Working memory interventions – the added value of a neuroscience perspective

Dr. Iroise Dumontheil

Department of Psychological Sciences

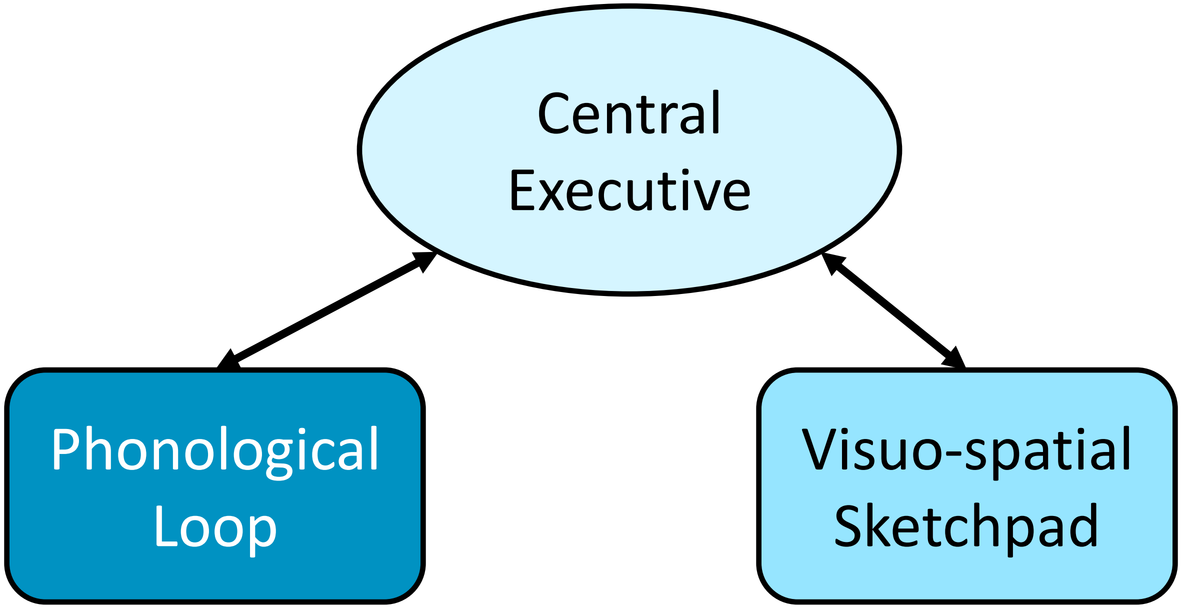
Birkbeck, University of London

Institute of Cognitive Neuroscience

University College London

Working memory

System that maintains in an active state a limited amount of information with immediate relevant to the task at hand while preventing distractions from the environment and irrelevant thoughts



Baddeley & Hitch (1974) model

Why is working memory relevant to education?

- Poor working memory is a risk factor for learning difficulties
- Children with poor working memory show:
  - Poor academic progress

More than 80% of children with poor WM fail to achieve expected levels of attainment in both learning and maths

Gathercole & Alloway, 2008

46 children aged 7 to 11 years identified as having reading disabilities, assessed in IQ, maths, language, working memory, verbal STM, phonological awareness

Hierarchical regression analysis for the criterion measure of reading scores

Independent variable	*B*	*SE*	*b*	*T*
Model 1				
Verbal IQ	−.092	.130	−.130	−.713
Performance IQ	−.026	.096	−.043	−.273
Language	.334	.129	.423	2.595* ⇦
Phonological awareness	.213	.149	.212	1.430
Complex memory	.349	.152	.371	2.295* ⇦
$R^2 = .443$, $F(5,40) = 6.375$, $p < .001$				

Hierarchical regression analysis for the criterion measure of mathematics scores

Independent variable	*B*	*SE*	*b*	*t*
Model 2				
Verbal IQ	.337	.173	.330	1.952
Performance IQ	−.031	.129	−.035	−.241
Language	.075	.172	.066	.436
Complex memory	.205	.205	.310	2.047* ⇦
Phonological STM and awareness	.428	2.98	.273	2.061* ⇦
$R^2 = .512$, $F(5,40) = 8.388$, $p < .001$				

Gathercole, Alloway, Willis & Adams, *J Exp Child Psychology* 2006

Why is working memory relevant to education?

- Poor working memory is a risk factor for learning difficulties
- Children with poor working memory show:
  - Poor academic progress
  - Difficulties in following instructions

“Put your sheets on the green table, arrow cards in the packet, put your pencil away and come and sit on the carpet.”

