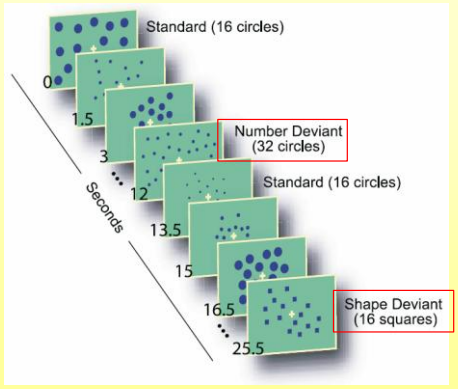
Math development 2
Developmental Dyscalculia

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?
  - Several potential representational problems
  - Are there different subtypes of DD?
- 50-60% of children with DD have a **persistent** condition. Around 95% of children with DD show **long-term weak** mathematical performance (Shalev et al. 1998)
- Lagging behind in maths usually noticed at Year 3. (2-year delay)
- **Current research** focuses on trying to understand the **functional basis** (causes) of DD.

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

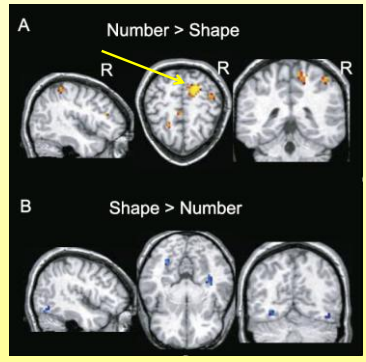
Numerical
Change detection
Paradigms
(fMRI)



Cantlon et al. 2006, PLOS One

Numerical
Change detection
Paradigms
(fMRI)

Number sensitive
Areas in 4-year-old children?



Cantlon et al. 2006, PLOS One

The „**number sense**" (intuition for magnitude) is **evolutionarily grounded** (Dehaene, 1997)

Ancient → Cultural

APPROXIMATE
Elementary sense (intuition) of magnitude
Evolutionarily grounded (Dehaene 1997)
Biologically primitive ability (precursor)

Already present in infants And animals?

EXACT
Symbol use (e.g. 1, 2, ..)
Languge of maths
Symbol manipulation

Makes higher maths possible

+
(HUMAN SPECIFIC) SUPPORTING SKILLS

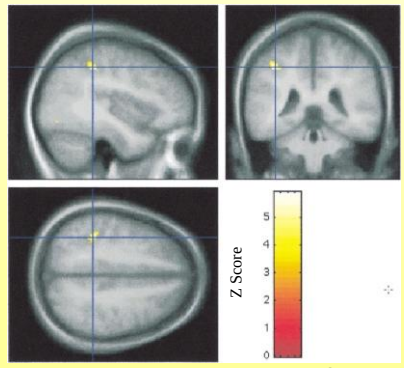
One view is that DD is related to the **domain specific** impairment of the **Simple number processing** ability (**number sense**) of the brain

Reduced gray matter volume in the **IPS; intra-parietal sulcus**.

Brain activity in this area has been shown to correlate with performance on **simple number comparison.** >

Can DD be related to impaired ability in simple number processing in the IPS?

(here: low birth-weight) children who showed **deficits in solving numerical operations)**

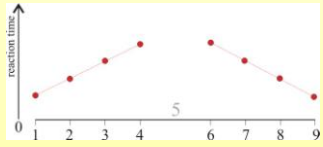


Isaacs et al. 2001, *Brain*

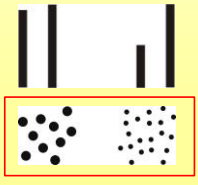
Simple number processing (e.g. number comparison) may rely on a Number sense OR Magnitude representation in the Intraparietal Sulcus (IPS)

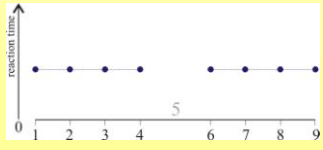
Pinel et al, 2004, Neuron

Distance Effect



Moyer and Landauer, 1967, Nature





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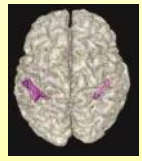

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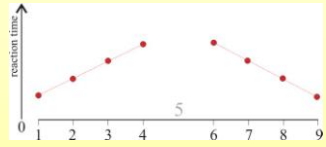

