Developmental dyscalculia (persistently weak mathematical ability) is related to weak *visuo-spatial memory* and *interference suppression*

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Maths is complex
Primary school children have to learn all this...

- **Magnitude/Quantitiy: Small vs. Large; Few vs. Many, etc.**
- Associative series: Early **verbal counting** – learning symbols: 'one' / 1
- Extended **ordered series**: N, N+1 (conceptual understanding): related digits
- **Associate quantity** with elements of series: 5 < 4 = more < less
- **Number Line**:
  - ***Visuo-spatial representation*** of **series**: positioning numbers on a line
  - Associating magnitude **with space**
- **Extended** number line: **zero**, **negative** numbers

Maths is complex

- **Language**:
  - Numerical facts in **long-term memory** (3×4 ; 2+3)

Try to memorize something like the **multiplication table** on a similar scale...
(*Dehaene 1997*)

  - Syntactic elements

Preference of operations: *([2×2+4]/4-1)×2)+1=?*
Embedding, operation **signs** [operators])

- **Concepts/logical elements**
  - **ZERO**: nothing....? **Continuum**?
  - A+B-B = A ; A+B-A=B (**abstract** level is harder...)

Maths is complex

- **Visuo-spatial** abilities?
  - Place Value: 1.2 ; 100.2 ; 0.2 ; 0.0002 ; 1E2 ; 1E-2

    347 > 3470?

  - Operation **techniques**: spatial manipulation

```
  1009
+ 2345
---------
  3354
```

Maths is complex

- **Part and whole relations**

- **Fractions**: There are numbers between 'numbers' in the number line
  - **strange operations**: e.g. Fraction division: 2/4 / 1/4 = 2/4 x 4/1 = 8/4 = 2

- **Story problems: forming an abstract model**
  - Translate an everyday problem into an abstract representation
    - And a series of numerical operations

There were 10 books on the bottom shelf, 30 books on the middle shelf and three books on the top shelf. How many books would be on each shelf if they were all shared out evenly?

Huge memory load!

Maths is complex: Cognitive functions Behind strengths and weaknesses are also multifaceted

For example:

- **Long-term verbal memory:** remembering math **facts** (long term)
- **Short-term verbal memory**: remembering **partial** results
- **Visuo-spatial memory**: number line, imaging operations, keeping results in mind

- **Attention**: staying focused, knowing where you are, selecting the right step

- **Suppression of unwanted information**: Resisting distraction (from classmates, irrelevant parameters, e.g. Nice figure on the side...)

- **General processing speed**: Maths is so complex that if you slow down at Some points you may e.g. forget partial results, operands, etc.

Developmental dyscalculia (DD)

- Affects about **6%** of children/adults.
- Usually defined as a **selective weakness of mathematics**.
  - Intelligence, reading and motivation to learn is **normal**
  - Access to appropriate educational provision is **normal**.

- There is **no** generally accepted **functional definition** of DD.
  - Single, multiple or heterogenous problem?
  - Exactly what cognitive function is deficient?
  - Are there different subtypes of DD?

- **Current research** focuses on trying to understand the **functional basis** (causes) of DD.

Review in Szucs & Goswami, 2013; *Trends in Neuroscience and Education*

Developmental dyscalculia (DD)

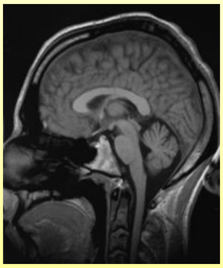
- Mathematics is <u>**COMPLEX**</u>
- It is highly likely that DD relates to weaknesses of <u>**various**</u> **cognitive functions implemented by the extended brain network** and **NOT** merely impairment of a special number sense:
  - Memory
  - Attention
  - Cognitive control
  - Inhibition/suppression of unwanted (mental) acts / facts

- E.g. solving the following equation requires **careful planning** even for adults; minor mistakes lead to radically different results: **((3 + 4) + (1 - 2)) / 2 * 3**
- **Our projects** examine how the above cognitive functions
  - Relate to DD
  - And to math expertise in children in general

Fias, Menon, Szucs; 2013; *Trends in Neuroscience and Education*
Szűcs et al. 2013; *Cortex*

MRI: Magnetic resonance imaging

Structural MRI



3D anatomical image of the brain

Measurement by usign strong magnetic field

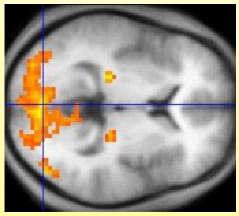
MRI: 1.5 to 4.0 or 7.0 Tesla
Earth: 5×10^{-5} (0.00005) Tesla