John (6 years) moved his sheet as requested, but failed to do anything else. When he realised that the rest of the class was seated on the carpet, he went and joined them, leaving his arrow cards and pencil on the table.

Gathercole & Alloway, 2008

Why is working memory relevant to education?

- Poor working memory is a risk factor for learning difficulties
- Children with poor working memory show:
  - Poor academic progress
  - Difficulties in following instructions
  - Place-keeping difficulties

When the teacher wrote on the board Monday 11th November and, underneath, The Market, which was the title of the piece of work, Nathan lost his place in the laborious attempt to copy the words down letter by letter, writing moNemarket.

Gathercole & Alloway, 2008

Why is working memory relevant to education?

- Poor working memory is a risk factor for learning difficulties
- Children with poor working memory show:
  - Poor academic progress
  - Difficulties in following instructions
  - Place-keeping difficulties
- And they are judged to have short attention span and high distractibility

"he's in a world of his own"

"he doesn't listen to a word I say"

"she's always day-dreaming"

"with him, it's in one ear and out of the other"

Gathercole & Alloway, 2008

Why do these children struggle to learn?

- Learning is a step-by-step process, based on successes in individual learning activities
- Children with WM impairments often fail in the classroom because the WM loads are excessive for them.
- Working memory failure leads to inattentive behaviour, simply because the child forgets what s/he is going.

Gathercole & Alloway, 2008

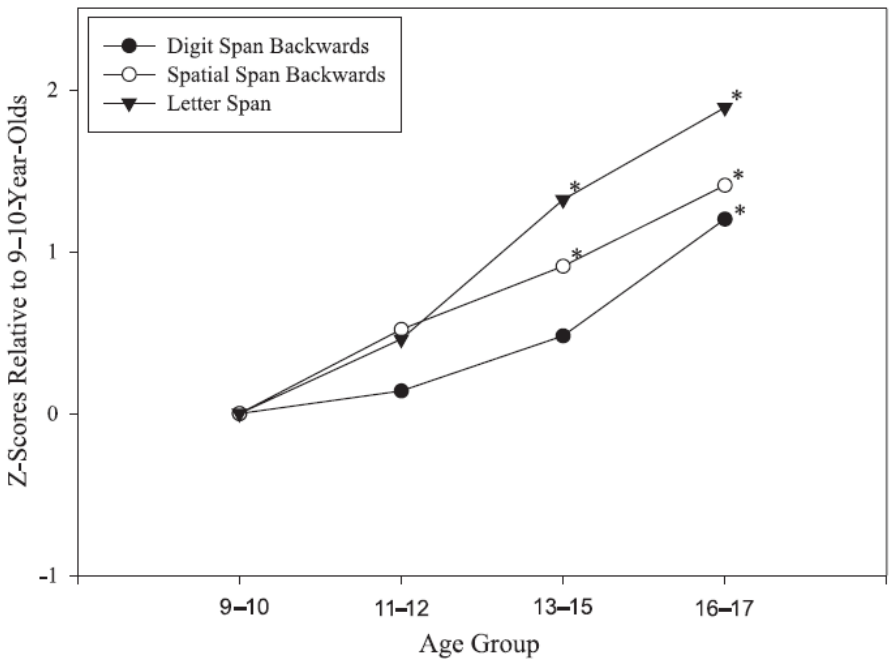
Working memory is a cognitive marker associated with arithmetical achievement

- WM capacity is correlated with arithmetical performance both in children with and without known learning difficulties.
- WM measures can predict future development of arithmetical ability independently of measures of general intelligence or reasoning abilities.
- The evidence is mixed regarding whether visuospatial or verbal WM has the most predictive value regarding the development of arithmetical abilities (Gathercole et al. 2003; Rasmussen and Bisanz 2005; Bull et al. 2008; Meyer et al. 2010).

