OVERVIEW

- Some of us
  - did not like math
  - had difficulties in the math classes
  - were anxious when they had to do math or take a math test
- Is it dyscalculia ???
- Is this a rare phenomenon ?
- What are the causes of dyscalculia?
- Can we do something about it ?

DSM V DEFINITION

Dyscalculia: difficulties learning number-related concepts or using the symbols and functions to perform math calculations.

- Can include difficulties with
  - number sense: 5 < 7
  - memorizing math facts: 3 x 6 =18
  - math calculations: 145 + 29=
  - math reasoning,
  - math problem solving "Jeanne has 8 marbles. Paul has 3 more. How many marbles does Paul have? "

DIAGNOSTIC CRITERIA

- All math learning disabilities are not dyscalculia
- These difficulties
  - (1) are objectivized by a standardized test
  - (2) appear during school age and interfere with the individual's academic performance
  - (3) persist for at least 6 months, despite the provision of specific interventions;
  - (4) are not due to a brain damage or diseases, neurogenetic disorders, premature birth, visual or hearing impairments, intellectual disabilities, or poor psychoeducational stimulation

PREVALENCE OF DYSCALCULIA

In Belgium, 3978 children (Desoete et al., 2004)

- Criteria:
  - (1) arithmetic performance at least 2 SD below the norms,
  - (2) performance lower than expected on basis of general school results or intelligence,
  - (3) not responsive to remediation at school
- 7.7% in third grade
- 6.6% in fourth grade

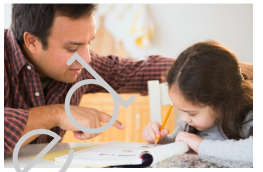
In Israel, 3029 children 10 y.o. (Gross-Tsur, et al. 1996)

- Criteria:
  - (1) math score : more than 2 years late
  - (2) IQ > 80
- 6.5 % meet the criteria

THE FUTURE OF PEOPLE WITH DYSCALCULIA

- Gross-Tsur et al. (1996):
  - 3029 Fourth grade children
  - 6.5% of them are 2-years behind despite normal intelligence and schooling
- Shalev & al. (2005).
  - 6 years later, retest those children with learning difficulties
  - Half of them are still DD (performance below pc 5)
  - 95% of them are performing in the lower quarter of a math test

SOME FAMILY AGGREGATE



31 families of children with persistent DD (over 3 years)

149 family members tested

Criteria for learning differences in math:

- Math performance < pc 25
- IQ > 85
- ≠ of more than 1 SD between IQ and math scores

➢ **Half of family members had difficulties in maths**

➢ **10 x more than the general population**

	% Math difficulties
mothers	67
fathers	41
siblings	53

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

TOO OFTEN UNDETECTED

- Barbaresi et al. (2005):
  - 5718 children born between 1976-82
  - difference between intelligence and maths score
  - 5.9 and 13.8% of children with dyscalculia
  - 50% not detected at school
  - Ratio of girls to boys: 11:10

COMORBIDITIES

Dyslexia

- about half of the DD children are poor readers (43% in Badian, 1983, 64% in Lewis et al., 1994, 62% in Luoni & al., 2023) and about half of the poor readers have DD

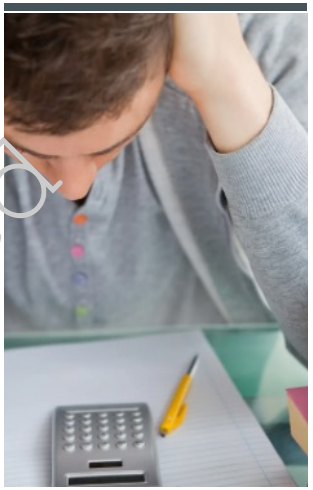
ADHD

- Between 25% (Gross-Tsur, Manor, & Shalev, 1996; Silva et al., 2015) and 42% (Desoete, 2008) of DD children have attentional problems

A LOT OF SUFFERING

- Moderator : How do the children feel in math class when they lose the thread?
- Child 1: It's horrible.
- Kid 1 : You feel stupid.
- Child 5 : When I don't know something, I'd like to be clever and I blame myself.
- Child 4: I want to cry and I want to be at home with Mum and I don't want to have to do any more maths.

