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Cognitive bases of developmental dyscalculia

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plan

- Definition - prevalence - associations
- Genetic contribution
  - Families studies, twin studies, genetic syndromes
- General cognitive factors
  - inhibition, working memory, long-term memory
  - Finger agnosia
- Numerical factors
  - The number sense
  - The access to the magnitude representation from symbols
  - The automatic activation of number magnitude

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*

A variety of difficulties

- Writing & reading numbers
  - Reading: *85 => eighty-two* (Paul; Temple, 1989)
  - Writing: *fifty thousand ninety => 50,90* (CM, Sullivan, Maracaruso & Sokol, 1996)
- Calculation procedures
  - Mastery of the procedures required to solve multi-digit written calculation: carrying, borrowing ... (SW, Temple, 1991)
- « visual-spatial dyscalculia »
  - Errors in counting random patterns of dots, problems in left-right orientation (< >; + x), mastery of the positional system of the Arabic notation (41 - 14), geometry (Spiers, 1987)
- <u>Arithmetical facts : 3+6; 9-2; 4x6; 12:3</u>
  - longer RTs, immature strategies (counting all, counting on fingers), less retrieval from long-term memory, more errors (counting & retrieval)

NR, a dyscalculia of arithmetical facts

- 33 y.o. woman, normal intelligence
- Simple 1-digit additions : 15% errors
  - 1+4=4 , 3+5=9
- Simple 1-digit multiplications : 39% errors
  - 5x5=35; 7x4=21, 0x5=5
- Divisions: impossible
- Count on her fingers
- => many difficulties with dealing with her money, shopping, comparing prices; did not obtain her certificate of primary school

Prevalence & associations

- Badian: 1476 American children, 7-14 y.o.
  - 3,6% difficulties in math (< pc 20 on the Stanford Achievement test),
  - 2,2% difficulties in reading
  - 2,7% difficulties in math & reading
- Lewis et al.: 1056 English children, 9-10 y.o.(NS < 85)
  - 1,3% difficulties in math
  - 3,9% difficulties in reading
  - 2,3% difficulties in math & reading
- Gross-Tsur, Manor & Shalev (1996): 3029 children from Israel, 10 y.o.
  - 6,5 % (score < two grade below mean & IQ > 80)
  - 1,1:1 girls:boys
  - 26% of the dyscalculic children met the criteria of ADHD (Conners Q)
- global batteries not suited to detect specific problems, different criteria

Selection criteria

- In the clinical setting
  - Scores on a numerical test < 2SD or
  - > 2 years behind and normal intelligence
- In research
  - ≠ cutoff
  - ≠ IQ

Landerl & al. (2004)	3 SD below the mean & teacher's classification, normal IQ
Jordan et al. (03)	< 35 percentile
Shalev et al. (97)	2 grades below CA, IQ > 80
Temple & al. (02)	1 year below CA

A persistent problem

- 3 year follow-up of 123 dyscalculic children (DC)
- Dyscalculic (< pc 5)
- 47% persistent dyscalculia
- 95% scored < 25 pc
- Persistant vs. Non-persistent DC
  - More attention problems
  - More anxiety problems
  - similar performance IQ (100.4 vs. 104.2)
  - equivalent verbal IQ if arith subtest is excluded
  - 46% vs 28% of siblings received arithmetic tutorials

Shalev, Manor et al. (1998), J. Pediatr.

Persisting difficulties

- 6 years follow-up
  - Among the 104 DC children
    - 40 % : score < pc 5 standardised test
    - 95% : score < pc 25
  - The profile may change
    - Difficulties in counting, difficulties in doing simple computations
    - Deficits in the retrieval of simple arithmetical facts from memory
    - Errors in complex (written) calculation
    - Difficulties to handle and understand fractions, decimals

Shalev & al. (2005). Dvptal Med & Child Neurolol

Genetic contribution: genetic syndromes

- Turner syndrome (Rovet & al., 94; Temple & al., 1998; Bruandet & al., 2004)
- Williams syndrome (Paterson & all, 1999)
- Fragile-X syndrome (Hagerman & al., 1992)
- 22q11 (Simon, 2005)

Genetic contribution: family studies

- 31 families of persistent DC (over 3years)
- 149 family members tested for DC
- DC criteria:
  - poor performance in arithmetic (< pc25),
  - IQ > 85,
  - significant ≠ between math and IQ (> 1 SD)

	% of DC
mothers	67
fathers	41
siblings	53

⇒ half of the family members were DC
⇒ 10 x more than in the general population

Shalev et al. (2001)., J. Learning Dis.

Genetic contribution: family studies ADHD and dyscalculia

- ADHD : criteria of the DSM III-R
- Exclusion: major sensorimotor disabilities, psychosis, reading problems, IQ < 80

	Males-ADHD	Males no-ADHD	Females-ADHD	Females no-ADHD
Probands (n)	140	120	140	122
Siblings (n)	174	129	143	131
Parents (n)	280	239	274	238

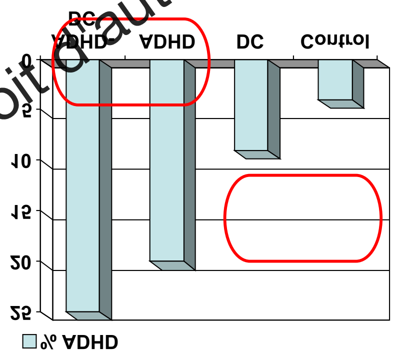
Monuteaux et al., J. Learning Dis. 2005

- Dyscalculia: discrepancy between the WRAT-R score and the one expected on the basis of IQ
  - 5.7% DC among the control probands
  - 10.7% DC among the ADHD probands
  - ≠ is significant (p=.05)

Monuteaux et al., J. Learning Dis. 2005

ADHD in relatives of probands

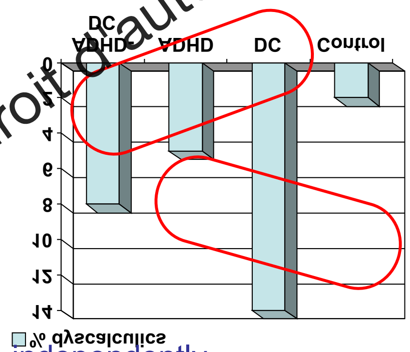
- Increased rate of ADHD in probands with ADHD (with and without dyscalculia) relative of control probands
  - ADHD-DC and ADHD ≠ from control ($p<.01$) and DC ($p<.05$)



Monuteaux et al., J. Learning Dis. 2005

Dyscalculia in relatives of probands

- Higher rates of dyscalculia in the relatives of dyscalculics probands (with or without ADHD) compared to the relatives of control probands
  - ADHD-DC and DC > control ($p<.05$)



« ADHD and dyscalculia are independently transmitted in families and are etiologically distinct »

Monuteaux et al., J. Learning Dis. 2005

Genetic contribution: twin studies

- Dyscalculic twins
  - 58% of monozygotic co-twins are DC
  - 39% of dizygotic co-twins are DC
  - Concordance rate is even higher when considering dyscalculic children with not reading difficulties
    - .73 vs .56 (mono and dizy)
    - .85 vs. .46 (mono and dizy; no reading diff)

Alarcon & al. (1997), J. Learn. Disabilities

What are the questions ?

- Why do some children present difficulties in learning math ?
  - General cognitive factors ?
  - Specific, numerical factors ?
  - Are these reasons the same for DC and DC-RD ?