Raghubar et al., *Learning and individual differences* 2010

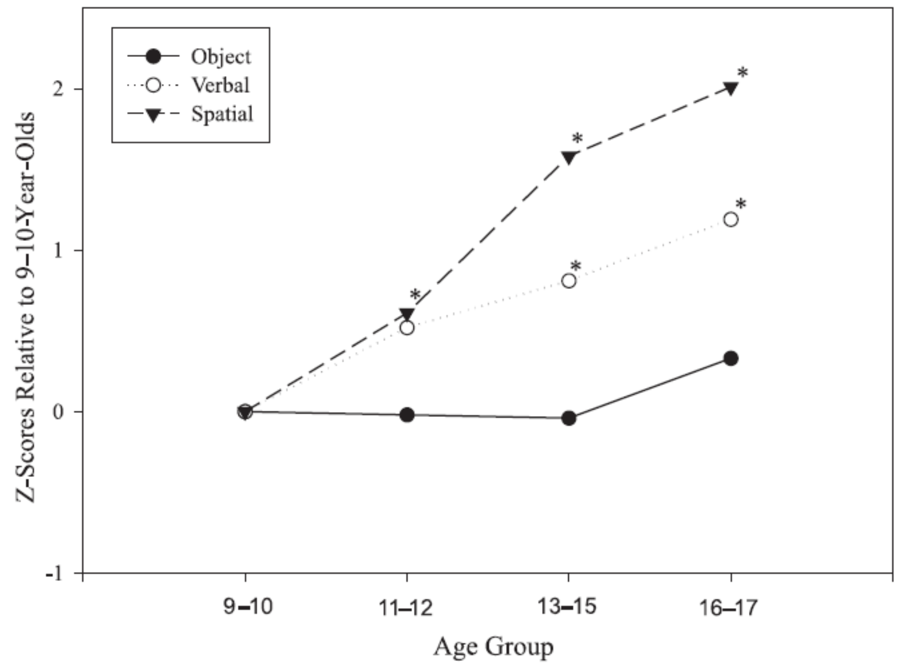
Working memory shows a prolonged development during childhood and adolescence

