2008 *JEP:G*

Comparing the magnitude of two number words

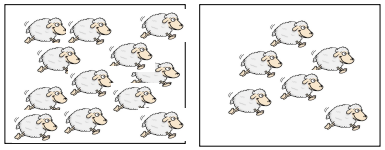
- Subset knowers who count at least up to ten
- 79% cr when comparing two known words
- 49% rc (chance) when unknwon numbers, although in their counting list

Condry & Spelke, 2008

Transformations that lead to a change of numerical label

- Subset knowers who count at least up to 8
- Two sets, one is labeled "*this tray has six sheep*" and then transformed
- Two types of number words
  - Known
  - Unknown but it the counting list

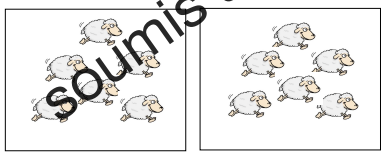
Condry & Spelke, 2008 *JEP:G*



This tray has six sheep,

no change: *point to the tray with six / twelve sheep*

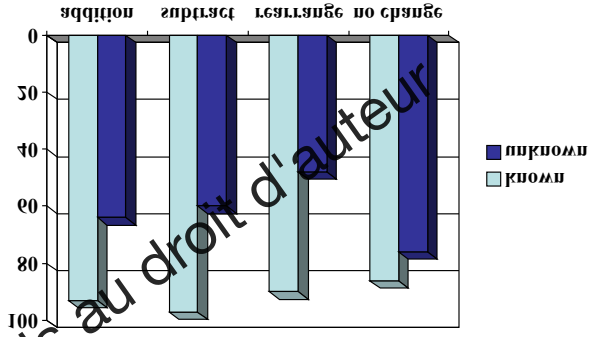
rearrangement: *point to the tray with six / twelve sheep*



This tray has six sheep

double one set: point to the tray with six / twelve sheep

halve one set: point to the tray with six / twelve sheep



- Correct answers for the "no change" condition
- Correct answers for known words (93%)
- Random answers for unknown words (57%)

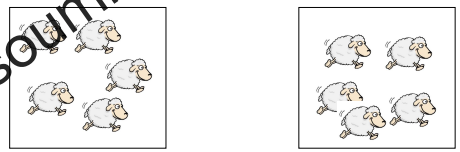
Subset knowers do not know which transformation affects the use of unknown number words

Condry & Spelke, 2008 JEP:G

- understand the counting principle and can give any number of items if the word is in their counting list
  - **Counting Principle knowers**

The successor function - direction

- N items placed on each plate,
  - E.g., *look 5 sheep here and 5 sheep there*
- E moves one item from one plate to the other.
- *Now, there is a plate with 4 and a plate with 6, where is 6?*



Sarnecka & Carey, Cognition, 2008

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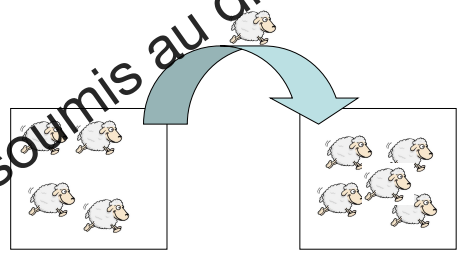

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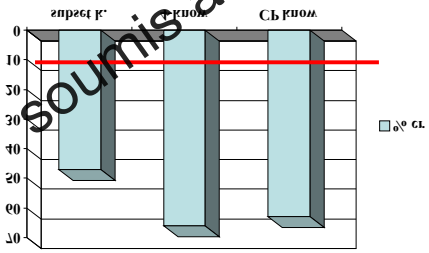
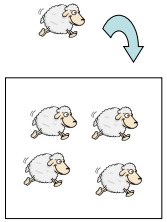
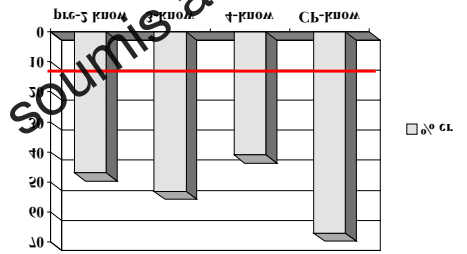


Sarnecka & Carey, Cognition, 2008

The successor function - unit of change

- the word for N+1 is the one just after N
  - E place N items in a box: "I am putting N (four) items. How many are there ?
  - Now I am adding one/two more items. Now is there N+1 or N+2 items ? (five or six?)
  - => **only CP knowers > random**





Sarnecka & Carey, *Cognition*, 2008

- Only 4-knowers and CP-knowers know that adding one item to a set gives a number word further away rather than before
- only CP-knowers know that adding one item to a set gives the number word just after
  - => they master the successor function and the counting principle

Sarnecka & Carey, Cognition, 2008

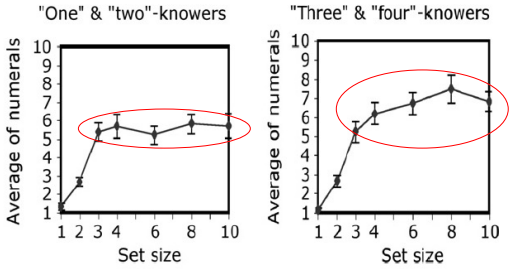
Mapping number words to the ANS: in subset and CP knowers