General cognitive factors: intelligence

- No problem of intelligence is one of the criteria of the DSM III
- Gross-Tsur & al. (96) selected DC children with an IQ > 80
  - IQ of DC: 98.2
  - Performance IQ: 102.4
  - Verbal IQ (no arith): 94.8
- 3 years later: persistent vs. non-persistent DC
  - Similar performance IQ (100.4 vs. 104.2)
  - Similar verbal (no arith)
- 6 years later: persistent vs. Non-persistent DC
  - ≠ in performance IQ: 98.7 vs. 104.7
  - ≠ in verbal IQ (no arith): 93.2 vs. 97.6

General cognitive factors: WM

- A frequent difficulty in DC concerns simple calculation
  - DC are slower
  - produce more errors,
  - use less mature strategies than controls
    - algorithm :
      - Counting all: 2 + 8 = 1,2,3,4,5,6,7,8,9,10
      - Counting on: 2 + 8 = 3,4,5,6,7,8,9,10
      - Counting min: 2 + 8 = 9,10
      - Retrieval: 2 + 8 = 10
    - support : finger - verbal - mental

Fleischner et al., 82; Geary et al., 87, Geary et al. 90

General cognitive factors: WM

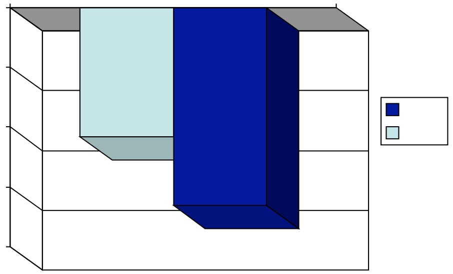
- Geary's hypothesis (1993; Psych Bull)
  - To form an AF in long-term memory, one needs to co-activate in WM the problem and the answer
  - Low WM capacities would prevent the formation of these associations
- The repeated use of counting to solve a problem does not lead to the constitution of an AF (problem-answer in LTM)
  - Thevenot, Barrouillet & Fayol (2001)
    - Addition: 39/16 /55 55 = the sum? 16 (= n1 or n2 ?)
    - Compare: 39/16/25 25 in between? 16 (=n1 or n2 ?)
    - Better recognition of 16 after compare than add

General cognitive factors: WM

- Weaker WM capacities in DC
- Poor WM is associated with immature addition strategies
- Poor WM is associated with less elaborated counting string
- Weak WM capacities may lead to some arithmetical disabilities

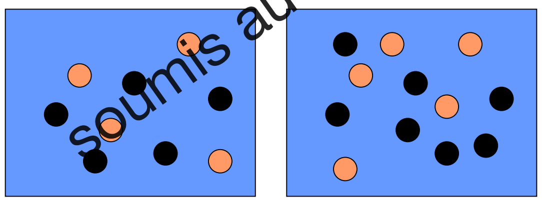
WM capacities in DC

- Lower forward digit span
  - Geary, Brown & Samaranayake (1991)
  - Hitch & McAuley (1991)



WM capacities in DC

- Weaker central executive capacities
  - Siegel & Ryan (1989)
    - counting span <
    - listening span =



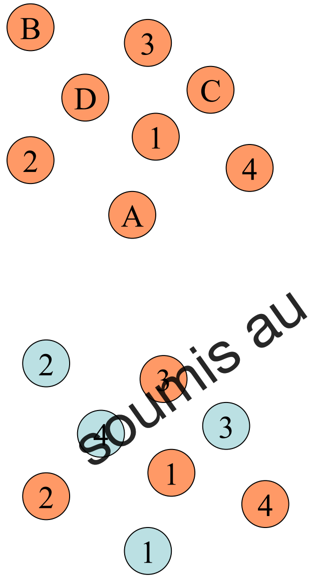
/ four five /

/ four /   / five /

WM capacities in DC :

Studies controlling for reading disabilities

- Mc Lean & Hitch (1999)
  - 8-9 y.o. children: DC (no reading probelms) and controls
  - PL
    - Forward digit span: DC < controls
    - Non-word repetition: no ≠
  - VSSP
    - Corsi: DC < controls
    - Matrices: no ≠
  - CE
    - trials tests: DC < controls
    - Missing items: DC < controls



Trial tests

Missing item

$2+3 = 4+? \quad =?$

WM capacities in DC

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WM capacities in DC

- Passolunghi & Siegel (2001; J. Exp Child Psyc)
  - Poor / good problem solvers
    - Listening span (.05)
    - Counting span (.02)
    - Animal dual task (.002)
    - Digit span (forward) (.05)
    - Digit span backward (.05)
    - Word forward (ns)
    - Word backward (ns)
- But Geary & al (99)
    - DC, DL, DC-DL, controls
    - forward digit span: No ≠ in
    - Backward digit span: DC-DL < 3 other groups

=> Poorer WM abilities in DC, especially CE
- Low processing speed ? (Bull & Johnston, 97)
- Low inhibition of no more relevant information ? (Passolunghi & al.)

WM and calculation strategies

- Test 3 groups: DC, DC-DL, controls
- in 1st, 3d and 5th grades
- Lower counting span for DC and DC-DL in the three school levels
- Counting span is correlated with
  - More finger counting
  - Less verbal counting
  - More errors in finger counting

Geary & al. (2004) J. Exp Child Psych

WM and calculation strategies

- Test of WM capacities (PL & CE) and processing speed when entering school (grade 1, November)
- Predictive power of these measures on addition
  - PL: digit span, short-word span, long-word span, non-word repetition
  - CE: listening span
  - Processing speed: code subtest (WISC)
- 4 months later: addition
  - algorithm :
    - Counting all: 2 + 8 = 1,2,3,4,5,6,7,8,9,10
    - Counting on: 2 + 8 = 3,4,5,6,7,8,9,10
    - Counting min: 2 + 8 = 9,10
    - Retrieval: 2 + 8 = 10
  - support : finger - verbal - mental

Noël, Seron & Trovarelly (2004)

Results

- the general processing speed measure had no significant predicting power

: p=.05:; p=.025: **, p<.01: ***

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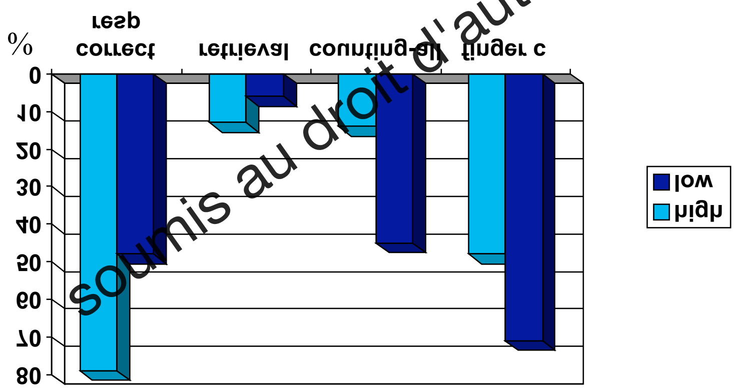
Subgroups with low vs. high PL capacities



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Interpretation

- Weak WM capacities => less accurate
  - => monitoring the counting string (cfr adult studies: Healy & Nairne, 85; Logie & Baddeley, 87):
  - => monitoring the number of counting steps
- Weak WM capacities => concrete support needed to monitor the counting steps
  - => finger counting
- Weak WM capacities => less mature counting strategies
  - Why ? Immature counting string ?

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WM in learning to count ?