Span tasks

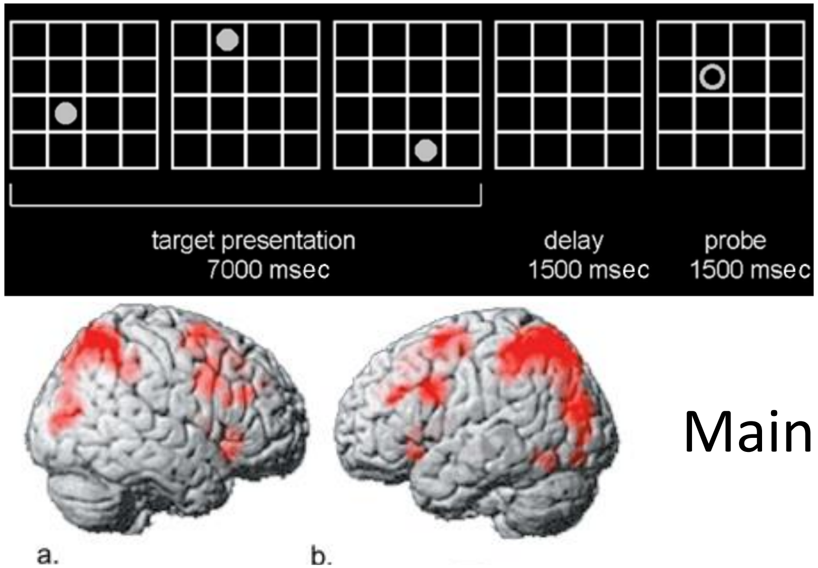


CANTAB test battery

Self-ordered tasks

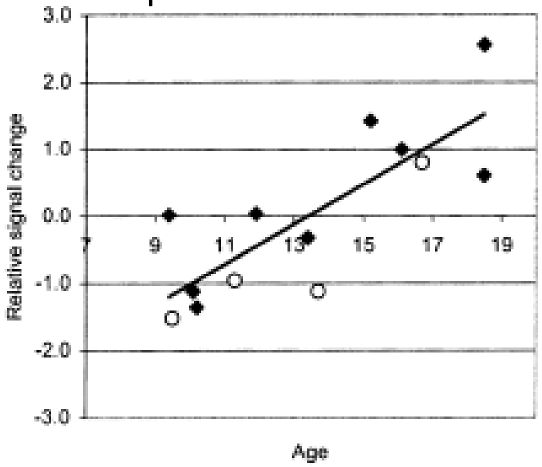


Conklin et al. *Dev Neuropsychology* 2007

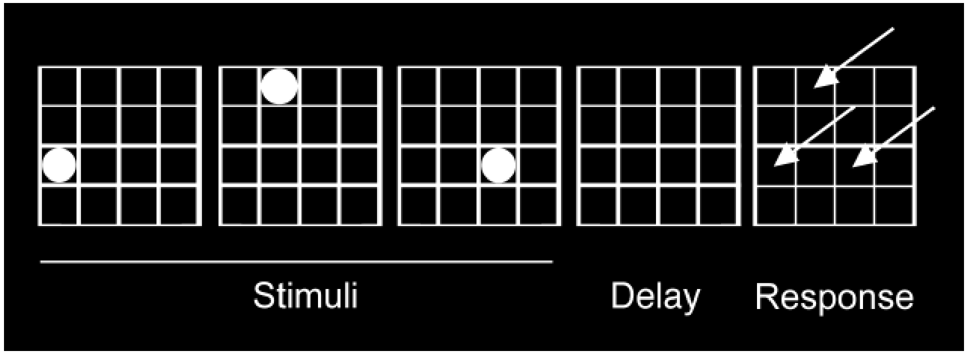


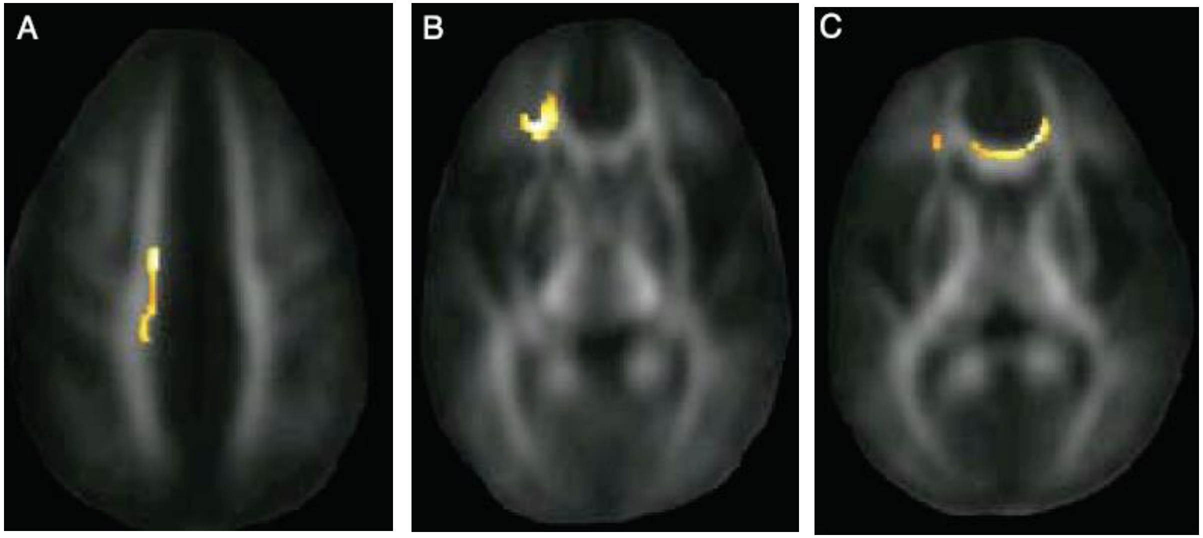
Main effect of WM

Superior frontal cortex



Klingberg et al. *Journal of Cognitive Neuroscience* 2002





Correlation between white matter anisotropy and working memory performance between ages 8 and 18 years.