Measurement depends on different magnetic properties of tissues

(e.g. Grey, White matter, blood vessles)

MRI: Magnetic resonance imaging

fMRI: functional MRI



Measuring the oxygen content of blood by magnetic fields [MF]

Assumption: More oxygen is used where the brain is more active

(Oxygen is attached to Hemoglobine [HB] in blood)

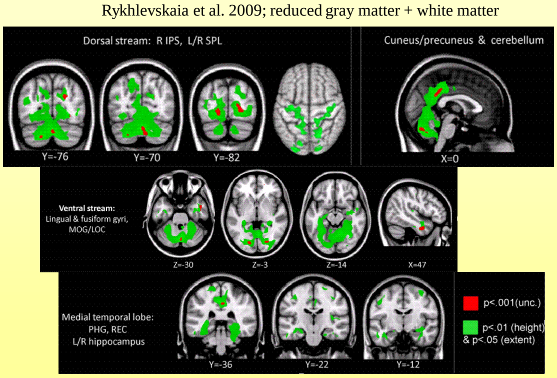
Oxygenated HB repulses from MF (diamagnetic)
De-oxygenated HB is attracted to MF (paramagnetic)

Magnetic suspectibility (intensity of magnetisation) of de-oxygenated blood is 20% greater than that of fully oxygenated blood

Measuring the proportion of de-oxygenated and oxygenated blood

Structural MRI data in DD: extended brain differences rel. to controls

Rykhlevskaia et al. 2009; reduced gray matter + white matter

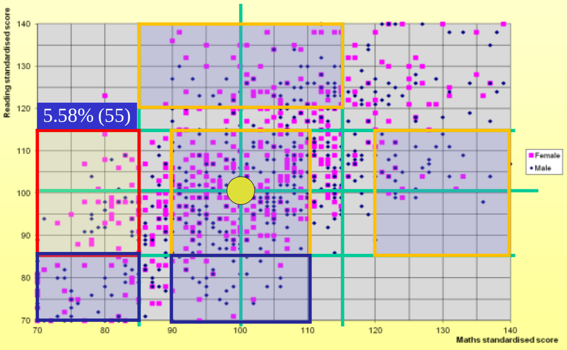


Large study on DD; Study phases

- **1,004** Year 3 and Year 4 children (526 boys and 478 girls) from 22 schools in Cambridgeshire, Hertfordshire and Essex in UK
- Phase 1 – group screening tests
  - Mathematics and reading: MALT + HGRT: UK standardized
  - Groups of interest selected for individual assessment based on their performance in both domains
- Phase 2: N=**115** – individual assessment: 18 stadardized tests
  - Mathematics; reading: WIAT-II:
    - Numerical Operations, Word Reading & Pseudoword Decoding
  - IQ: WISC-III, Raven's Matrices ; WM: AWMA
  - Socioeconomis status; ADHD: Barkeley scales
- Phase 3 – custom tasks + experimental tasks
  - Measuring automatic access to numerical information and inhibition
- Phase 4: EEG and MRI

Szűcs et al. 2013; *Cortex*; 2013

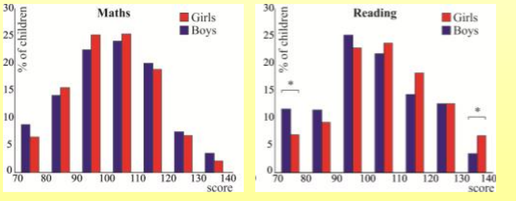
Distribution of math and reading scores:
1004 nine-year-old children (East of England, UK)



Devine, … Szűcs et al.; 2013; *Learning and Instruction*

Group test results
Gender differences?

Mathematics scores were positively correlated with reading scores (r = .626, p < 0.001) and this correlation remained when controlling for gender (r = .632, p < 0.001).