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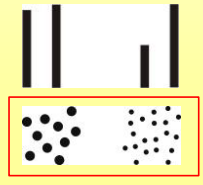
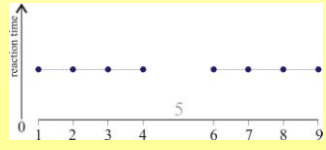
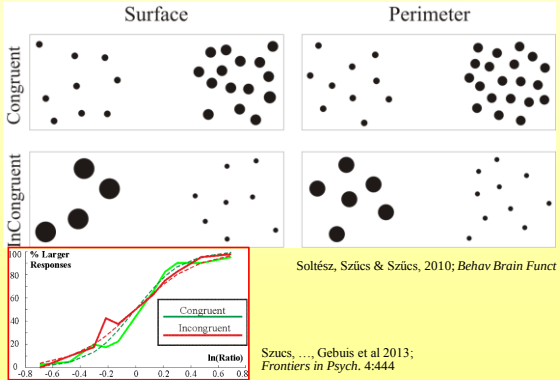




Non-symbolic dot comparison tasks: results need to be interpreted **cautiously**

Task: Which side has more dots?

A typical measure of 'number sense' in children



Soltész, Szűcs & Szűcs, 2010; *Behav Brain Funct*

Szucs, …, Gebuis et al 2013; *Frontiers in Psych*. 4:444

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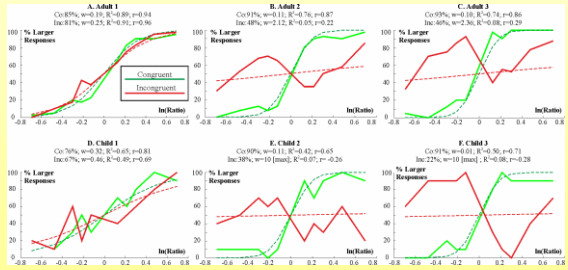

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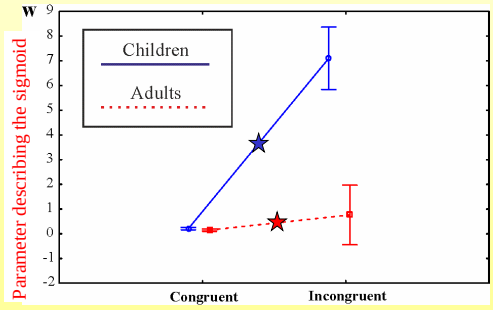

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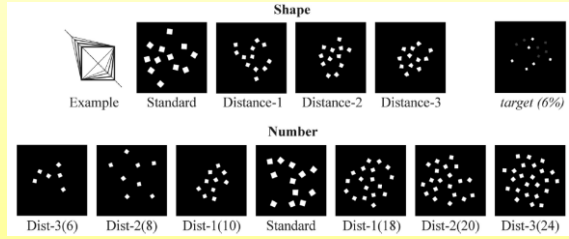

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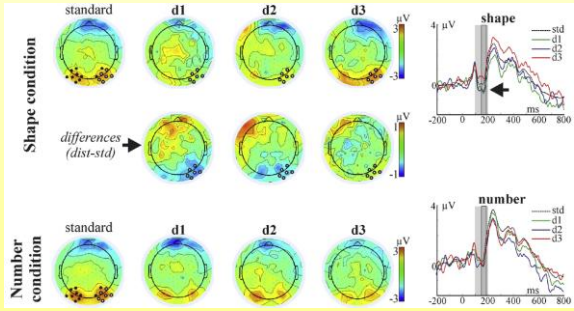

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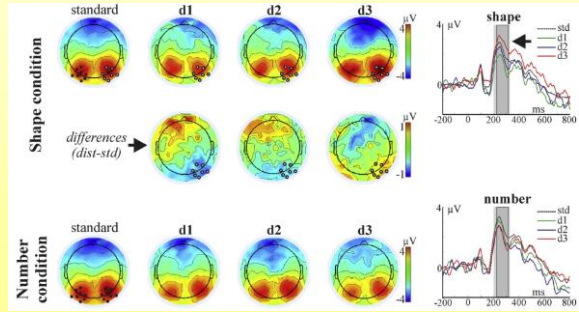

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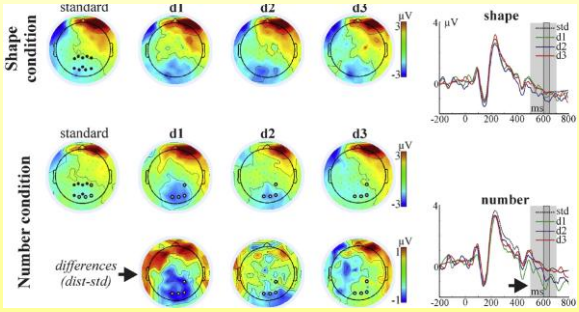