- PL capacities have been shown to predict vocabulary acquisition
- What about the number words ?
- Particularities
  - Number words must be recited in a specific order
  - The counting string needs to be elaborated
    - *Unbreakable list*
    - *Breakable chain (start counting from n≠1)*
    - *Numerable chain (counts number words)*
    - *Bidirectional chain (recite in both directions)*

WM in learning to count ?
Predictions

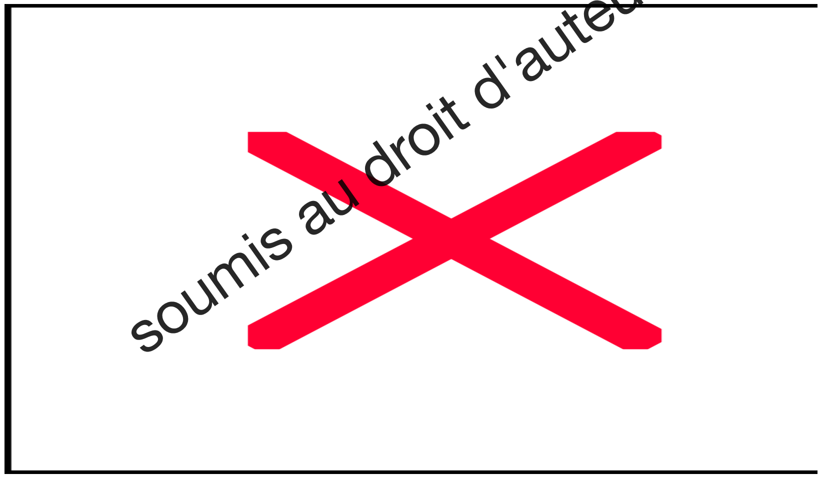
- Phonological loop capacities are related to
  - Development of the number vocabulary
  - Development of the counting string (order)
- Central executive capacities are related to
  - The level of elaboration of the counting string
  - Ability to use counting to solve additions

WM in learning to count ?
Method

- Population
  - 4 y.o. Children (38) & 5 y.o. Children (42)
- Evaluation of
  - Counting level
    - Count as far as you can
    - Number fluency
    - Count from / up to a number
    - Count x steps from a given number
  - WM capacities
    - Storage: word span and nonword repetition / Corsi span
    - CE: reverse order word span / short-words span with categorical restitution

WM in learning to count ?
Results

- Split of the population in two subgroups
  - Those with lower memory spans than expected for their age
  - Those with higher memory spans than expected for their age
- No ≠ when groups are based on the VSSP measure
- ≠ when groups are based on the PL or the CE measures



Low WM: a way to DC ?

- Weak WM capacities =>
  - Smaller number vocabulary
  - Less extended number string
  - Lower level of elaboration of the counting string
  - Less mature counting strategies in addition
  - Weaker abilities to monitor counting for calculation
  - More calculation errors
  - Use of external support
  - Poor conditions for establishing an association in LTM between a problem and the correct answer

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General cognitive factors: inhibition

- DC have low CE capacities because they can not suppress no more relevant information from WM (Passolunghi & Siegel, 2001, 2004)
- DC is often associated with ADHD (inhibition problem)
- DC's problems with AF (slow RTs and more errors) could be due to their difficulty to deal with interference in the AF network

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General cognitive factors: inhibition

- AF are stored in a long-term memory network with many interference
  - Errors are often table-related (8 x 4 = 24)
  - There can also be naming errors (2 x 8 = 28)
  - There is an operation effect (4 + 5 = 20)

=> inhibition is needed to deal with that interference

<u>Inhibition = Active</u> suppression mechanism that prevents irrelevant information from disrupting cognitive processing (Harnishfeger, 1995)

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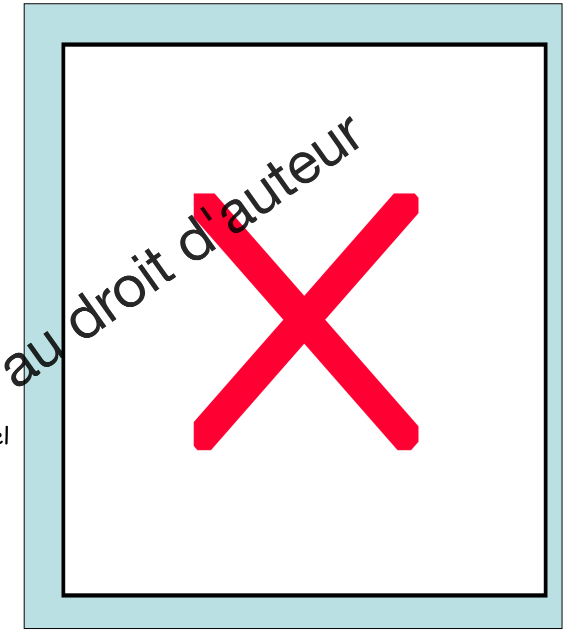

Network Interference Model

Campbell (1994, 1995)

- the presentation of a problem activated many different responses

General cognitive factors: inhibition

- Barrouillet, Fayol & Lathulière (1997)
  - Adolescents with learning difficulties in math
  - Multiple choice task
    - 4 x 6 = 18, 24, 28, 30 (table-related foils) 74% cr
    - 4 x 6 = 21, 24, 25, 27 (table -unrelated foils) 83% cr
    - 4 x 6 = 22, 23, 24, 26 (non-table foils) 82% cr
  - => more difficulties when foils are table-related
  - But children with very low IQ (mean of 75), no control group
- Bull & Sceríf (2001)
  - 7 y.o. Children: significant correlation between math performance and a numerical Stroop (222, 333: say how many symbols) but not with a Colour Stroop (blue)

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General cognitive factors: inhibition

- Inhibition has ≠ functions (Friedman & Miyake, 2004)
  - Controlling interference from external distracters
  - Inhibiting dominant responses
  - Suppression of no more relevant information
  - 8 x 4 =>
    => 16, 24, 32
    => 16, 20, 24, 28, 32, 36
    => selecting 32 but inhibiting 16 or 24
    => inhibition of the dominant response ?

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- **Learning disabled**: 11 y.o, n=15; IQ 98±9; > 2 years behind in math and reading
- **Controls**: 11 y.o., n=15; IQ=104±12; no learning problems

	Congruent -	Incongruent
• Inhibition of external distracters		
– Flankers letters:	DDDDDDD	GGGDGGG
– Flankers digits:	2222222	1112111
• Inhibition of a dominant response		
– Colour Stroop	red	blue
– Digit Stroop	22	33

Censabella & Noël, Journal of Learning Disabilities, (2005)

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Censabella & Noël, Journal of Learning Disabilities, (2005)

Congruity effects

Flankers letters   Flankers digits   Color Stroop   Digit Stroop

General cognitive factors: inhibition

- Problem for inhibiting information that are no more relevant for the task at hand ?
- When learning AF
  - 6 + 3 = 7, 8, 9
  - Keep in WM the problem and the last number produced (the response) but inhibiting the intermediate results

General cognitive factors: inhibition

- **Math disabled**: 10 y.o., n=20; IQ 98,4±7; <pc15 math; >pc50 reading
- **Controls**: 10 y.o., n=20; IQ=101±9; >pc 50 math & reading

Congruent - Incongruent

- Inhibition of external distractors
  - Flankers letters: DDDDDDD GGGDGGG
- Inhibition of a dominant response
  - Stroop colour: red blue
- Suppression of irrelevant information
  - Intrusion in a listening span: The crone if for the **king**. Horses live in **nests**. Wrong answer: crone - nests

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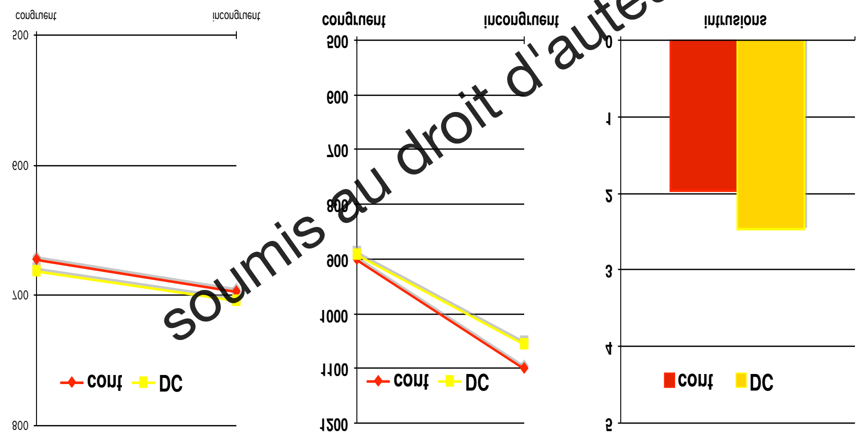
Controls vs. DC