Butterworth, 2000 “the mathematical brain”



A LOT OF SUFFERING

Adults

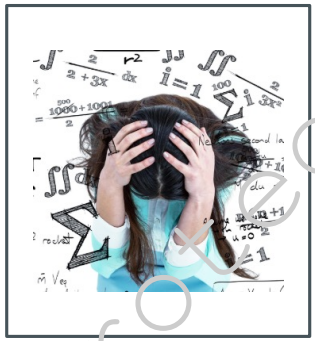
- *“I’ve never been good with numbers, but, being articulate and an excellent reader, it was dismissed as me being lazy or disruptive … (…) (I was) feeling stupid, angry, miserable and very very alone”*
- *"When I was in secondary 2, they agreed to let me pass on condition that I never studied math" … "I couldn't calculate what the cashier gave me back, so I never dared to do a student job" … "I don't manage my budget very well, or I have to write everything down"* (26-year-old woman).

MATH ANXIETY

“When I'm faced with a calculation, I liquefy, I break out in a cold sweat, then I have panic attacks, paralysing anxiety, my intellectual capacity collapses, I don't understand anything anymore, everything gets mixed up and I fall into a nervous breakdown that exhausts me for several hours. I can't do my tax return, I have enormous difficulty understanding the advice of my banker or my pension fund. “ (Woman with DD and an IQ of 140+)

Children with DD

- have more math anxiety than typical children (Kucian, 2018)
- are twice as likely to have high mathematics anxiety (Devine et al., 2018)
- but 7% of children with high mathematics anxiety had typical or high mathematics performance, so DD ≠ math anxiety (Devine et al., 2018)



CONSEQUENCES

In children

- Impact in school performance
- Higher math anxiety, lower self-esteem (Fritz, & al., 2019)

In adulthood

- Lower performance in numerical daily activities (Vigna et al., 2022)
  - **Time** (e.g., can you tell me for how long we have been doing this interview?),
  - **Measure** (what would be the amount of pasta in an average portion?),
  - **General semantic numerical** knowledge (e.g., do you remember the dates of the last world war?),
  - **Money** (e.g., if a shirt normally costs 50 euros but it is discounted by 10 %, how much would you have to pay for it?).
- Lower range of working opportunities, lower salaries, poorer financial well-being (Brunie de Bruin et al. 2021; Parsons & Bynner, 1997, Rivera-Batiz, 1992)
- Less access to Internet technology (e.g., computers and cell phones) (Jenson & al, 2010)

WHAT ARE THE CAUSES OF DYSCALCULIA ?

GENERAL COGNITIVE FACTORS

WHAT ARE THE CAUSES OF DYSCALCULIA ? ROLE OF GENERAL COGNITIVE FACTORS

Working memory: ability to hold and process information in short-term memory

- Weak WM leads to slower learning in preschool (Noël, 2009, Develp Psychology)
  - Of the number words
  - Of the counting list
  - Of the elaboration of that counting list (counting from ..)
- Weak WM leads to slower learning in grade 1 (Noël, Seron, Trovarelly, 2004, Current Psyc of Cognition)
  - Less mature strategies to solve simple additions
  - More errors in solving additions
  - More frequent counting on one's fingers
- Later on: difficulties in mental calculation, problem solving ...
- Could account for comorbidities with other learning disabilities

WHAT ARE THE CAUSES OF DYSCALCULIA ? ROLE OF GENERAL COGNITIVE FACTORS

Hypersensitivity to interference in memory

- Traces of information that are similar get confused
- This leads to quite specific difficulties in learning the arithmetical facts: 6 x 4 = 24

WHAT ARE THE CAUSES OF DYSCALCULIA ? ROLE OF GENERAL COGNITIVE FACTORS

Hypersensitivity to interference in memory

- Traces of information that are similar get confused
- This leads to quite specific difficulties in learning the arithmetical facts

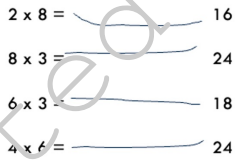
Louis and Pierre live in the street Emile Jean

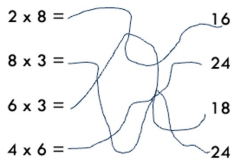
Pierre and Jacques live in the street Louis Denis

Jean and Jacques live in the street Emile Pierre

Denis and Jean live in the street Louis Denis

Replace	This gives ....
Emile: 1 Louis: 2 Jacques: 3 Denis: 4 Jean: 6 Pierre: 8	2 x 8 = 16 8 x 3 = 24 6 x 3 = 18 4 x 6 = 24



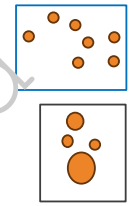


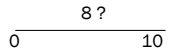
WHAT ARE THE CAUSES OF DYSCALCULIA ?