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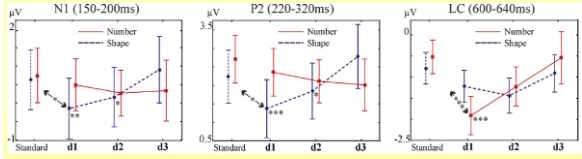
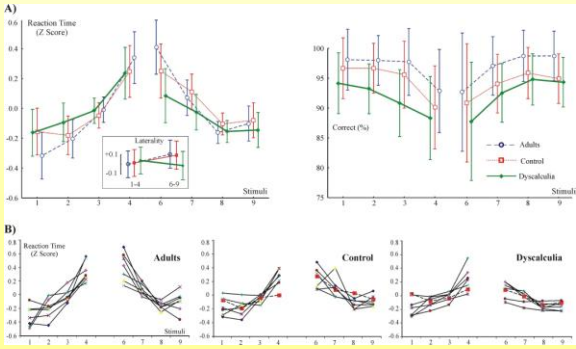


Soltesz and Szucs, 2014; *Biological Psychology*

Behavioural and EEG distance effect in Developmental Dyscalculia
Symbolic number comparison; compare to 5 N=7, all girls
120 trials for each number, 144 practice trials



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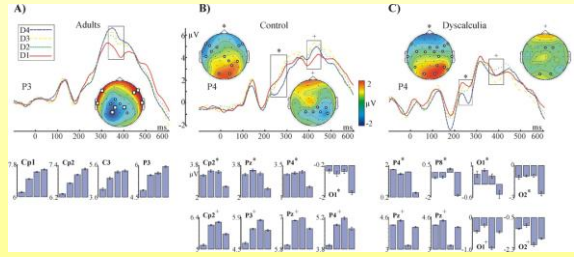

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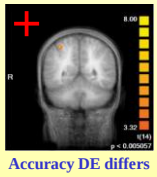
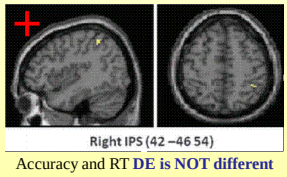
Functional MRI data about the distance effect in DD (functional marker of number sense) is weak

Price et al. 2007



Accuracy DE differs

Mussolin et al. 2010



Accuracy and RT **DE is NOT different**

Kucian et al. 2006: **no difference** between DD and controls

Kovas et al. 2009: **no difference**, **no ratio effect** in IPS

Kucian et al. 2011: **no difference** in IPS

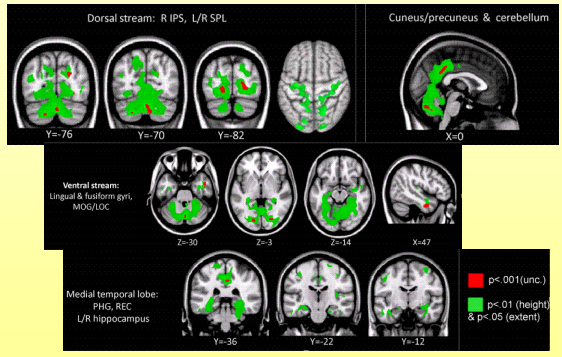
Davis et al. 2009: **no IPS difference** in *approximate* calculation

Structural: Left / Right / Right + other regions
> If there is IPS difference - what does it mean?

Reviewed in Szűcs et al. 2013; *Cortex*; In Press

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

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



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Developmental dyscalculia (DD)

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

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:
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  - IQ: WISC-III, Raven's Matrices ; WM: AWMA
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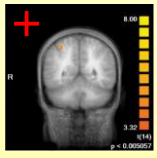
- Phase 4: EEG and MRI

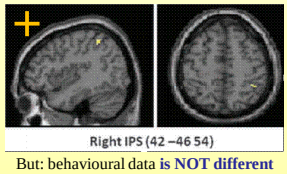
Szűcs et al. 2013; *Cortex*; In Press

However, functional MRI data about impaired number sense in children with DD is weak

Price et al. 2007



Mussolin et al. 2010



But: behavioural data **is NOT different**

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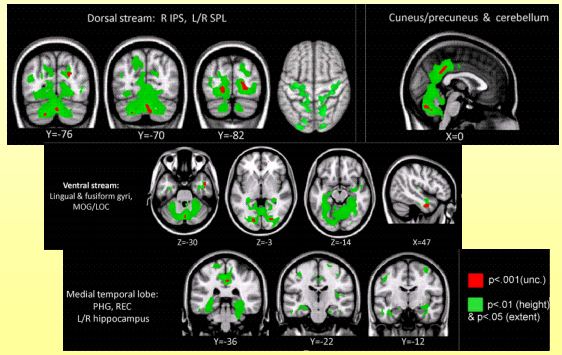