Flankers lettres   Color Stroop   Listening span

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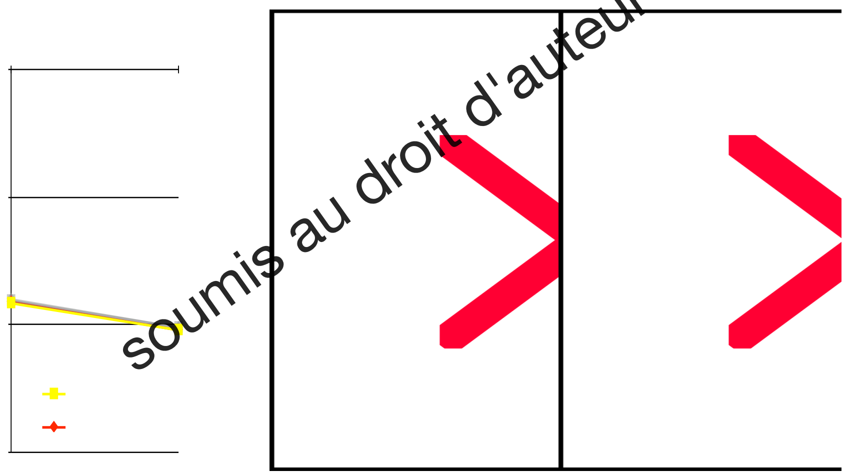
Contrôles vs. Weak in arihmetical facts

Fluency in multiplication (1’ test): < pc 25



General cognitive factors: inhibition ?

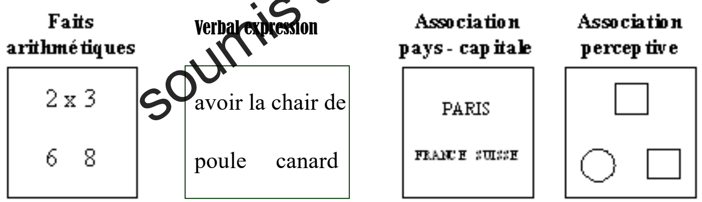
- When considering DC children with adequate IQ (DC only, DC-dyslexics or DC for AF), there was not sign of inhibition deficiency in any of the three functions of inhibition
  - Inhibiting external distractors
  - Inhibiting dominant responses
  - Inhibiting no more relevant information
- same conclusion by van der Sluis et al. (2004). *J. of Experimental Child Psychology*.

General cognitive factors: Long-term memory

- DC children have difficulties to store and retrieve AF in LTM
- AF might be stored in a verbal format in LTM (Dehaene, 1992)
  - DC children are slower
    - in speeded naming tasks (Geary & al., 91; Kirby & Becker, 1988) but not always (Geary & Brown, 1991)
    - DC chidren are slower to count (Hitch & McAuley, 1991)
  - Significant correlation between articulation speed and frequency of AF retrieval in LTM (Bull& Johnson, 1997)

=> Geary et al. (2000): hypothesis of a deficit in retreiving verbally coded information from LTM

- Associate a multiplication to its product
- Associate a verbal expression to its ending word
- Associate a capital to its country
- Associate a form to another similar form (speed of processing, of selecting an answer, no retrieval from LTM)



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General cognitive factors: Long-term memory

- If deficit is specific, the only ≠ between the 2 groups is for the multiplication
- If deficit is in learning verbal association then ≠ could be seen in multiplication and verbal expressions
- If dficit is in learning « arbitrary associations » then ≠ could be seen in multiplication and in country/capitals
- If they are globally slower, ≠ should be seen in all the tasks

General cognitive factors: Long-term memory

- Population
  - 18 DC children (score < pc10 au KRT)
  - 18 controls (score > pc40 au KRT)
  - No reading problems (tests L3 et LUM)
  - IQ > 85
  - Two groups paired on age, sex, IQ and education

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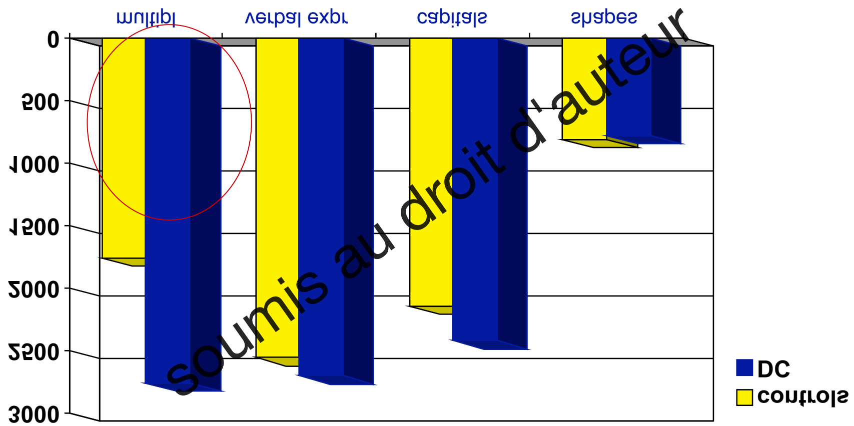
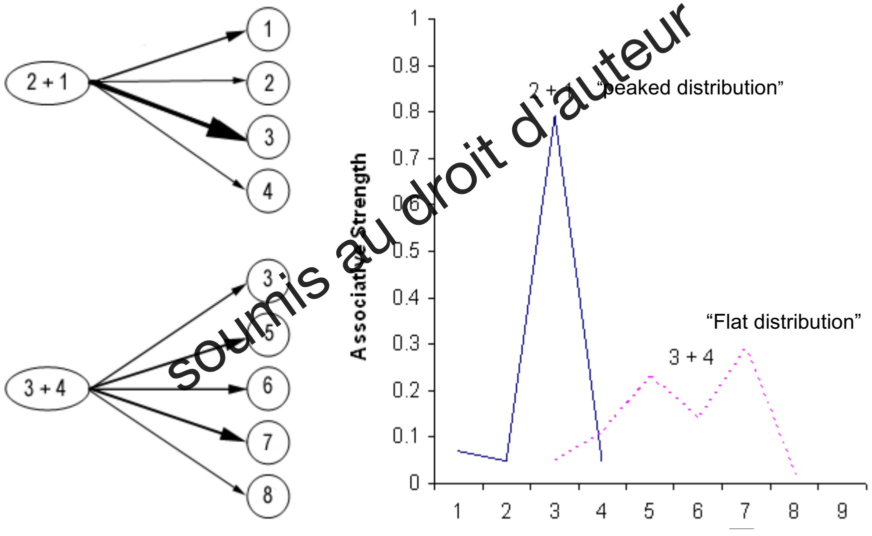


=> Specific difficulties in accessing AF from LTM, why ?

Siegler's Distribution of Associations Model (1988, 2000)

- Developmental model
- Each time an answer is generated in response to a problem, an association between this problem and that answer is created in LTM
- => problems are associated to the appropriate response as well to errors
- The associative strength between a problem and an answer increases with the frequency of production of that answer
- What is really important is the relative associative strength,
  - The associative strength of a given answer relative to the associative strengths of all answers to that problem
- This determines whether this answer will be the one retrieved and the speed to retrieve it

Distribution of Association



DOA in DC ?