Nagy et al. *Journal of Cognitive Neuroscience* 2004

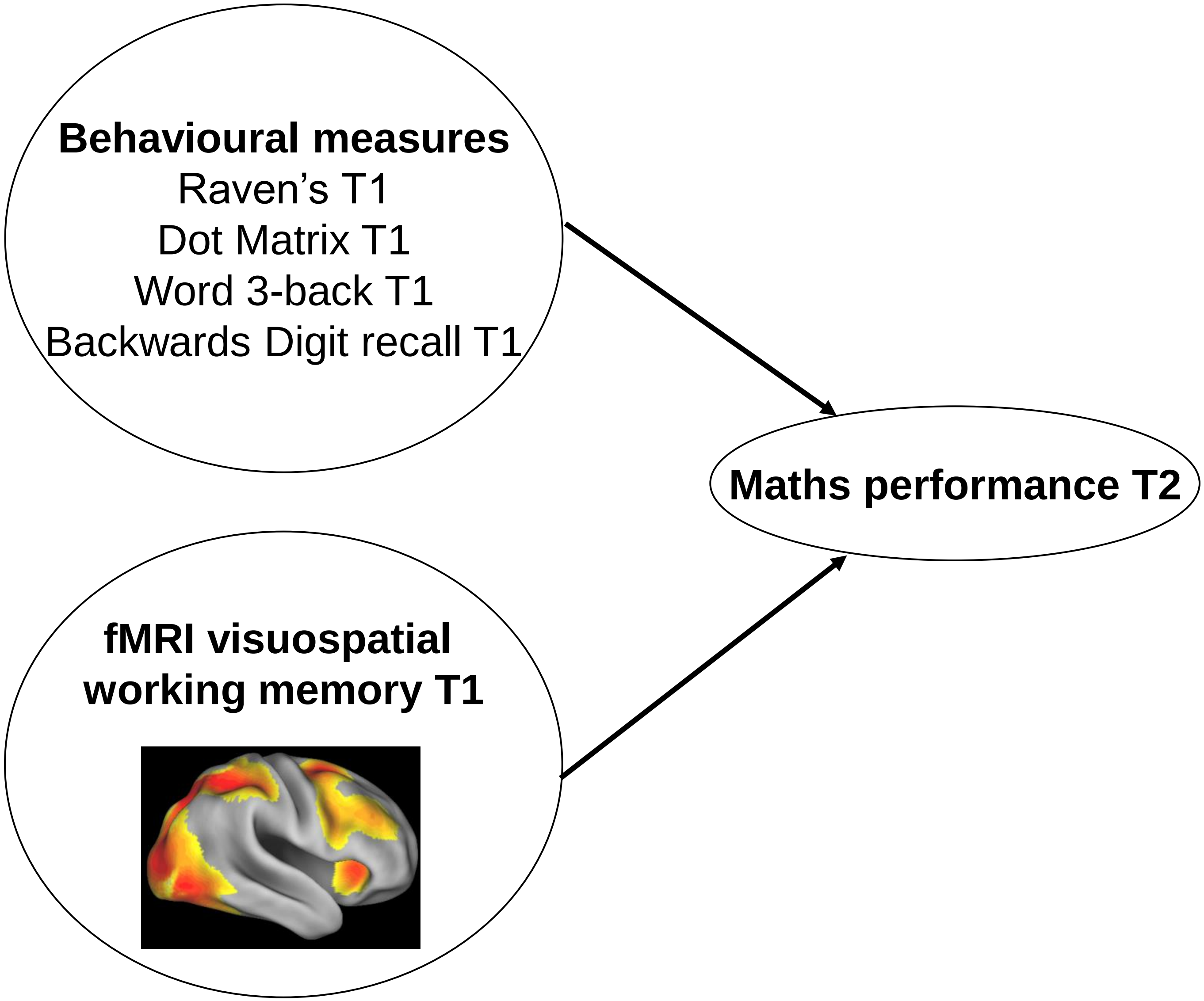
Can neuroscience inform our understanding of educational performance?

Learning

(Arithmetics)

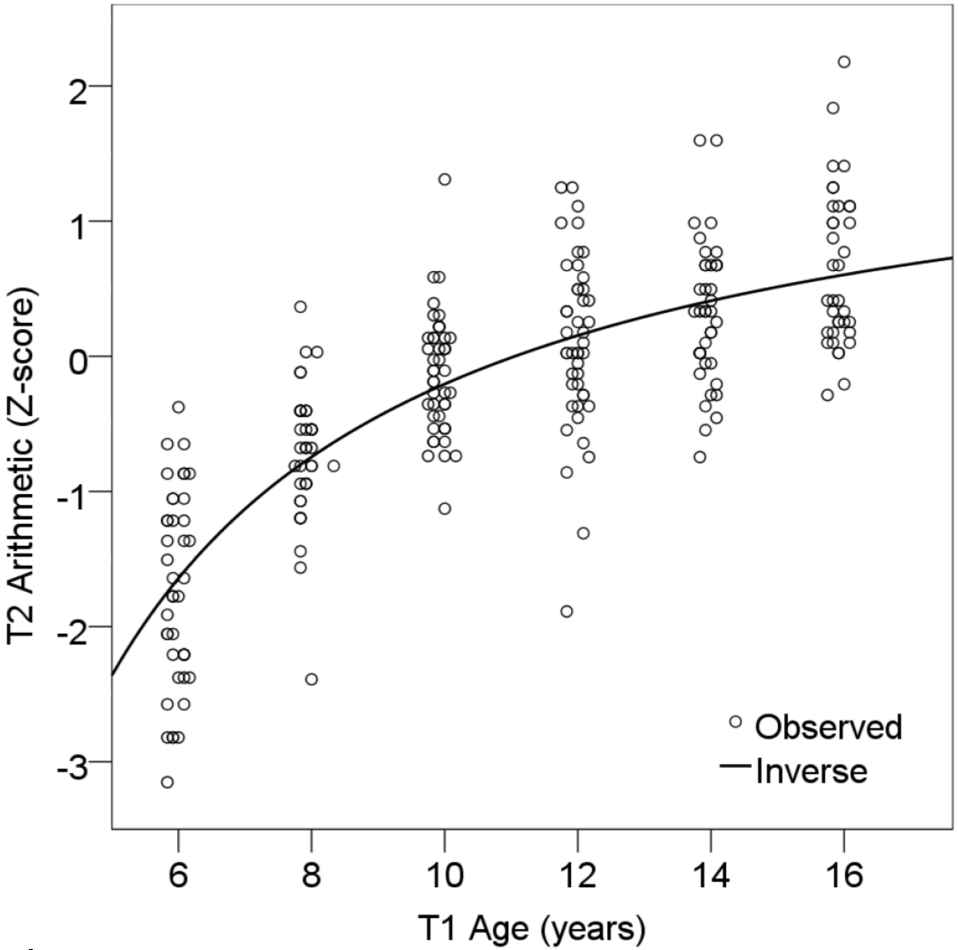
Working memory

?