Maths and reading performance normally distributed (p>.1 for both)

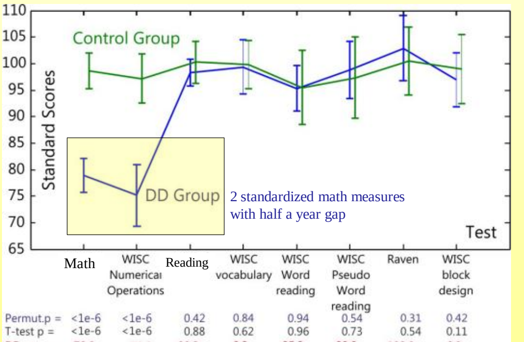
Devine, … Szűcs et al.; 2013; *Learning and Instruction*

Phase 3: Experimental investigations

- Speed of general cognitive functioning
- Spatial skills
- Behavioural control functions
- Attention
- **Memory**: visual/verbal STM/WM
- **Suppression** of unwanted mental and motor acts
- Simple number processing
- Arithmetic
- Number knowledge

Szűcs et al. 2013; *Cortex*; 2013

DD vs. Control sample: 12 vs. 12 children (9 to 10 year-olds)
(Age: 110 vs. 109 months; p=0.5)



	Math	WISC Numerical Operations	Reading	WISC vocabulary	WISC Word reading	WISC Pseudo Word reading	Raven	WISC block design
Permut.p =	<1e-6	<1e-6	0.42	0.84	0.94	0.54	0.31	0.42
T-test p =	<1e-6	<1e-6	0.88	0.62	0.96	0.73	0.54	0.11
DD group:	78.9	75.2	98.3	9.3	95.3	99.8	102.9	6.9
Control:	98.6	97.2	100.3	9.8	95.5	97.3	100.4	8.9

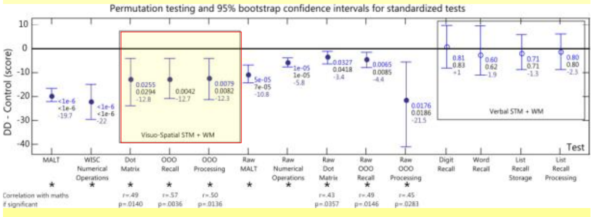
Szűcs et al. 2013; *Cortex*; 2013

DD children performed worse than control children in

- **Visuo-spatial short-term and working memory**
- **suppression of unwanted information**

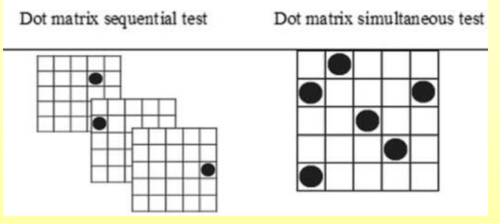
are weak in DD

Permutation statistics: 1 million random re-groupings into 2 groups of N=12
Bootstrap: 1 million bootstrap samples with replacement



Szűcs et al. 2013; *Cortex*; 2013

Typical visual memory task and inhibition task

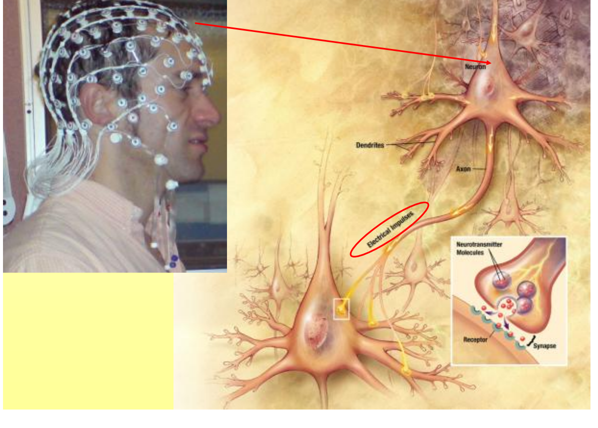


Respond RIGHT

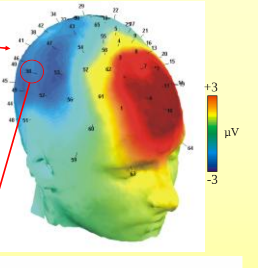
Szűcs D et al. 2009.
Journal of Cognitive Neuroscience.

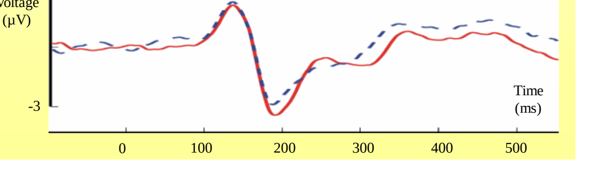
Bryce, Szucs et al. 2011;
NeuroImage

Neurons (Information processing units) & their communication



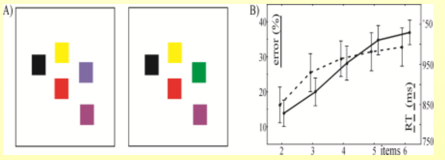
Event-related brain potentials (ERPs)

