DYSCALCULIA: DEFINING, DIAGNOSING, AND EXPLORING ITS COMPLEXITIES

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PLAN

I. What do we know ?

II. Two questions under discussion
- What is the basic number deficit underlying dyscalculia
- What are the subtypes of dyscalculia?

III. Conclusion

DEFINITION: DSM V

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

Can include difficulties with
- number sense,
- memorizing math facts,
- math calculations,
- math reasoning, and
- math problem solving

These difficulties
- (1) persist for at least 6 months, despite the provision of specific interventions;
- (2) appear during school age and can last until adulthood, interfering with the individual's academic or occupational performance;
- (3) not due to a brain damage or diseases, neurogenetic disorders, premature birth, visual or hearing impairments, intellectual disabilities, or poor psychoeducational stimulation

CRITERIA IN RESEARCH

- below **35th percentile** in both 1st and 2nd grade, IQ > 80 (Geary et al., 2000: MLD),
- below **25th percentile** (Passolunghi & Mammarella, 2012: MLD), Wilson & Lee Swanson, 2001: disabilities in mathematics)
- below 1 *SD* to mean (about the **16th percentile**) in two tests, over 4 years , IQ > 70 (Bugden & Ansari, 2016: DD)
- below **10th percentile** (Mazzocco et al., 2011: DD)
- < 2 DS on a math test (about **2nd percentile**), IQ > 85, no other neuropsychological disorder (ADHD, motor disorder, ...) (Decarli et al., 2023: DD)
- below **3 *SD*** on an arithmetical fact test (Landerl et al., 2004: DD)
- lagging **1.5 years** in school (van der Sluis et al., 2004: arithmetic-learning deficit).

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MLD ≠ DD : severity of the difficulties + exclusion criteria

PREVALENCE

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

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

PERSISTENT DIFFICULTIES

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

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)

ADHD

- Between 25% (Gross-Tsur, Manor, & Shalev, 1996; Silva et al., 2015) and 42% (Desoete, 2008) of DD children have attentional problems
  - Ashkenazi and Henik (2010) observed deficient attentional functions in adults diagnosed with DD

Math anxiety

- 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 77% of children with high mathematics anxiety had typical or high mathematics performance, so DD ≠ math anxiety) (Devine et al., 2018)

TESTIMONIALS

Children

Moderator : How do the children feel in maths 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 : 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.

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 do a student job" … "I don't manage my budget very well, or I have to write everything down" (26-year-old woman).

IMPACT

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?).
- people with low numeracy have a lower range of working opportunities, lower salaries, poorer financial well-being (Bruine de Bruin et al. 2021; Parsons & Bynner, 1997, Rivera-Batiz, 1992)
- less access to Internet technology (e.g., computers and cell phones) (Jensen & al, 2010)

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))

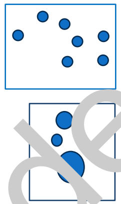
Reading and writing numbers (Temple 1989, Sullivan et al., 1996, Karagiannakis & Noël, 2020

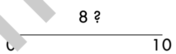
Subitizing: smaller range (Moeller & al., 2009, but see Decarli, 2020, Karagiannakis & Noël, 2020)

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)

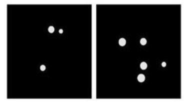




DIFFICULTIES THAT REMAIN EVEN IN ADULTS

Difficulties in adults in very basic numerical skills

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

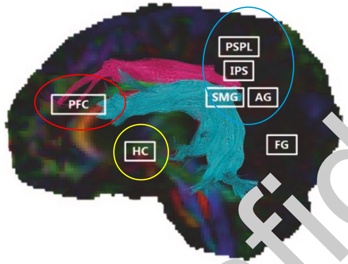


6 2

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

BRAIN PECULIARITIES

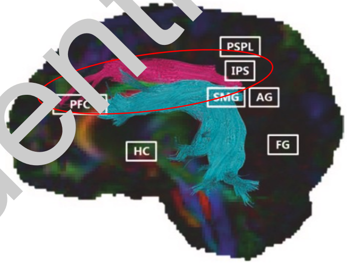
Brain structure: less grey matter in the **posterior parietal cortex**, including the IPS (Isaacs, & al., 2001; Rotzer et al., 2008; Rykhlevskaia, & al., 2009), in **prefrontal cortex** (Rotzer et al., 2008) and in **hippocampal areas** (Rykhlevskaia et al., 2009)



De Smedt, Peters, Ghesquière (2019)

BRAIN PECULIARITIES

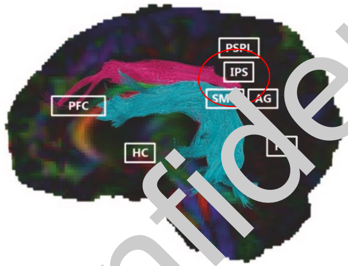
- Brain connectivity: weaker connections between the **prefrontal cortex and the posterior parietal** cortex (Tsang, & al., 2009; Van Beek, & al., 2014, Rykhlevskaia et al., 2009, Kucian et al., 2014).