Dumontheil & Klingberg, *Cerebral Corex* 2012

Behavioural sample (N = 246)



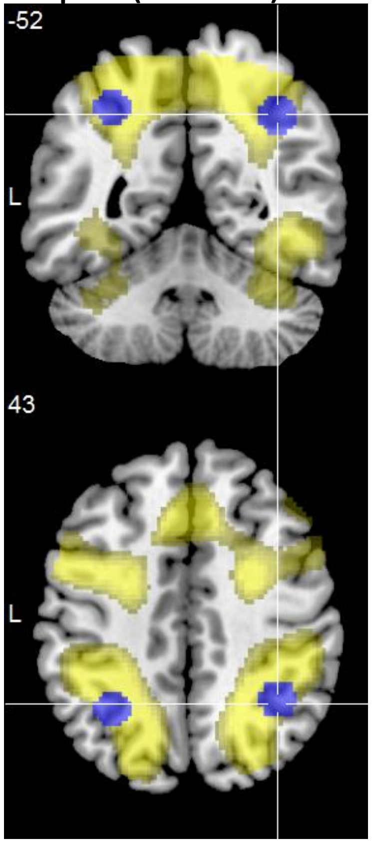
Regression models:

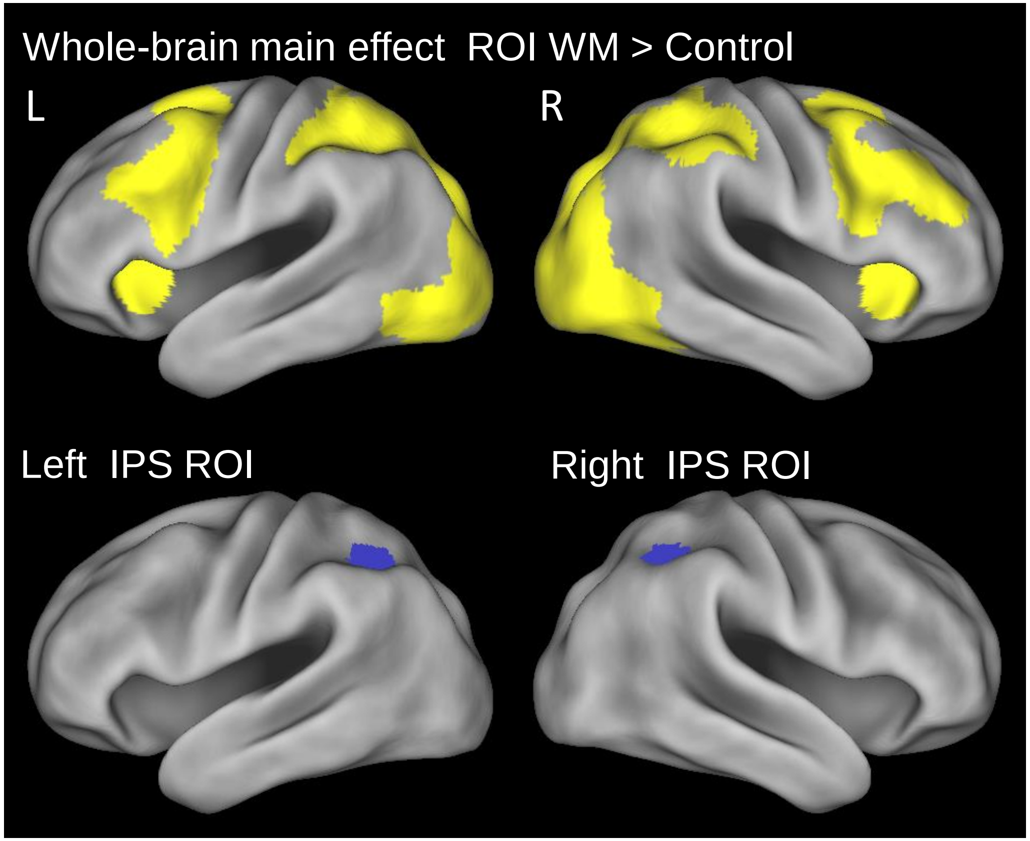
T1 age^{-1}: R^2 = 64.2%

T1 age^{-1}, Raven, Dot Matrix, Backwards Digit, 3-back: ΔR^2 = 13.0% ($p < .001$)