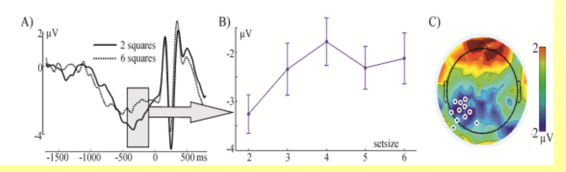




Visual Working Memory task with EEG

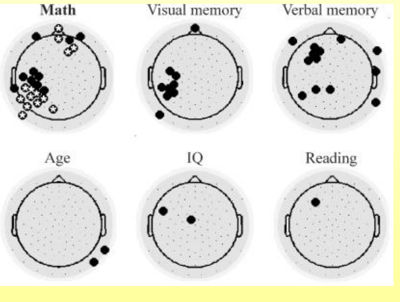
Math and visual WM: 9-year-old children





Soltesz, Devine and Szucs, submitted, 2015

Math and visual WM: 9-year-old children



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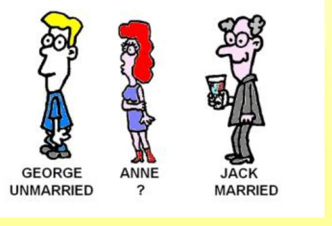
Logical reasoning in DD and in gifted children (9 to 10 year-olds)

Jack is looking at Anne, but Anne is looking at George.
Jack is married but George is not.
Is a married person looking at an unmarried person?

a) yes
b) no
c) cannot be determined

For children:
Gorillas are stronger than dogs.
Dogs are stronger than rabbits.
Are gorillas stronger than rabbits?



Morsanyi,…, Szucs, 2013; *Developmental Science*

Logical reasoning in DD and in gifted children

16 (transitive inference) problems with the following structures:

1. A>B, B>C A>C? (**valid**, easy structure)
2. A>B, C>A C>B? (**valid**, difficult structure)
3. A>B, B>C C>A? (**invalid**, easy structure)
4. A>B, C>A B>C? (**invalid**, difficult structure)

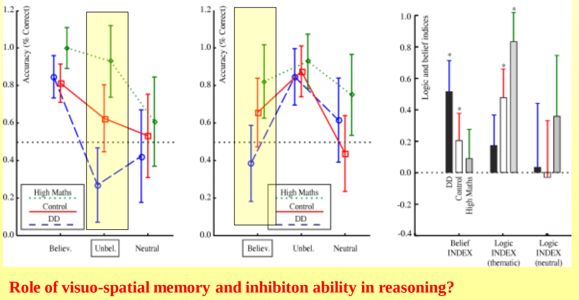
e.g. Gorillas are stronger than dogs.
Dogs are stronger than rabbits.
Are gorillas stronger than rabbits?

8 **belief-laden** problems:
- 4 with **believable** conclusions (e.g., *elephants are bigger than mice*)
- 4 with **unbelievable** conclusions (e.g., *rabbits are stronger than gorillas*)

- 8 **belief-neutral** problems (neither believable nor unbelievable):
  - 4 **visual-spatial (**e.g., *the panda is behind the giraffe*)
  - 4 **non-visual** (e.g., *Sarah is older than Anne*)

Morsanyi,…, Szucs, 2013; *Developmental Science*

Logical reasoning in DD and in gifted children



Role of visuo-spatial memory and inhibiton ability in reasoning?

Morsanyi,…, Szucs, 2013; *Developmental Science*

INTERIM CONCLUSIONS 1

Cognitive structure related to math in **9-year-old children**:

1. The most robust impairment in DD is that of **visuo-spatial short-term memory and working memory**

1. **Suppression of unwanted information** is weak

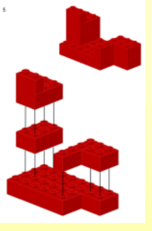
1. **Logical reasoning skills** are also impaired in DD and strongly relate to mathematical ability (when problems are visualizable).