- A basic number skills problem

DIFFICULTIES EVEN IN BASIC NUMERICAL TASKS CHILDREN WITH DD

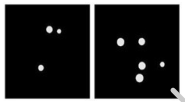
- Reciting the counting sequence: slower (7 y.o., Landerl & Butterworth, 2004)
- Enumeration of sets: slower, weaker understanding of the underlying principles (Landerl & Butterworth, 2004, Geary & al., 1992, Karagiannakis & Noël, 2020)
- Reading and writing numbers (Temple 1989, Sullivan et al., 1996, Karagiannakis & Noël, 2020
- Subitizing: smaller range (Moeller & al., 2009, but see Decarli, 2020, Karagiannakis & Noël, 2020)
- Comparing the magnitude of two numbers: slower and less accurate (Rousselle & Noël, 2007 and many others)
- Positioning numbers on a number line: less precise (Geary, Hoard et al., 2008, Karagiannakis & Noël, 2020
- One-digit calculation: more errors, slower, less mature strategies (Karagiannakis & Noël, 2020)





DIFFICULTIES THAT REMAIN EVEN IN ADULTS

- Smaller subitizing range [Cohen & al., 2019; Gliksman & al., 2019]
- Difficulties in number magnitude comparison [Ashkenazi, & al., 2010, Mussolin & al. 2011, Cappelletti & Price, 2014, De Visscher & al., 2018, Lenoiteviin & al., 2023]
- difficulties with basic arithmetical concepts such as the base-10 system and calculating with decimals and fractions (Eckstein, 2016)



6 2

« *affected children do not 'grow out' of DD* » (Kaufmann et al., 2020)

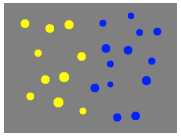
A BASIC NUMBER SKILL PROBLEM

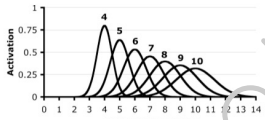
The approximate magnitude system

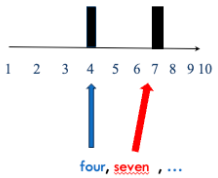
- Babies (and many animals) can discriminate between two dots collections if they are sufficiently numerically distant from one another (Xu & Spelke, 2000)
- This system would be the basis for understanding the meaning of number words and for all math learning
- Dyscalculia would be due to an impaired Approximate Number Sense - ANS (Wilson & Dehaene, 2007)

The exact number system

- As humans, we learn symbolic number systems: the number words, the Arabic digits that require to build a precise magnitude representation
- Dyscalculia would be due to a difficulty in grasping the number sense of symbolic numbers and processing these numbers (Noël & Rousselle, 2011)



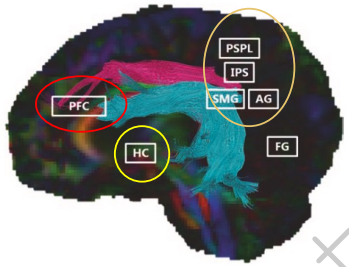




BRAIN PECULIARITIES

- Brain structure: less gray matter in the **posterior parietal cortex**, including the IPS (Isaacs, & al., 2001; Rotzer et al., 2008; Rykhlevskaia, & al., 2009), in **prefrontal cortex** (Rotzer et al., 2008) and in **hippocampal areas** (Rykhlevskaia et al., 2009)

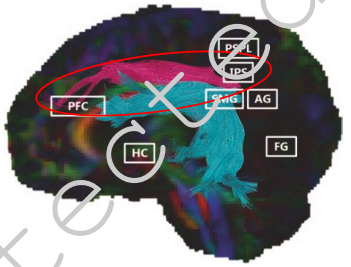
⚠ no brain lesion ! not diagnostic !