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; Soltesz, & 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), may be 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



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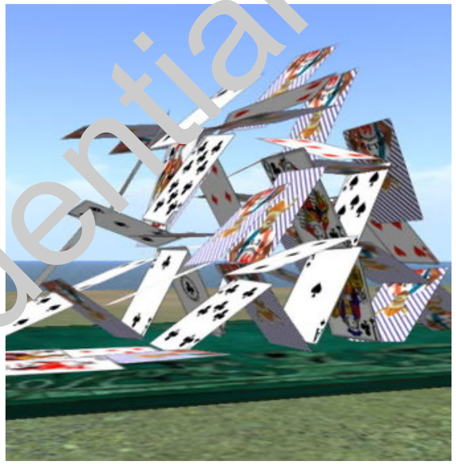
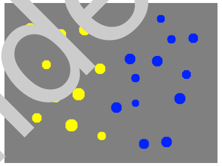
II. QUESTIONS UNDER DISCUSSION

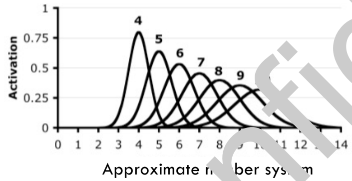
Q1: what is the basic number deficit?



Q1: WHAT IS THE BASIC NUMBER DEFICIT?

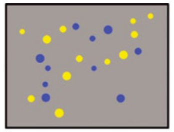
- Dyscalculia would be due to an impaired Approximate Number Sense - ANS (Wilson & Dehaene, 2007)
- Babies (and many animals) can discriminate between two dots collections if they are sufficiently numerically distant from one another (Xu & Spelke, 2000)



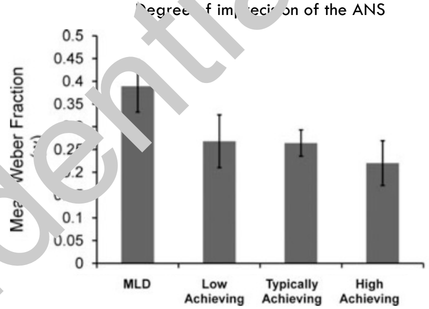


DEFICIT IN THE ANS: MAZZOCCO, FEIGENSON, AND HALBERDA, 2011

14 y.o. children,
10 MLD : performed < pc 10 on a math test
9 LA: pc 11-pc25
HA: > pc 95



Question: Are there more blue dots or more yellow dots?



PUBLISHED RESULTS: IMPORTANCE OF THE AGE

	Age	symbolic	Non-symbolic
De Smedt & Gilmore, 2011	6 y.o.		DD=C
Rousselle & Noël, 2007	7 y.o.		DD=C
Landerl & al., 200	8-9 y.o.		-
Iuculano et al. 200	8-9 y.o.		DD=C
Decarli & al. 202	9 y.o.		DD=C
Mazzo & al. 2010	10 y.o.		DD<C
Mussolin, Mejias & Noël, 2010	10-11 y.o.		DD<C
Price & Ansari, 2007	12 y.o.		DD < C
Anobile & al. 2018	12 y.o.		DD < C
Mazzocco, Feigenson & al. 2011	14 y.o.		DD < C

The first deficit is not in the non-symbolic comparison

(updated Noël & Rousselle, 2011)

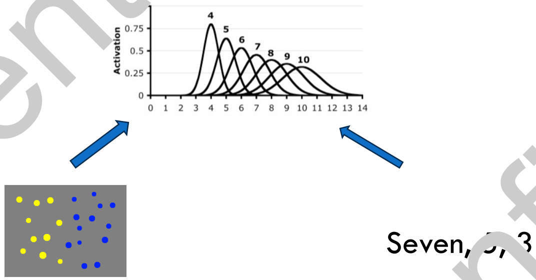
HUMANS ALSO USE NUMERICAL SYMBOLS

The words: one, two, three, four ….