Dumontheil & Klingberg, *Cerebral Corex* 2012

fMRI sample (N = 46)





(coordinates from Cohen Kadosh et al. 2008)

Regression models:

T1 age^{-1}: R^2= 68.7 %

T1 age^{-1}, whole-brain fMRI + left IPS fMRI: ΔR^2 = 5.4 % ($p < .01$)

T1 age^{-1}, behavioural measures, whole-brain fMRI + left IPS fMRI: ΔR^2 = 2.5 % ($p < .05$)

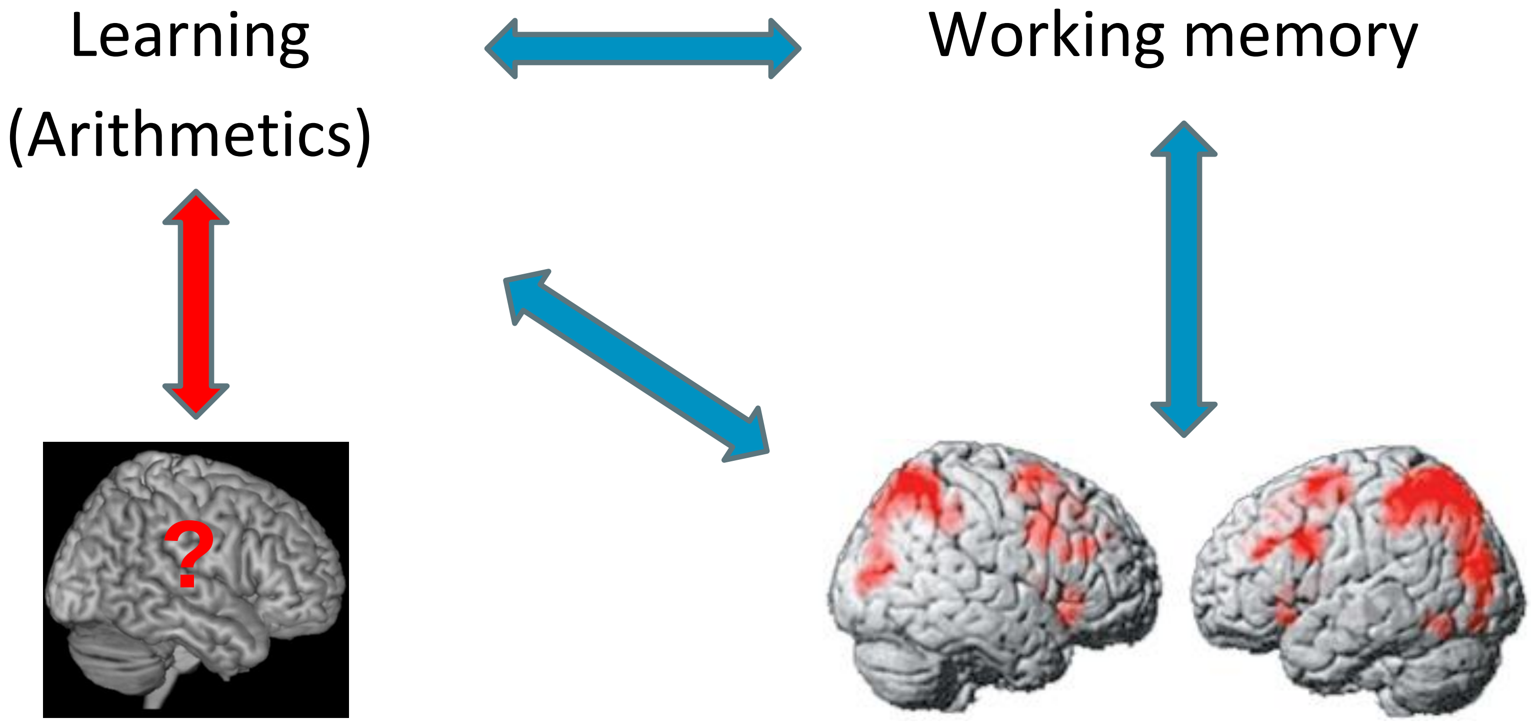
Dumontheil & Klingberg, *Cerebral Corex* 2012