- 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
  - 74 **CP knowers**

Le Corre & Carey, 2007, Cognition

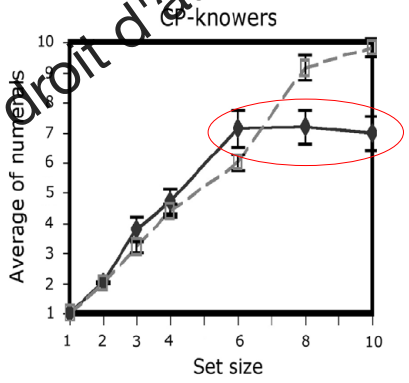
Mapping symbols to ANS

- Estimate without counting (1 s.) the number of dots (1 to 15)
- Average numeral produced according to the size of the target
  - Beyond the # they know, the curve is flat for subset knowers



Le Corre & Carey, 2007, *Cognition*

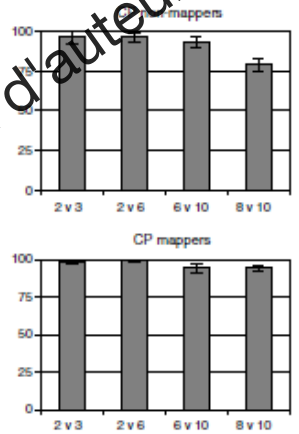
- For the CP knowers, two groups emerge:
  - flat curve : **CP knowers non-mappers**
  - curve increasing with the size of the target: **CP knowers mappers**



Le Corre & Carey, 2007, *Cognition*

ANS

Same ANS for both groups



Le Corre & Carey, 2007, Cognition

Summary of the developmental steps

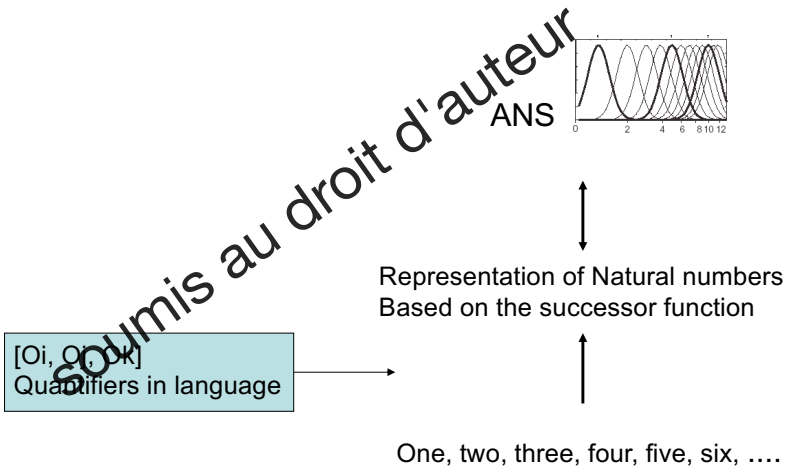
- Innate ANS & parallel individuation system
- Acquisition of the counting list
- Slow and progressive acquisition of the cardinal meaning of the number words one to four: **subset knowers**
- Understanding the successor function and then the counting principle => acquisition of the cardinal meaning of all the words in the count list: **Counting Principle knowers**
- ± 6 months later: mapping number words to the ANS: **CP mappers**

Le Corre & Carey, 2007, *Cognition*

- Thus, the development of the understanding of the cardinal of number words and the principle of the counting precede the mapping between the ANS and the symbols, so they are not learn by this mapping !
- Hypotheses: the meaning of one, two, three, is based on
  - parallel individuation systems that can create in WM, models of small sets [Oi, Oj, Ok]
  - Semantics of the quantifiers in language (cfr cross-linguistic differences)
- Understanding the meaning of the the first number words leads to discover the succession function, and then the principle of the counting => creation of a representation of natural numbers
- Then mapped onto the ANS

Le Corre & Carey, 2007, Cognition

- A developmental model



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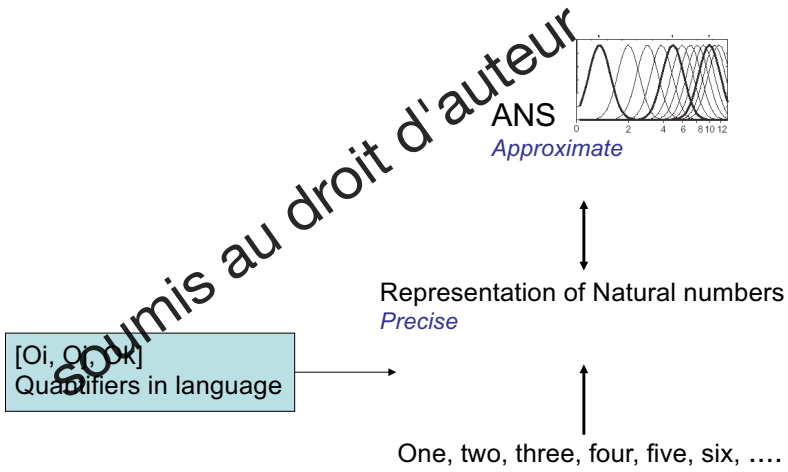
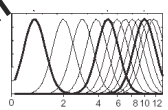