The Arabic digits: 1, 2, 3 , 4 …

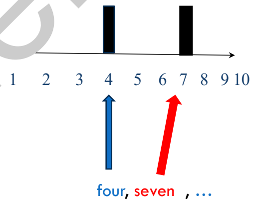
ANS MAPPING HYPOTHESIS

- Children learn the meaning of number words by mapping them onto the ANS
- the ANS is the basis for all math learning – a more acute ANS allows a better learning of numbers and math



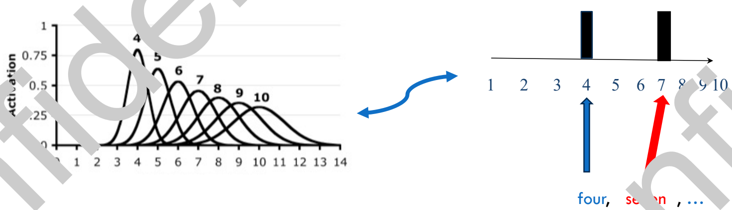
NEW REPRESENTATION HYPOTHESIS

Learning the meaning of number words is a long process because it requires the child to create a new type of representation: a precise representation of number magnitude.



NEW REPRESENTATION HYPOTHESIS

Only after, the child will connect both representations together and be able, for instance, to estimate the size of a collection without counting it.



=> this exact system is the main basis for calculation

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Decarli & al. 2020	9 y.o.	DD < C	DD=C
Piazza & al., 2010	1[illegible] y.o.	-	DD<C
Mussolin, Mejias & Noël, 2010	10-11 y.o.	DD<C	DD<C
Price & Ansari, 2007	12 y.o.	-	DD < C
Anobile & al. 2018	12 y.o.		DD < C
Mazzocco, Feigenson & al. 2011	[illegible] y.o.		DD < C

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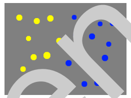
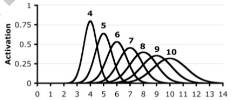
(updated Noël & Rousselle, 2011)

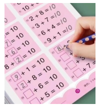
SCAFFOLDING OR REFINEMENT ?

- Scaffolding: the ANS is the basis for all math learning



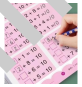


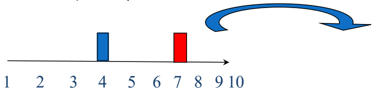
5, 3

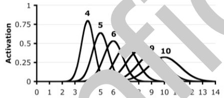


- Refinement: learning symbolic numbers and processing them (arithmetic) leads to a better (more precise) ANS (Noël & Rousselle, 2011)

Two, 3, five, ...







SUMMARY OF RESULTS

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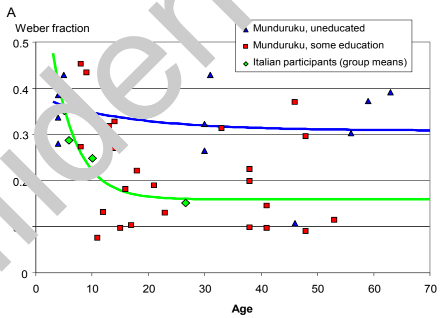

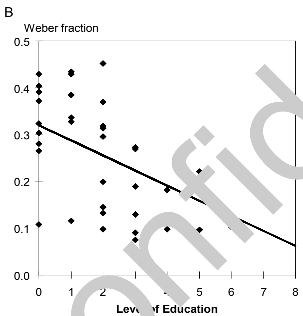

Piazza & al. Psych Science 2013

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SCAFFOLDING OR REFINEMENT ? SUAREZ-PELLICIONI & BOOTH, 2018

38 children tested at 10 and 13 y.o.

- Test of Symbolic arithmetic (additions, subtractions and multiplications)
- Magnitude comparison of two sets of dots: performance and brain activation in the IPS

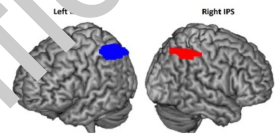
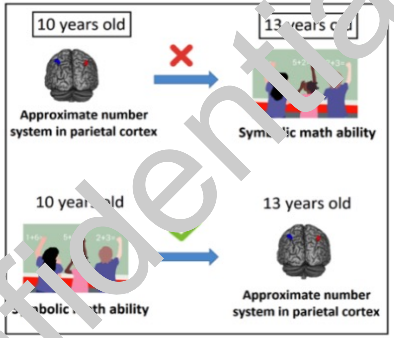


FIGURE 3 ROIs in the left and right IPS. ROIs were anatomically

SCAFFOLDING OR REFINEMENT ? SUAREZ-PELLICINI & BOOTH, 2018



Results:

Dot comparison (performance and brain activation) at 10 y.o. does **not** predict math skills at 13 y.o (~~scaffolding account~~)

Symbolic arithmetic skills at 10 y.o. predicts both performance and brain activation in the dot comparison at 13 y.o

=> supports the refinement account

Q1: CONCLUSION

The core number deficit is still debated

⇒Current data are in favor of the refinement account: learning symbolic numbers (words and Arabic digits) leads to the development of an exact number representation that will refine the ANS

⇒If children have difficulties understanding and processing symbolic numbers, the refinement of their ANS is slower

⇒ in terms of the precision of the ANS: the difference between them and typical children increases over time

II. QUESTIONS UNDER DISCUSSION

Q2: what are the subtypes of DD?