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Maths is complex

- **Magnitude/Quantity: Small vs. Large; Few vs. Many, etc.**

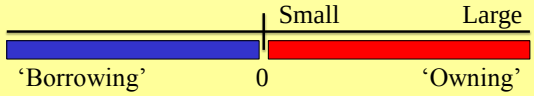
- Associative series: Early **verbal counting** – learning verbal symbols

- Generalized **ordered series**: N, N+1 (conceptual understanding): 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
  - 'Dutch' educational tool: The empty number line

- **Extended** number line: zero, negative numbers



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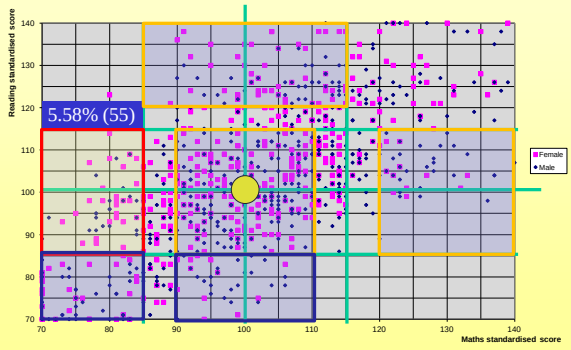
Szűcs et al. 2013; *Cortex*

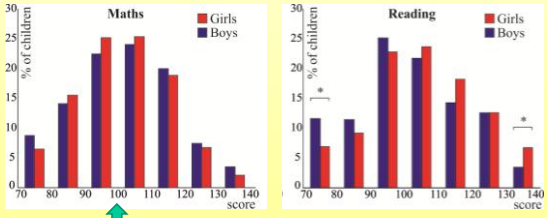
Distribution of math and reading scores:
1004 nine-year-old children (East of England, UK)



Devine et al.; 2013; *Learning and Instruction*

Gender differences in dyscalculia

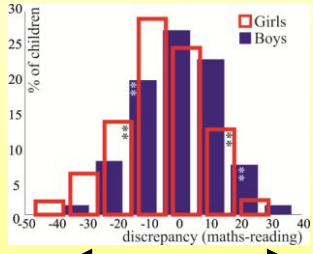
1004 **Nine to ten-year-old** children in the East of England, UK

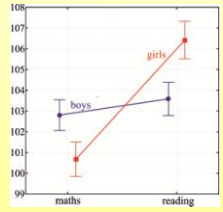


Worse **Better**

Mean=100
SD=15

Devine et al.; 2013; *Learning and Instruction*



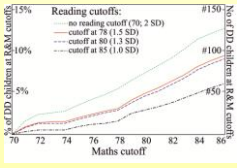


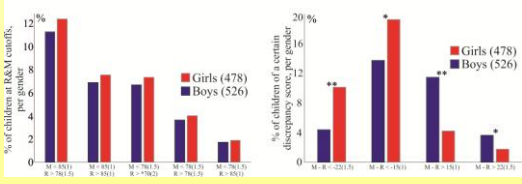
Better Reading

Better maths

Devine et al.; 2013; *Learning and Instruction*

Prevalence and gender ratio of DD





Devine 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
- **Inhibition** of unwanted mental and motor acts
- Simple number processing
- Arithmetic
- Number knowledge

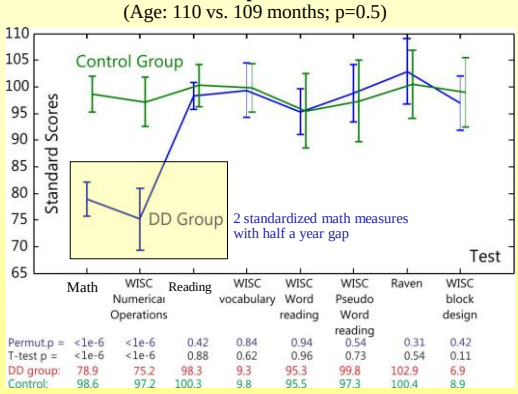
Respond RIGHT

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

Bryce, Szucs et al. 2011;
NeuroImage

Szűcs et al. 2013; *Cortex*

DD vs. Control sample: 12 vs. 12 children
(Age: 110 vs. 109 months; p=0.5)