- 3 groups
  - DC 4th grade
  - Control -same age
  - Control - Ability-Matched
- DC criteria
  - Mental arith test < pc 25
  - Reading test > pc 31
  - IQ > 85
- DC and ability matched have the same score on a multiplication fluency task

	DC	Age-Matched	Ability-Matched
N	11	11	11
Age (in months)	117.09 (3.48)	115.91 (3.27)	105.00 (4.60)
IQ	102.11 (8.90)	102.64 (9.21)	102.11 (8.11)
LVS-Mental Arithmetic	37.18 (7.64)	54.82 (2.04)	
Multiplicat° Fluency	30.55 (8.21)	54.36 (14.62)	30.27 (8.04)

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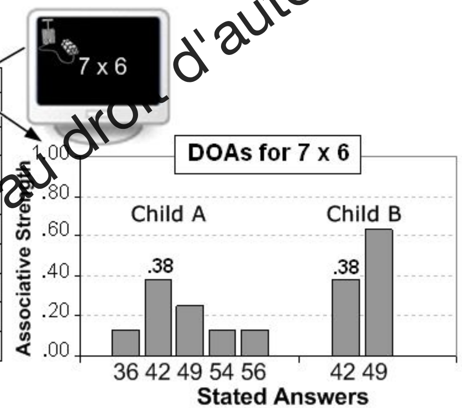
12 multiplications presented 8 times
Stressing the speed of responses (within 3 sec)

	Answers	
Block	Child A	Child B
1	36	49
2	42	42
3	49	49
4	42	42
5	49	49
6	54	49
7	56	49
8	42	42



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- Speed for accurate responses:
  - DC = ability matched > controls same age
- Errors: more errors and flatter distributions for DC than ability-matched, and controls of the same age

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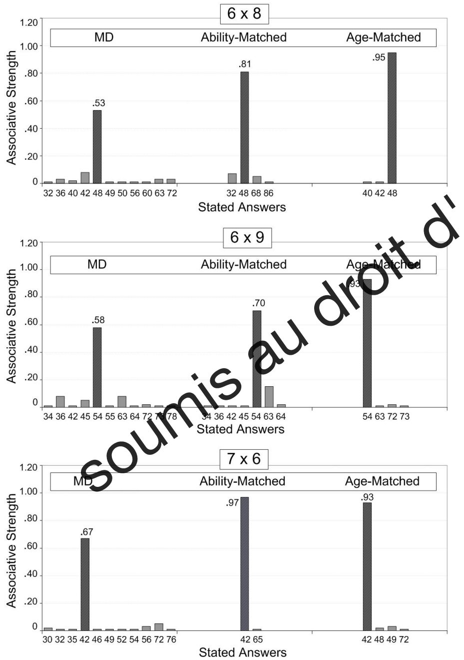

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DOA in DC ?

- Flatter distribution in DC than in ability-matched
- More aberrant associations
  – non-table errors
  – very distant operand-related errors
- Many competitors => weaker relative associative strength with the correct response
  => less retrieval of correct responses
  => Slower retrieval of correct responses
- => no need to resort to an hypothesis
  – of weaker active inhibition capacities
  – of a general problem to access information in LTM
- Why do DC children build these flat DOA ? Weak WM ?

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General cognitive factors: finger agnosia ?

– "*whenever a counting technique (...) exists at all, finger-counting has been found (...)*" Dantzig
– Common ethymological roots : "digit" - "digital"; "five" - "fingers"
– Fingers are used to count (one finger for one object) and to touch the objects we count
– Fingers can be used to access the magnitude of number words
  • *Which is bigger, three or five ?*
  • => recite the number names, raise one finger more each time, compare the collections of fingers
– Fingers are used to calculate: add - subtract
– Fingers are used in a regular order => configurations to represent numerosities => help accessing the cardinal meaning of a number words

General cognitive factors: finger agnosia ?

- Gerstmann syndrome (1924)
  – Lesion on the dominant parietal lobe: acalculia, finger agnosia, left-right disorientation & agraphia
- Kinsbourne & Warrington (63):
  – 8 children with finger agnosia, 6 of them were at least 2 years behind their age in mathematics
- Fayol, Barrouillet & Marinthe (98)
  – Neuropsychological test including finger gnosia in 189 children (5;9 y.o.) predicts mathematical performance 1 and 3 years later
- Noël (2005)
  – Finger agnosia at 6 years better predicts math skills one year later than processing speed

General cognitive factors: finger agnosia ?

- Population: 98 children (6 y.o.):
  - 16 with low scores in finger gnosia
  - 16 with high scores in finger gnosia
- Significant ≠ between the two groups in the numerical tasks
  - Slower to show x with your hands
  - Less good in "Count as far as you can"
  - Slower in Arabic digits: which one come first when you count ?
  - Reduced subitizing rank
  - More errors in simple additions
- Poster: playing a musical instrument leads to better finger gnosia as well as to better numerical skills (in grade 5 but not in grade 2 after one year of practice)

Gracia-Bafalluy & Noël

General cognitive factors: finger agnosia ?

- Fingers have a critical role in the development of numerical abilities in children
- Finger gnosia predicts numerical abilities
- In case of lesion, finger agnosia can be associated with acalculia
  - *"how loss of the finger sense leads to dyscalculia in skilled adults who no longer count on their fingers?"* (Butterworth, 99)

General cognitive factors: finger agnosia ?

- Finger mouvements and finger positions, as they are used in numerical tasks, get associated with numerical meanings
- Finger and hand shapes are represented in the parietal lobe (mirror cells for planning movements of the hand and fingers)
- The number representation gets associated with finger/hand representation in the parietal lobe

Functional relationship => geographical proximity
Links in development links in acquired cases

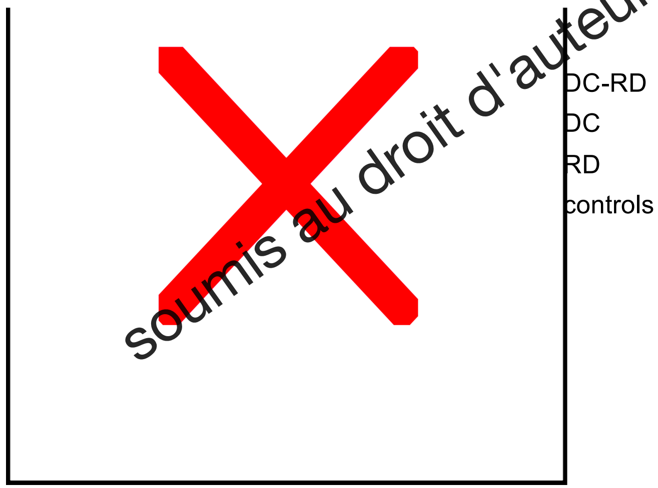
Butterworth, 1999

General cognitive factors: visual-spatial factors ?