Q2: SUBTYPES OF DYSCALCULIA ?

- Different studies, using cluster analyses for instance, have tried to distinguish among subtypes of people with DD
- Very different profiles were obtained
- No clear ideas of the mechanisms underlying the different subtypes of dyscalculia

=> "subtyping has not yielded consistent domain-specific differences among children with dyscalculia, and has not proved useful in understanding or treating the disorder" (Shalev & von Aster, 2008)

Q2: SUBTYPES OF DYSCALCULIA ? DE VISSHER, & NOEL

- One type of dyscalculia concerns people who have serious difficulties with arithmetic and, in particular, with remembering arithmetical facts (3 x 5=?)
- We have reported the case of a woman (high IQ) who had severe difficulties in AF, especially multiplication facts and showed that is was due to a hypersensitivity to interference in memory (DeVisscher & Noël, 2013, *Cortex*)
- Group study of grade 4 children: those with low arithmetic fluency show greater sensitivity to interference in memory (*De Visscher & Noël, 2014 Developmental Science*)

- Memorize

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

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

2 x 8 = 16

8 x 3 = 24

6 x 3 = 18

4 x 6 = 24

2 x 8 = 16

8 x 3 = 24

6 x 3 = 18

4 x 6 = 24

Q2: SUBTYPES OF DYSCALCULIA ?

DE VISSHER, VAN DER LINDEN & NOËL (2015, *COGNITION*)

Hypothesis

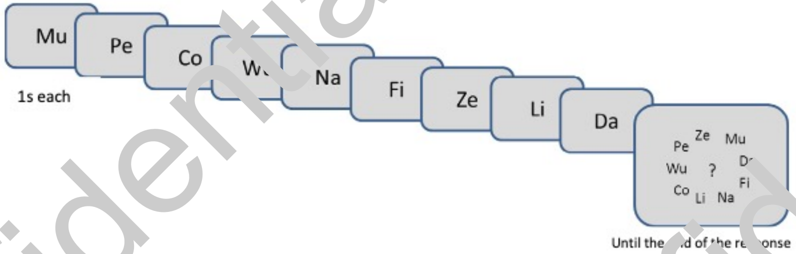
- A hyper-sensitivity-to-interference in people suffering from an AF dyscalculia
- An order deficit in people with global dyscalculia that prevents them from learning ordered series, even non-numerical series

Population

- 20 adults with no learning difficulties (control)
- 18 adults with math difficulties since primary school; reasoning (Raven) > 30th percentile; no other difficulties
  - Global DD: < 7th percentile on a global math test and weak in AF as well
  - Specific AF deficit: in the norms for the global math test but < grade 5 children on an AF test

TASK

Learning non-sense sequences: Hebb paradigm



De Visscher, Szmalec, Van der Linden & Noël, 2015, *Cognition*

Fillers: all different sequences

Order	Repetition	CONDITION	1 Syll	2 Syll	3 Syll	4 Syll	5 Syll	6 Syll	7 Syll	8 Syll	9 Syll
1	1	Fillers	Co	Na	Mu	Fi	Pe	Li	Wu	Ze	Da
2	1	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
3	2	Fillers	Mu	Ze	Da	Li	Co	Pe	Fi	Wu	Na
4	1	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri
5	3	Fillers	Wu	Da	Mu	Pe	Na	Fi	Li	Ze	Co
6	2	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
7	4	Fillers	Da	Na	Mu	Ze	Pe	Co	Li	Wu	Fi
8	2	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri
9	5	Fillers	Ze	Wu	Li	Pe	Co	Na	Fi	Mu	Da
10	3	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
11	6	Fillers	Wu	Da	Pe	Fi	Co	Na	Mu	Li	Ze
12	3	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri

Experimental sequences repeated several times during the experiment and made of the same syllables as the fillers = interfering