De Smedt, Peters, Ghesquière (2019)

BRAIN PECULIARITIES

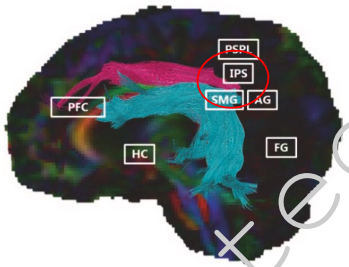
- Brain connectivity: weaker connections between the **prefrontal cortex and the posterior parietal** cortex (Tsang, & al., 2009; Van Beek, & al., 2014, Rykhlevskaia et al., 2009, Kucian et al., 2014).



De Smedt, Peters, Ghesquière (2019)

BRAIN PECULIARITIES

- Less brain activity in **the IPS** during nonsymbolic comparison (Price, Holloway, Räsänen, Vesterinen, & Ansari, 2007), symbolic comparison (Mussolin et al., 2010; Soltész, & al., 2007), and symbolic ordering (Kucian et al., 2011).
- Sometimes, increased brain activity in the frontoparietal network (e.g., during arithmetic, Davis et al., 2009; Rosenberg-Lee et al., 2015), maybe compensatory mechanisms characterized by stronger recruitment of supporting areas associated with working memory or control processes
- Often, no difficulty-related modulation of the frontoparietal network in children with DD

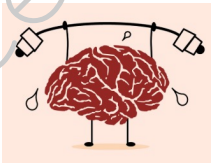


De Smedt, Peters, Ghesquière (2019)

HOW CAN WE HELP ?: GENERAL COGNITIVE FACTORS

As these domain-general skills impact all the learning process, training them might have a wide impact on the child's learning

Training programs to enhance working memory capacities



Study of Honoré & Noël (2017, Journal of Numerical Cognition)

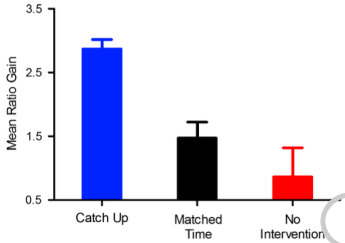
- 46 preschoolers randomly assigned to
  - 25 sessions (in 5 weeks) of WM training
  - Control condition
- Impact on 3/5 of memory tasks but no impact on the numerical tasks (0/6)

Similar results in Honoré & Noël (2017, J. of Educ & Training Studies), Park, & al., 2016 (J. of Child Ecp Psych)

HOW CAN WE HELP? TRAINING THE NUMERICAL SKILLS

The Catch-up program of Holmes & Dowker (2013, Res. in Math Educ)

- Children with MLD (selected by their teachers, mean age: 8)
- Three groups
  - The Catch-up intervention group : N=34. two 15 minute sessions per week, during 4 months, delivered by classroom assistants who received 3 half-days of training
    - diagnostic assessments of the child's ability in each component of numeracy.
    - identifying an appropriate focus for intervention based on the child's specific area of difficulty
    - Ongoing monitoring
  - matched-time control group (N=50): receive the same amount of individual intervention but not using the program;
  - no-intervention control group (n 42): receive only their usual classroom lessons.



HOW CAN WE HELP? TRAINING THE NUMERICAL SKILLS

Six Principles of Effective Intervention for Students with MLD (Fuchs & al., 2008)

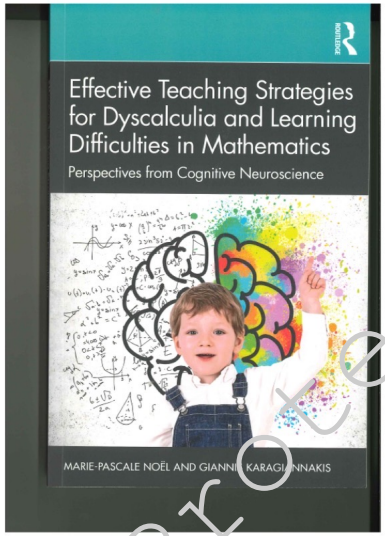
- instructional explicitness: A meta-analysis of 58 math studies revealed that students with MLD benefit more from explicit instruction than from discovery-oriented methods (Kroesbergen & Van Luit, 2003)
- instructional design to minimize the learning challenge: anticipate and eliminate misunderstandings with precise explanations and the use of carefully sequenced and integrated instruction so that the achievement gap can be closed as early as possible.
- instruction provides a strong conceptual basis for the procedures that are taught.
- Drill and practice
- cumulative review,
- incorporate motivators to help students regulate their attention and behavior and to work hard.