1. A **modelling approach** found three main domains behind math skills:
2. - **visuo-spatial** ability and visuo-spatial memory
3. - **language-based** knowledge (e.g. artihmetic fact knowledge!)
4. - **co-ordinative processes**

Szucs et al. 2014; Developmental Science (modelling)
Szucs et al. 2013; Cortex (Dyscalculia)
Devine et al. 2013; Learning and Instruction (Demographic data)

Review in Szucs & Goswami, 2013; *Trends in Neuroscience and Education*

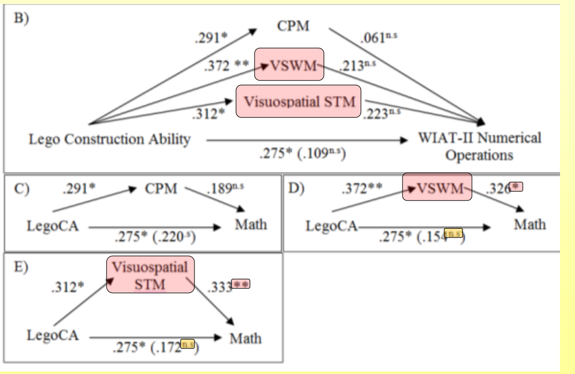
Visuo-spatial STM/WM in the classroom? 7 year-olds



- WIAT – II
  - Numerical and Reading
- Raven's Children's Progressive Matrices
- Automated Working Memory Assessment

	Verbal	Visuospatial
WM	Listening recall	Odd One Out
STM	Digit recall	Dot Matrix

Nath & Szucs, 2014. *Learning and Instruction*; In Press



Nath & Szucs, 2014. *Learning and Instruction*; In Press

INTERIM CONCLUSIONS 2

Cognitive structure related to math in **9-year-old children**:

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1. **Inhibition** function seems impaired as well

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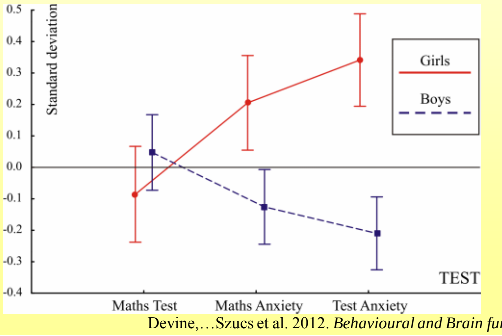
1. **Construction tasks as potential intervention?**
2. **(has to be tested further)**

Review in Szucs & Goswami, 2013; *Trends in Neuroscience and Education*

Emotional factors: Mathematics anxiety

433 children in the UK; School Years 7,8 and 10



Devine,…Szucs et al. 2012. *Behavioural and Brain functions*

Emotional factors: Mathematics anxiety

182; 8-11 year-olds in the UK; School Years 7,8 and 10

In a **structural equation modelling** study we investigated whether the origins of MA relate to the experience of **(un)controllability** of mathematics experience.

Buttler (1988):
(1)Autonomous control; Striving for independent mastery
(2)Ability focused control; masking incompetence; avoidant/covert help seeking
(3)Expedient; *Executive* style control/help seeking: e.g. relying too much on teacher.

(Un)controllability perception in mathematics seemed to be an **antecedent of math anxiety**.

The relationship of math anxiety with **gender** was fully mediated by adaptive **perception of control** (i.e. controllability).

Zirk, Lamptey, Devine, Haggard, Szucs. 2014; *Developmental Science*, In Press

CONCLUSIONS

Cognitive structure related to math in **9-year-old children**:

1. The most robust impairment in DD is that of **visuo-spatial short-term memory and working memory**

2. **Inhibition** function seems impaired as well

3. **Logical reasoning skills** are also impaired in DD and strongly relate to mathematical ability (when problems are visualizable).

4. **Mathematics anxiety** and **emotional factors** in math have to be taken into account; especially regarding **gender** differences.

5. **Educational implications:**
6. **Interventions** to improve mathematical skill may want to focus on enhancing abilities in the above domains / anxiety
7. The C*onstruction task* as a promising starting point.

Review in Szucs & Goswami, 2013; *Trends in Neuroscience and Education*

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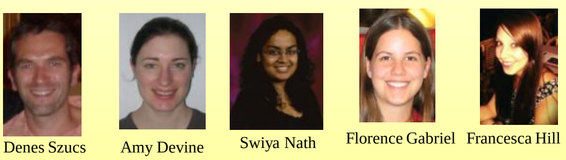
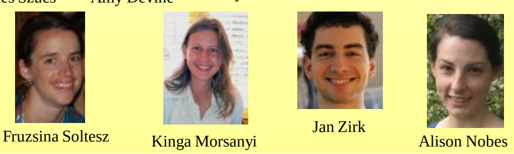
Thank you!



Denes Szucs, Amy Devine, Swiya Nath, Florence Gabriel, Francesca Hill



Fruzsina Soltesz, Kinga Morsanyi, Jan Zirk, Alison Nobes