Numerical factors: number sense

- Populations (8-9 y.o), IQ =
  - 18 control children
  - 10 RD (< pc25 in reading)
  - 10 DC (< -3ET in AF)
  - 11 DC and RD
- DC and DC-RD are slower
  - Reading 1 & 2-digit Arabic numbers ...even when controlling for colour naming speed
  - count 1-20, 45-65, 2 to 20 (by 2), 20-1
  - Dot counting
  - Comparing the magnitude of 2 Arabic digits, but not their physical size

Landerl, Bevan & Butterworth (2004) Cognition



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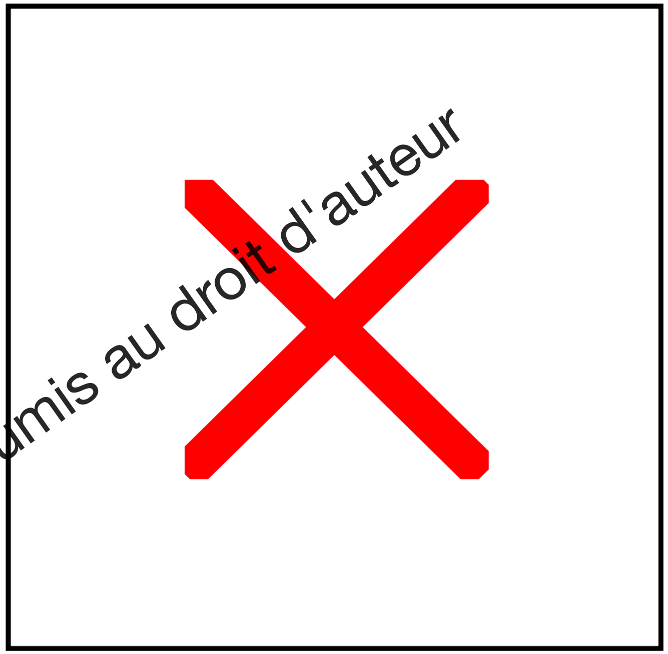
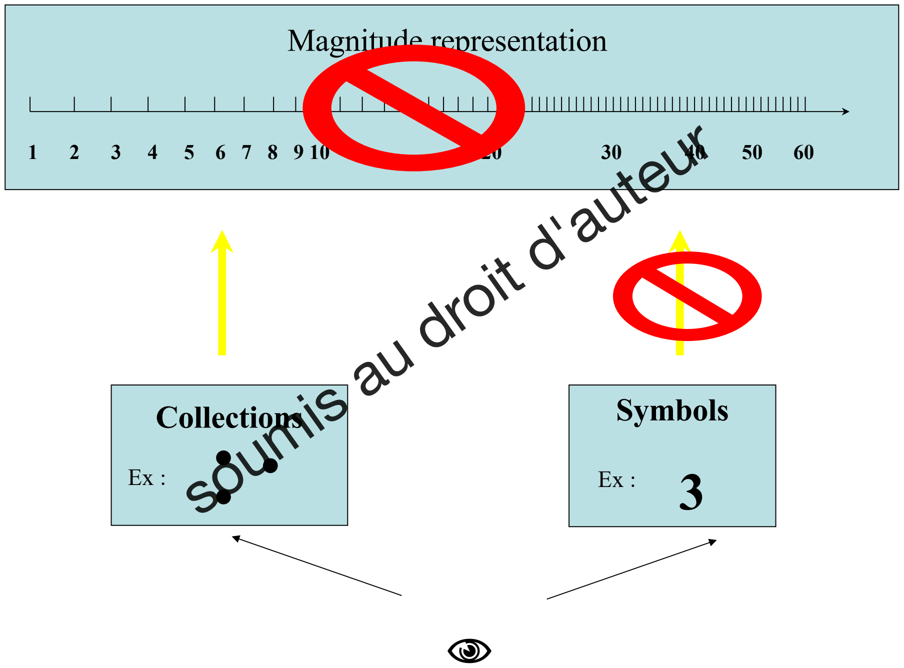


Landerl, Bevan & Butterworth (2004) : Dysfunction of the number sense

But all the tasks used require the processing of symbols (Arabic digits or number words)

↳ Possible hypothesis

↳ Magnitude representation is intact but the problem lies in the access to this representation from symbolic codes



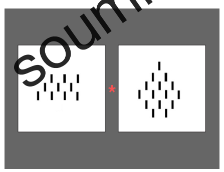
Rousselle & Noël (Cognition, 2006)

- 499 second grade children
- Selection on the basis of a collective testing
  - Writing Arabic numbers
  - Comparing Arabic numbers
  - Transcoding tokens into Arabic numbers
  - Additions & subtractions with no temporal constraints
  - Additions fluency
- if score < pc 15 and same evaluation by the teacher
  - 46 DC children (half were DC-RD)
  - 47 control children
- => same age (8 y.o), same intellectual level (WISC)

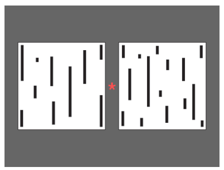
- processing quantities from a symbolic code

2 5

- processing quantities from collections



Easy Condition

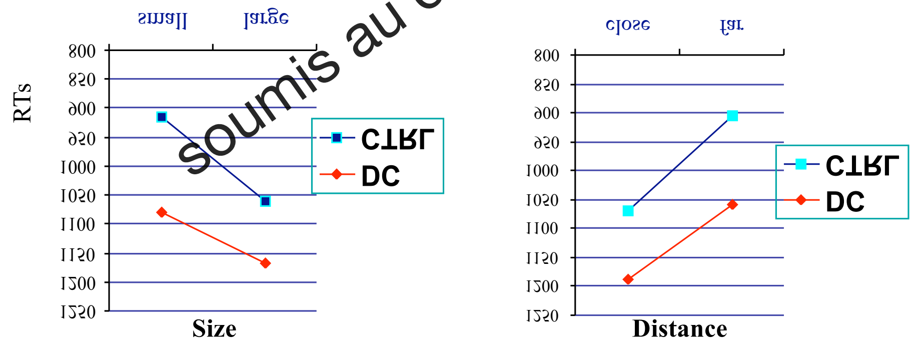


Difficult Condition

Comparaison of Arabic digits

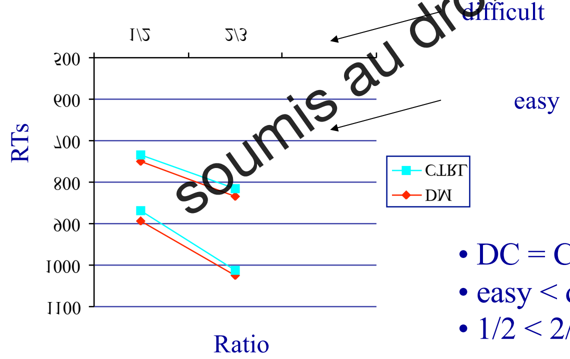
	Distance 1	Distance 3-4
small	1-2 2-3 3-4	1-4 1-5 2-5
large	6-7 7-8 8-9	5-8 5-9 6-9

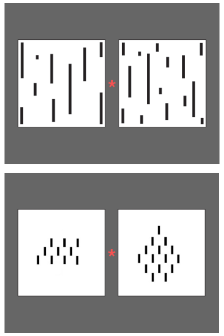
- DC are globally slower
- Show reduced size and distance effects



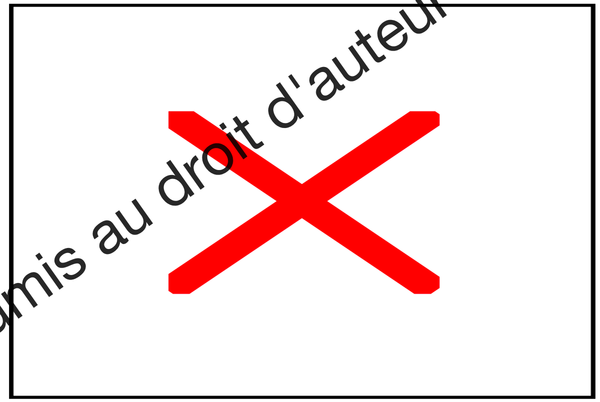
Comparing collections

easy		difficult	
1/2	2/3	1/2	2/3
6-12 8-16 14-28	6-9 10-15 16-24	6-12 8-16 14-28	6-9 10-15 16-24

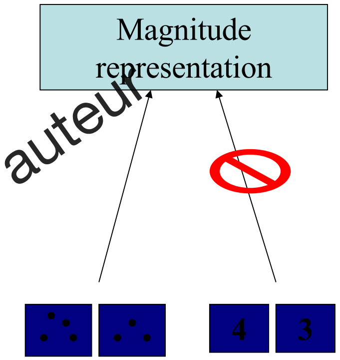




- DC = CTRL
- easy < difficult
- 1/2 < 2/3



Conclusion



⇨ Magnitude representation is preserved

⇨ Difficulties in accessing magnitude representation from symbolic codes

Numerical factors: automatic access to the magnitude representation

2 8

Number comparison
-Effect of congruency
- similar in all the groups

Size comparison
-No effect of congruency

Landerl & al. 2004, Cognition

Automatic activation of magnitudes ?