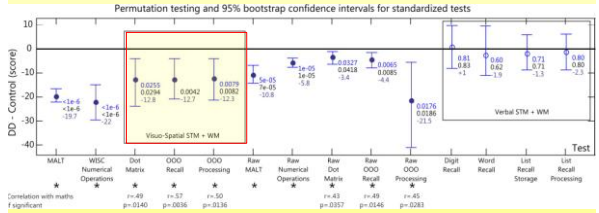
Szűcs et al. 2013; *Cortex*

DD children performed worse than control children in

- **visual STM**
- **visual WM**
- **inhibition = weak interference suppression in Stroop tasks**

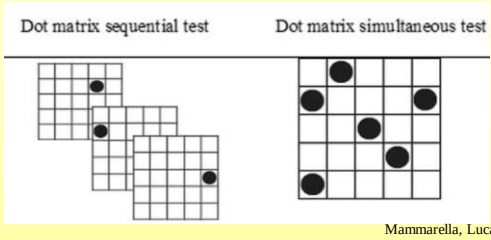
(number sense did not discriminate DD)

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*

Typical visual memory task and inhibition task



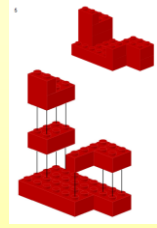
Mammarella, Lucangeli, Cornoldi, 2010

Respond RIGHT

Szűcs D et al. 2009. Journal of Cognitive Neuroscience.
Bryce, Szucs et al. 2011; NeuroImage

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, *Learning and Instruction*; 2014

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

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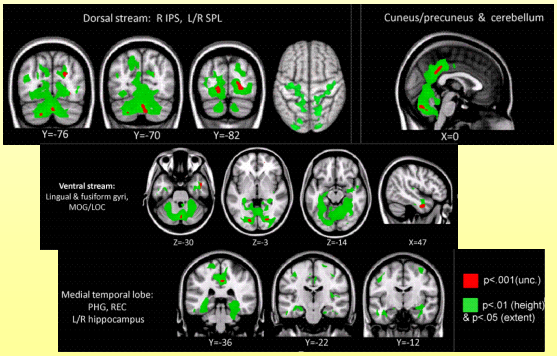
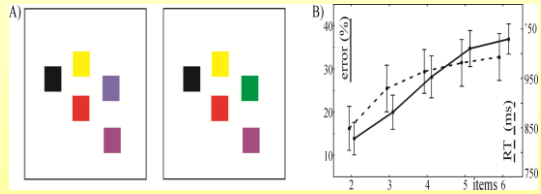


Reviewed in Szűcs et al. 2013; *Cortex*; In Press

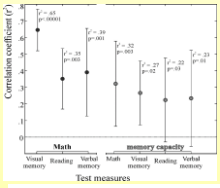
Math and visual WM

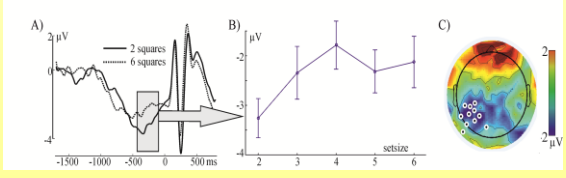


Paradigm: Vogel and Machizawa, Nature, 2004

Soltesz, Devine and Szucs, submitted, 2015

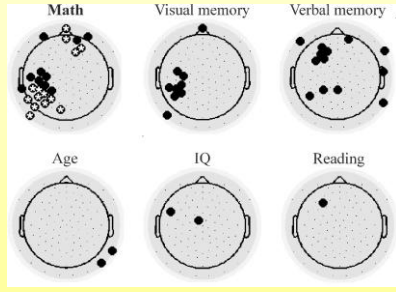
Math and visual WM





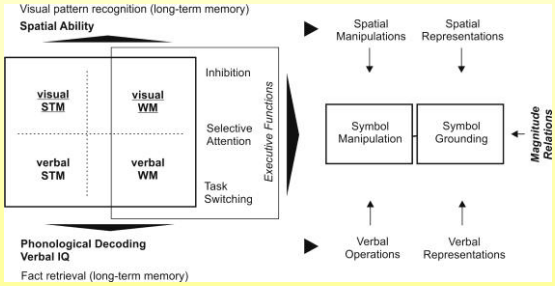
Soltesz, Devine and Szucs, submitted, 2015

Math and visual WM



Soltesz, Devine and Szucs, submitted, 2015

Modelling numerical competence (N=98; 9-year-olds)



Szucs et al. *Developmental Science*, 2014

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**.
- Support for the impaired number sense theory of DD is **not clear**.
- **Visuo-spatial WM** seems weak in children with DD
- **Can we improve** visual WM to rehabilitate DD?

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