=> need to have a clear idea of

- the developmental pathway of the child in each of the numerical domains,
- the possible misunderstanding or typical errors observed in children with MLD
- What works best in research of training or intervention

Noël, M.P. & Karagiannakis, G. (2022):

A bridge from cognitive science to detailed practices



AN EXAMPLE OF CAREFULLY SEQUENCES INSTRUCTION FOR SIMPLE ADDITIONS AND SUBTRACTIONS: THE MATH FLASH

16 weeks, 3 sessions per week (25 min)

- Lessons 1 & 2: facts of + 1 and - 1, using manipulatives and the number line, teaching the commutative property of addition, and emphasizing that this property does not apply to subtraction.
- Lessons 3 & 4: facts of + 0 and - 0 are introduced, using manipulatives and the number line.
- Lessons 5 & 6: revision of the + 1, - 1, + 0, - 0 math facts
- Lesson 7: learning doubles from 0 to 6 (i.e., 0 + 0, 1 + 1, 2 + 2, 3 + 3, 4 + 4, 5 + 5, 6 + 6, 0 - 0, 2 - 1, 4 - 2, 6 - 3, 8 - 4, 10 - 5, 12 - 6), using manipulatives and rehearsing doubles chants.
- Lesson 8: learn facts with + 2 and – 2 using manipulatives and the number line
- Following lessons: Difference between "just know" the math fact, and « do not know » => so using the count up. Counting-up strategies for addition and subtraction are taught using the number line and their fingers, family of 3, 4, ...)
  - Addition : start counting with the bigger number and count up the smaller number on your fingers. The answer is the last number spoken. 5 + 2 = 5, 6, 7

Motivation: Games, system of rewards

=> strong conceptual basis using manipulatives and number line

Fuchs, Fuchs, Powell, Seethaler, Cirino et Fletcher, (2008)
Learning Disability Quarterly

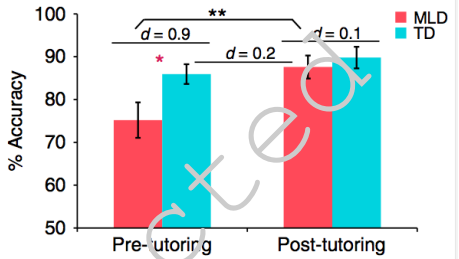
THE MATH FLASH INTERVENTION PROGRAM:

Each session

- *flash card warm-up: cards with learnt problems. If answered* incorrectly, the tutor instructs them to "count up" and the card is placed in the "incorrect" pile. After 2 minutes, the flash cards answered correctly are counted, and the student graphs this number on his/her flash card graph. **=> *review and direct feedback***
- *conceptual and strategic instruction*: tutors introduce or review concepts and strategies.
- *lesson-specific flash card practice* for 1 minute with only problems seen at that lesson **=> drill & practice**
- *computerized practice* : the computer game include 10 lesson-specific facts and 5 review facts; children see the problem for 1.3 sec and then have to retype it and get applause if correct **=> *cumulative review***
- *reinforcement program* : Tutors award gold stars following each component of the tutoring session; 16 stars : the student chooses a small prize from a real treasure box. **=> motivators**

Fuchs, Fuchs, Powell, Seethaler, Cirino et Fletcher, (2008)
Learning Disability Quarterly

- 15 children with MLD and 15 control children (3d grade), same age, IQ, sex, WM
- Better performance for MLD children after the training

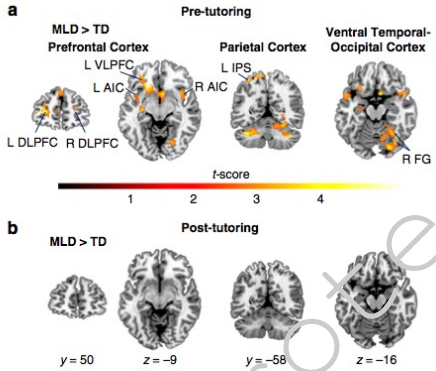


Iculano, Rosenberg-Lee, Tenison, Fuchs, Supekar & Menon, 2015, *Nature Communications*