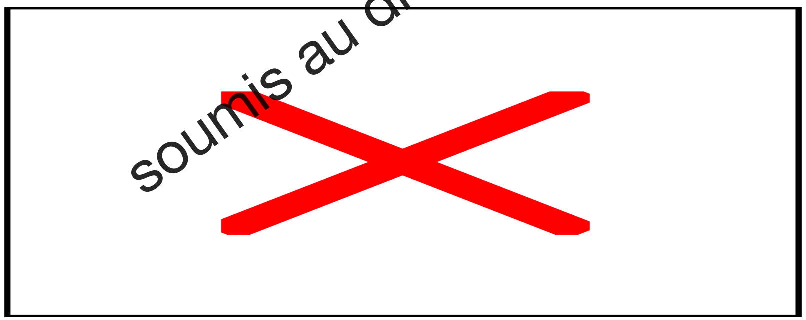
- Adults:
  - 19 who were diagnosed in the past as having dyscalculia difficulties (DC) (no dyslexia or ADD or ADHD);
  - 19 controls
- Three comparisons

Physical size	*Height*	*Grayness*
5 3	5 3	5 3

Rubinsten & Henik, 2005, Neuropsychology

Automatic activation of magnitudes ?

- Group x task x congruity (p=.05)
  - *Grayness*: congruity effect in controls (interference) but not in DC
  - *Height*: congruity effect in controls (interference) but not in DC
  - *Size*: group x congruency: ns; congruity effect in controls (interference & facilitation) and in DC (interference)



Rubinsten & Henik, 2005, Neuropsychology

Automatic activation of magnitudes ?

- Conclusion
  - “DC group have an intact internal representation of magnitude (...) if it had been damaged, no congruency effect could have appeared in any of the tasks”
  - “people with DC have problems automatically associating internal representations of magnitude to Arabic numerals”

Rubinsten & Henik, 2005, Neuropsychology

Automatic activation of magnitudes ?

- Population
  - 17 dyscalculics adults (no dyslexia or ADD or ADHD)
  - 17 dyslexics adults
  - 1 controls adults

  - Numerical Stroop
    - Numerical comparison: select the larger number
    - Physical comparison: select the digit in the bigger physical size

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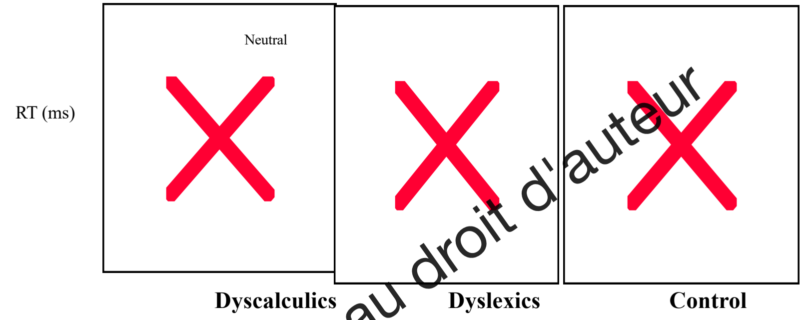
Rubinsten & Henik, in press, Educ. Psych.

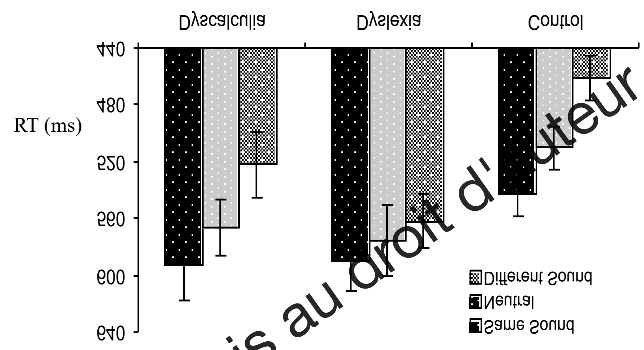


- Physical judgment was faster than numerical comparison
- This difference was larger for the dyscalculics
- Numerical comparison
  - Same congruity effect (of the irrelevant physical sizes) in the three groups
- Physical comparison
  - Smaller congruity effect in the dyscalculia group, composed only of an interference effect

Rubinsten & Henik, in press, Educ. Psych

- Navon task:
  - a big Hebrew letter made of small letters with the same sound or a ≠ one
  - Name the larger or the smaller letter

Rubinsten & Henik, in press, Educ. Psych



- Responding was faster in controls
- Phonological congruity effect, but smaller in the dyslexics

Rubinsten & Henik, in press, Educ. Psych

Automatic activation of magnitudes ?

- The ability of the dyscalculia group to automatically associate Arabic numerals with their representation of magnitude is not fully automatic
- The ability of converting graphemes to phonemes would not be fully automatic in dyslexic participants

Rubinsten & Henik, in press, Educ. Psych

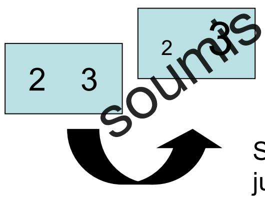
Automatic activation of magnitudes ?

- In Landerl & al., the ≠ between the physical judgment and the numerical judgment might have been so important that the numerical information did not have the time to interfere with the physical judgment
- In Rubinsten & Henik (in press), the ≠ between physical and numerical judgment was larger for dyscalculics than the other groups ... This could possibly explain their smaller congruity effect ?

Rousselle & Noël, 2006, Cognition

Automatic activation of magnitudes ?

- Paradigm used by Mussolin & Noël (J. Clin Exp Neuropsy, in press)
- Balancing the speed of physical and numerical judgment
  - Measuring the speed of numerical judgment 2 - 5
  - Measuring the speed of physical judgment 2 - 2

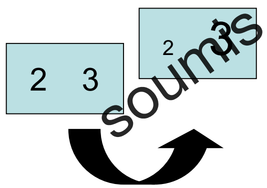


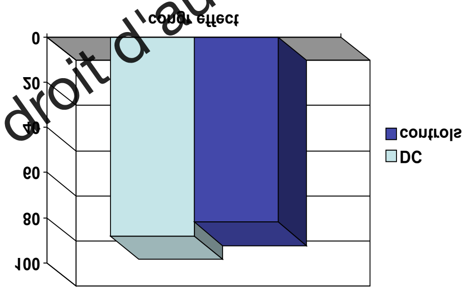
SOA : the ≠ between physical & numerical judgment, calculated for each individual

Rousselle & Noël, 2006, Cognition

Automatic activation of magnitudes ?

- Congruity effect
- Similar in the two groups





Rousselle & Noël, 2006, Cognition

Automatic activation of magnitudes ?

- Dyscalculic children are slow to access magnitude from numerical symbols
- But if that particularity is taken into account, they show the same automatic activation of magnitude as controls

conclusion

- General cognitive factors ?
  – Not a problem of inhibition nor of accessing information from long-term memory
  – For some DC, a problem of WM
- Numerical factors
  – Maybe not a default in the number sense
  – Maybe not a default in the automatic access to magnitude
  – Probably a default in accessing magnitude representation from symbols
  – Fingers might play a role in this connection: analogical representation, serial order, typical configurations that act as first symbols ?
- DC and DC-RD:
  – not different ... Just more difficulties for DC-RD in situation where language plays an important role

- These conclusions hold for groups of participants, not for each dyscalculics !
  – ≠ between control and dyscalculic children in magnitude comparison of Arabic digits
  – But only 9/42 dyscalculics have RTs > controls by 2 SD
  – 13/42 have normal RTs (< .5 SD from the controls)
- It is possible that different (cognitive) causes provoke dyscalculia

Thanks to my PhD studies and all the team !