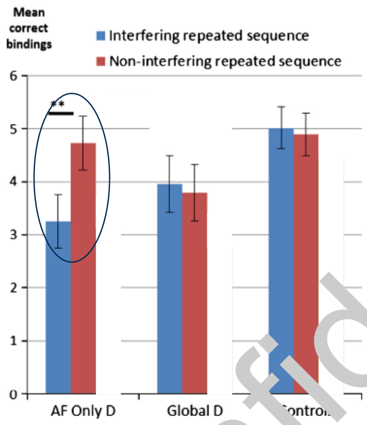
Order	Repetition	CONDITION	1 Syll	2 Syll	3 Syll	4 Syll	5 Syll	6 Syll	7 Syll	8 Syll	9 Syll
1	1	Fillers	Co	Na	Mu	Fi	Pe	Li	Wu	Ze	Da
2	1	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
3	2	Fillers	Mu	Ze	Da	Li	Co	Pe	Fi	Wu	Na
4	1	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri
5	[illegible]	Fillers	Wu	Da	Mu	Pe	Na	Fi	Li	Ze	Co
6	2	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	[illegible]	Mu
7	4	Fillers	Da	Na	Mu	Ze	Pe	Co	Li	Wu	Fi
8	2	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	[illegible]	Ve	Ri
9	5	Fillers	Ze	Wu	Li	Pe	Co	Na	Fi	Mu	Da
10	3	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
11	6	Fillers	Wu	Da	Pe	Fi	Co	Na	Mu	Li	Ze
12	3	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri

Experimental sequences repeated several times during the experiment and made of other syllables: non-interfering

Order	Repetition	CONDITION	1 Syll	2 Syll	3 Syll	4 Syll	5 Syll	6 Syll	7 Syll	8 Syll	9 Syll
1	1	Fillers	Co	Na	Mu	Fi	Pe	Li	Wu	Ze	Da
2	1	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
3	2	Fillers	Mu	Ze	Da	Li	Co	Pe	Fi	Wu	Na
4	1	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri
5	3	Fillers	Wu	Da	[illegible]	Pe	Na	Fi	Li	Ze	Co
6	2	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
7	4	Fillers	Da	Na	Mu	Ze	Pe	Co	Li	Wu	Fi
8	2	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri
9	5	Fillers	Ze	Wu	Li	Pe	Co	Na	Fi	Mu	Da
10	3	Interf_Rep	Pe	Co	Na	Wu	Li	Da	Ze	Fi	Mu
11	6	Fillers	Wu	Da	Pe	Fi	Co	Na	Mu	Li	Ze
12	3	No_interf_Rep	Ja	So	Gu	Be	Ka	Xu	Ti	Ve	Ri

RESULTS

- People with a specific AF impairment show a hypersensitivity to interference in memory



De Visscher, Szmalec, Van der Linden & Noël, 2015, *Cognition*

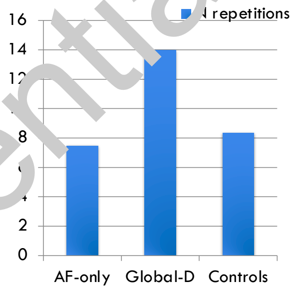
RESULTS

- People with Golbal DD have order memory problem

The Hebb learning stopped when the participant correctly reproduced two successive non-interfering repeated conditions

Number of repetitions needed to reach the stopping criteria

- Global D needed more repetitions that Control or AF-only (p=.031)

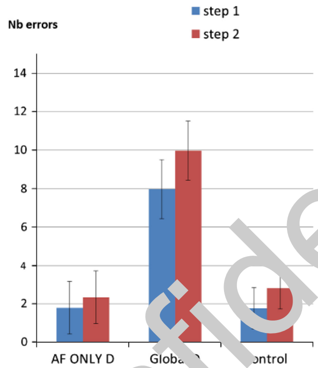


People with global deficit show reduced learning in all the conditions

When asked to say the syllable one or two steps further in the (non-interfering repeated) sequence, much more errors

=> global problem of memory (order memory)

=> two types of profiles, two underlying mechanisms



* AF deficit: due to a hypersensitivity to interference in memory
* Global deficit: associated with a problem in order memory

Q2: CONCLUSION

Profiles of persons with DD can be quite different

There is not yet a clear categorization of these profiles, nor of their underlying mechanisms

De Visscher, Szmalec, Van der Linden & Noël (2015) made a first attempt in this direction

Future research should follow this avenue and try to associate specific math profiles with specific cognitive mechanisms and, related to this, specific interventions programs

CONCLUSIONS

Dyscalculia is a frequent learning disability that is still underdiagnosed.

Research shows that it is both due to specific numerical deficit (probably at the level of the precise number representation) and some general cognitive factors like memory

- Hypersensitivity to interference in the case of AF deficits
- More global order memory problem for more global DD problems

THANKS VERY MUCH FOR YOUR ATTENTION !