- Before the intervention: MLD showed higher brain activation in different areas: need for additional neural resources
- After: normalization of the brain activity

➢ Possible to improve children's performance in a specific math process and to change the brain's activation while doing a certain math process

⚠ ≠ "curing" MLD
often need of a lasting support program



MATH ANXIETY

Young et al. (2012) observed, in highly math anxious children,

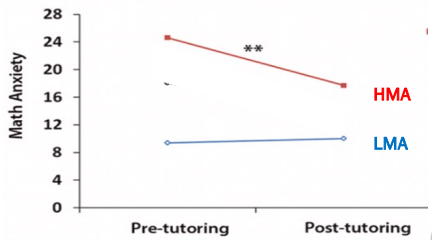
- increased activity in the right amygdala, a brain region associated with processing emotion, which is involved in the fight-or-flight response
- decreased activity in fronto-parietal regions that support numerical problem solving.

Can we intervene ?

- Supekar et al., 2015: math intervention in a positive atmosphere could act at an exposure therapy

Method:

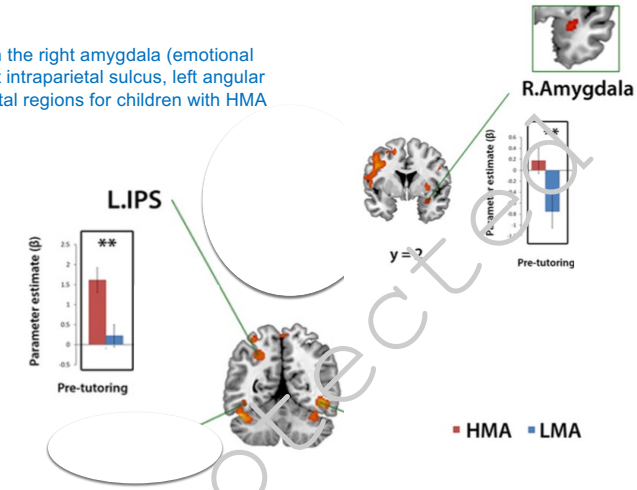
- 28 children in 3rd grade
- 2 subgroups according to their level of math anxiety (Q):
  - 14 low math anxiety (LMA),
  - 14 high math anxiety (HMA)
- No ≠ age, IQ, WM, performance in small calculations
- same intervention as the previous study



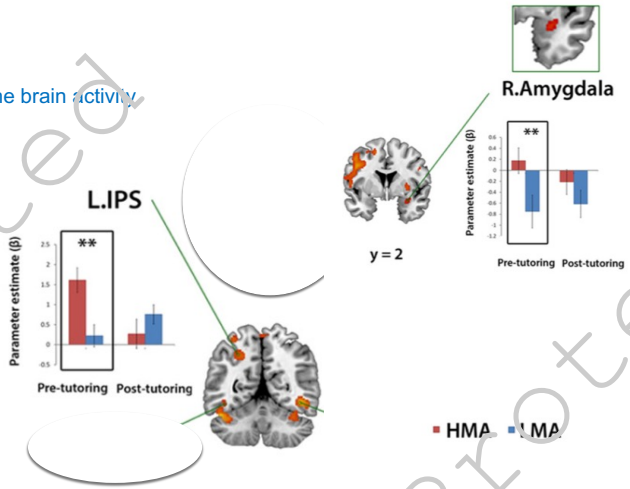
↘ math anxiety in the HMA group after the intervention

Supekar, Iuculano, Menon (J of Neurosc, 2015)

Before the training
higher activation in the right amygdala (emotional regulation) and left intraparietal sulcus, left angular gyrus, and prefrontal regions for children with HMA



After the training:
normalization of the brain activity



TRANSCODING DIFFICULTIES IN AN ADULT PATIENT

- A 34 y.o. woman
- Failed primary school and redirected to special education
- Brain MRI with no particularities
- Normal intelligence (total IQ 87)
- Normal reading capacities