- Laurence Rousselle
- Christophe Mussolin
- Sandrine Censabella
- Maria Gracia-Bafalluy
- Gaelle Meert
- Sandrine Mejias
- And Xavier Seron and Mauro Pesenti and ...

Kindergarten predictors of math learning disability

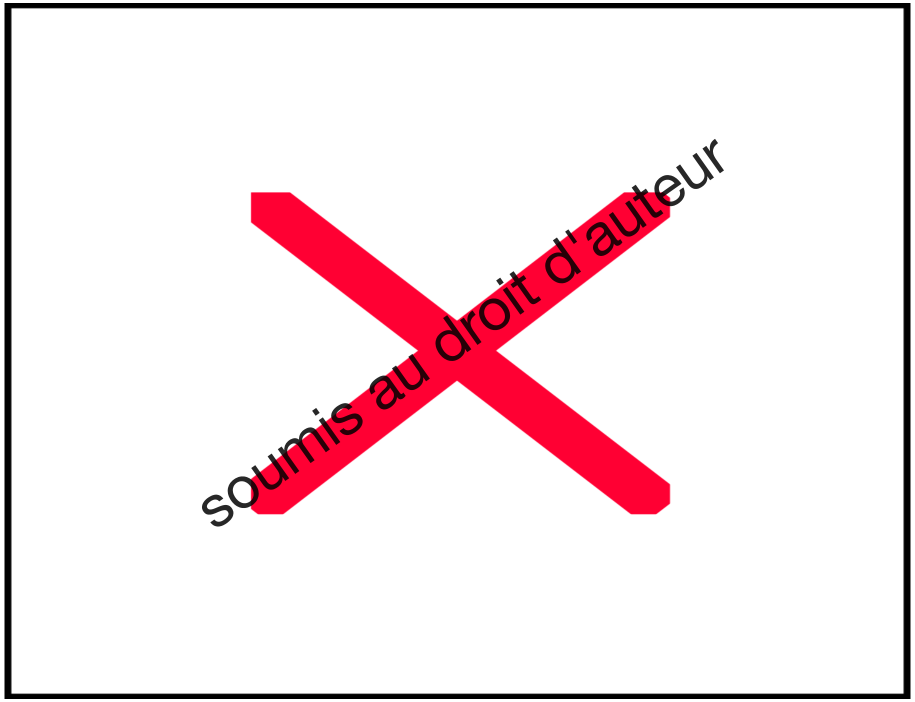
- 210 children studied for 4 years
- Testing in kindergarten
  - Basic math
    - Key-math test (numeration, addition, measurement & geometry)
    - TEMA: Tests of Early mathematics Ability
    - Woodcock Johnson-R Math calculation subtest (basic concepts, operations, applications)
  - Reading-related skills
    - Letter word identification;
    - RAN: rapid automatized naming (colours, numbers, objects)
  - Visual-spatial skills
    - Developmental test of visual perception
  - Stanford Binet Intelligence test
- Prediction MLD: <10 pc on both grade 2 & 3 => n=23

Mazzocco & Thompson, 2005, Learning Disabilities Research & Practice

Kindergarten predictors of math learning disability

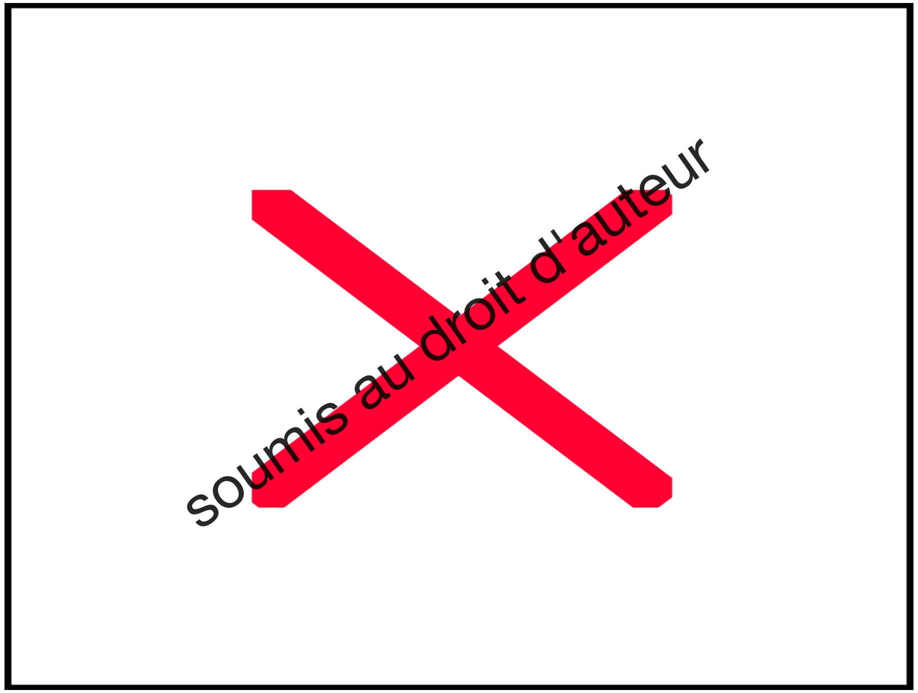
- Predictive models based on test scores
  - Key-math (geometry & measurement subtests): 78.7% correctly classified
  - Key-math (the 4 subtests) and TEMA: 83.5% cc
  - Key-math (the 4 subtests), TEMA, visual perception test and RAN: 79.1% cc
    - o note: 4 items are always included in these models
- Prediction based on items
  - Number consistancy (with fewer than 6 items)
  - Reading 1-digit numerals
  - Additions with 1-digit numbers (manipulatives)
  - Comparing 2 1-digit numbers
    - => 83.7% cc
    - But low PPV% of MLD among those who test positive (38.8%) => too much false positive (but are they also weak learners in mathematics ?)
- => best predictors : some numerical skills (not RAN on numbers, not counting larger sets (> 13) or small ones (<6)), no visual-spatial skills, no reading skills

Mazzocco & Thompson, 2005, Learning Disabilities Research & Practice



Etude de Molko et al. **Neuron (2003)**

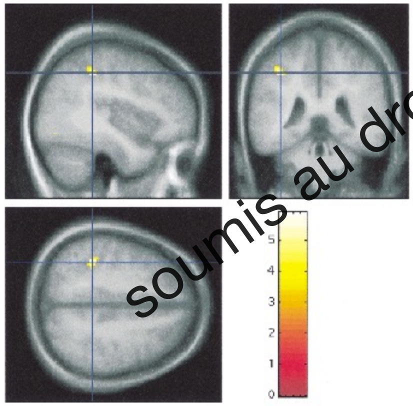
- Comparaison de sujets adultes contrôles vs. porteurs d 'un syndrome de Turner
- IRM structurale: altérations structurale du sillon intrapariétal droit chez Turner (longueur, profondeur)
- IRM fonctionnelle dans des tâches de calcul: variations atypiques de l 'activité cérébrale en fonction de la taille des nombres.



Etude de Isaacs, Edmonds, Lucas & Badian (2001)

- Deux groupes d 'adolescents nés prématurés
  - Résultats en calculs comparables à ce qui est attendu sur base de leur intelligence
  - Résultats en calculs inférieurs à ce qui est attendu sur base de leur intelligence
- Imagerie par résonance magnétique au repos

Résultats



- Une seule région distingue les deux populations:
  - *Sulcus intrapariétal gauche*
  - Densité de matière grise inférieure chez sujets pauvres en calcul