- A developmental model

Secondary deficit in DD

ANS



Approximate

Increased acuity

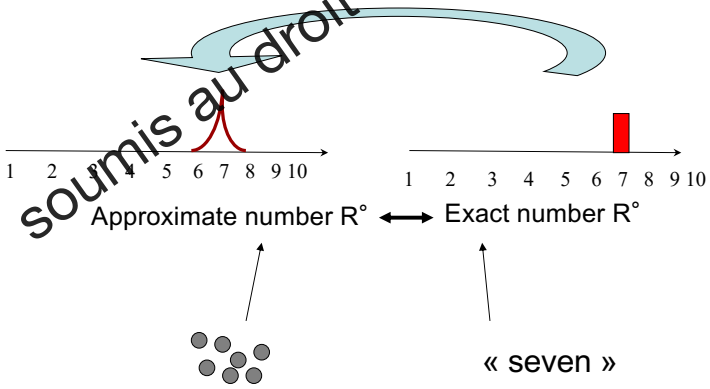
Representation of Natural numbers

Precise

First deficit in DD

One, two, three, four, five, six, ….

- First deficit is on the symbolic tasks
- Later: deficit on non-symbolic tasks as well
  - Hypoth: connecting the exact number R° with the approximate magnitude system would increase the precision of the later
  - This refinement process would be weaker in MLD children, thus leading to ≠ between MLD and control children

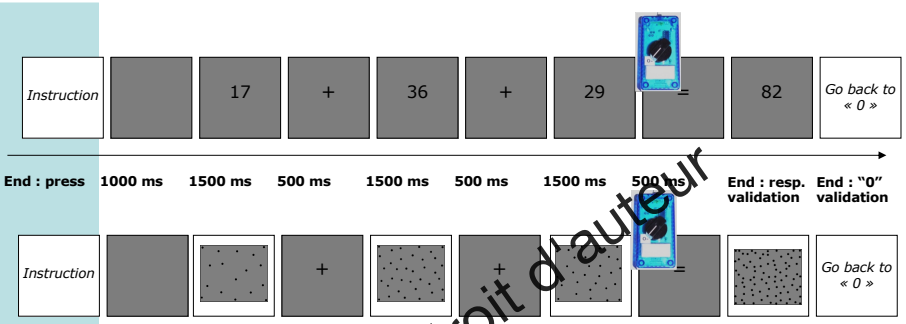


The point we want to make ....

- The ANS deficit seen in dyscalculics
  - is secondary
  - It might even be temporally ....

What is the fate of MLD children ?

- MLD: math learning disability
  - Many difficulties in exact calculation
  - Quid in approximate calculation ?



Mejias & Noel, submitted

populations

- **Children**
- 19 MLD (10-11 y.o.)
  - < pc 15 in arith fluency (+,-,x)
  - <pc15 global math battery
  - Teacher: some or severe math diff
- 19 controls (10-11 y.o.)
- Normal reading and IQ

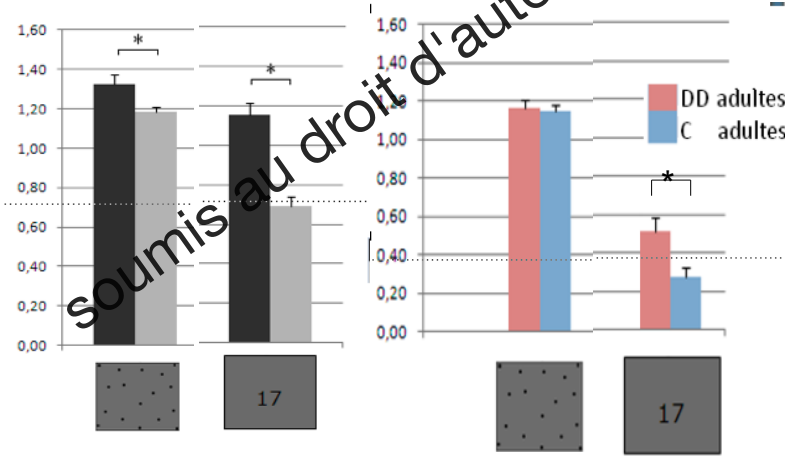
- **Adults**
- 17 MLD adults (25±10 y.o.)
- 17 adults control, same age, same studies or profession
  - Global math battery
    - Error rate: MLD (20±11) > CTR (6±5): t(32)=4.95** (**-2.8 SD**)
    - RT: MLD (1235±370 s) > CTR (755±284s): t(32)=4.24** (**+1.7 SD**)

Mejias & Noel, submitted

Log AES = log | estimate - target |

10 y.o. children

adults



We like simple stories but reality might be more complex

Thanks very much !