- objectified numerical difficulties
  - 80 calculations: 43/80 CR (-5.41 SD) and too slow (-2 SD)
  - Transcoding (writing AN under dictation): 44/60 CR (deficit)
- + mathematical anxiety

Fraitteur, De Visscher & Noël, unpublished

EXPLE OF ERRORS IN NUMBER DICTATION

- /40 003/ => 40.03
- /40 025/ => 40.25
- /200 006/ => 200.06
- /604 205/ => 6040.205
- /365 00/2 => 365.02

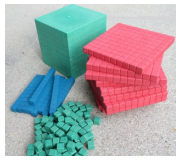
AN reading : prononciation of the zero
60.001 read « sixty thousand zero one »
400.026 read « four hundred thousand zero twenty-six »

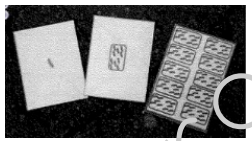
	Before
Transcoding	
writing AN under dictation	53%
Reading AN	70%
Number comprehension ?	
AN comparison	100%
VN comparison	100%
Number production?	
Bills (of 1, 10, 100, 1000 and 100,000) to AN	30%
Bills (same values but in written words) to VN	87%
Base 10 understanding	
A product costs 325 euros, and you only have 10-euro bills. How many should you give? (oral presentation)	51%

EXPLE OF ERRORS

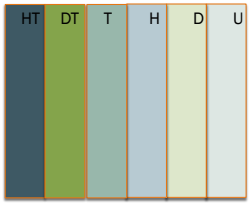
- **Dictation**
  - /40 003/ => 40.03
  - /40 025/ => 40.25
  - /200 006/ => 200.06
  - /604 205/ => 6040.205
  - /365 00/2 => 365.02
- **Bills => AN**
  - 60 001 => 60.01
  - 50 205 => 5205
  - 500 004 => 500.04
  - 503 402 => 53402
  - 516 004 => 516.04

- 7 sessions: work on base 10 and its positional aspect
- Base 10 of verbal numbers
  - If you want to buy x number of sweets, how do you do it? (e.g. 36: I take 36 sweets or 3 bags and 6 sweets…): draw these representations.
  - Work on equivalence: 36 sweets or 3 bags and 6 sweets.
  - Working first with 2-, then 3-digits numbers, then with even larger numbers
- Introduction of the abacus and the concepts of U, D, H…. And similar games with the abacus





cards with 1 candy,
a bag of 10 candies,
a case of 100 (10 bags),
a pallet (of 10 cases),
a truck (10 pallets)
a candy factory (10 trucks)



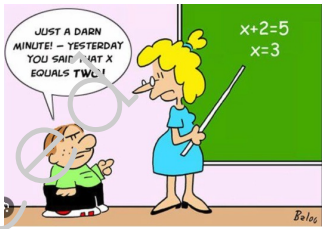
	Before	After	1 year after
Transcoding			
writing AN under dictation	53%	100%	100%
Reading AN	70%	100%	100%
Number comprehension ?			
AN comparison	100%	97%	100%
ON comparison	100%	100%	100%
Number production ?			
Bills (of 1, 10, 10, 1000 and 100,000) to AN	30%	100%	100%
Bills (same values but in written words) to ON	87%	100%	100%
Base 10 understanding			
A product costs 40,025-francs, and you only have 1000-franc bills. How many should you give? (oral presentation)	51%	100%	100%

=> This is never too late !!!!

CONCLUSION

- DD is not a rare phenomena : about 6.5 % of children affected
- Still under-diagnosed
- High comorbidity with dyslexia and, to a lesser extend, with ADHD
- Emotional suffering (lower self-esteem, math anxiety …) and socio-economic impact
- Difficulties already in very basic number skills, especially with the meaning of symbolic numbers
- Influence of general cognitive factors such as WM and sensitivity to interference in memory
- Brain peculiarities: fronto-parietal areas
- Intervention targeting the numerical skills are effective (performance and brain activity)
- They need to be based on a clear understanding of the child's developmental pathway in the different numerical processes

THANK YOU !



Thanks to the EDDA for organizing this event

Thank you for listening and for all the attention you will give to people who suffer from math learning difficulties. We need to change the way we consider these people, and each and every one of you is part of that change !

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