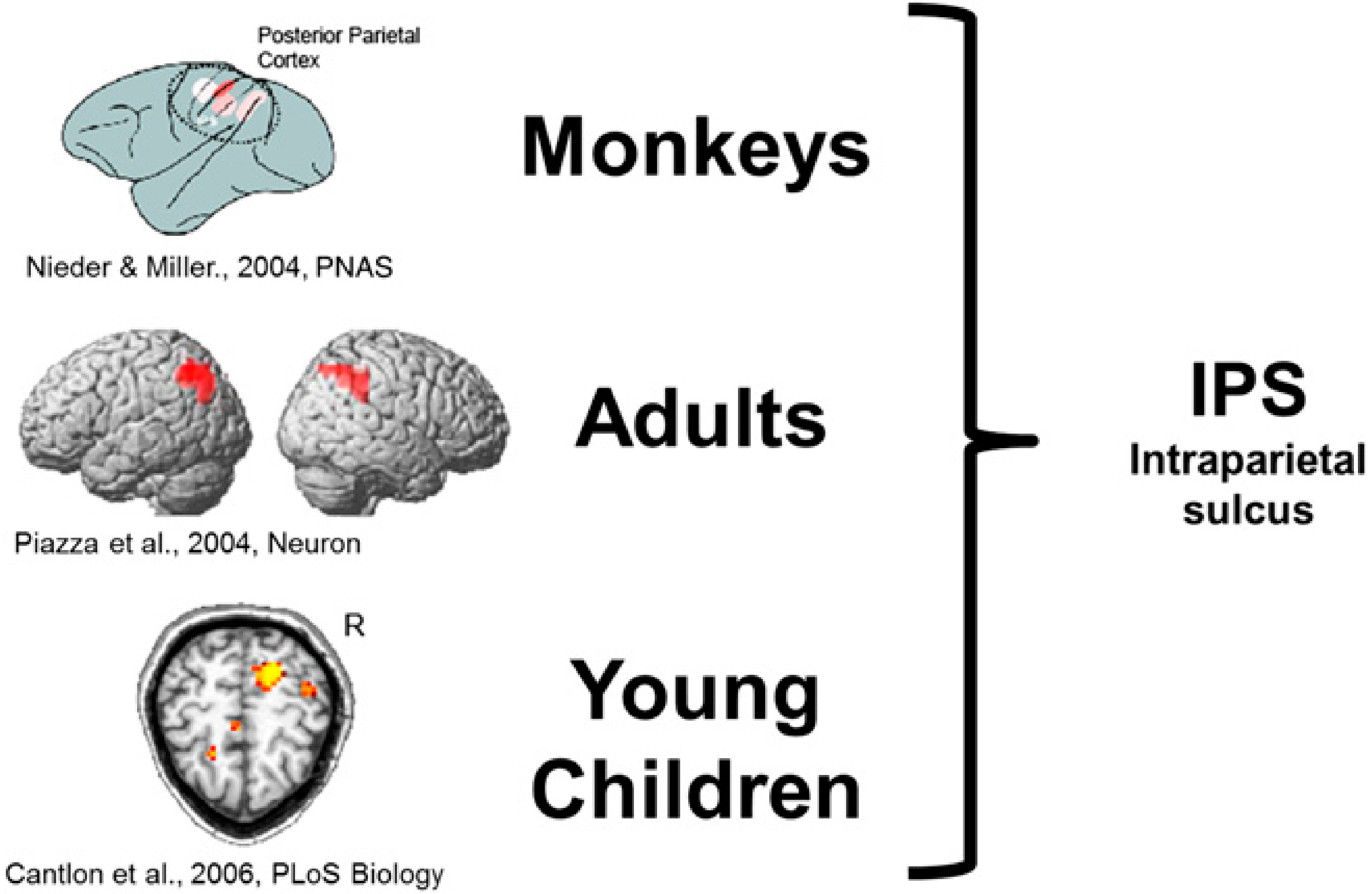
Logistic regression analysis

	Lower 20%	Higher 80%	Sensitivity	Specificity	Accuracy	
Age^{-1}	0/9	37/37	0 %	100 %	80.4 %	
Age^{-1}, Raven, Dot Matrix, Backwards Digit, 3-back	2/9	36/37	22.2 %	97.3 %	82.6 %	$\chi^2_4 = 8.6$, ($p = .073$)
Age^{-1}, Raven, Dot Matrix, Backwards Digit, 3-back, whole-brain & left IPS BOLD	5/9	35/37	55.6 %	94.6 %	87.0 %	$\chi^2_2 = 6.5$, $p = .039$

Dumontheil & Klingberg, *Cerebral Corex* 2012

Can neuroscience inform our understanding of educational performance?



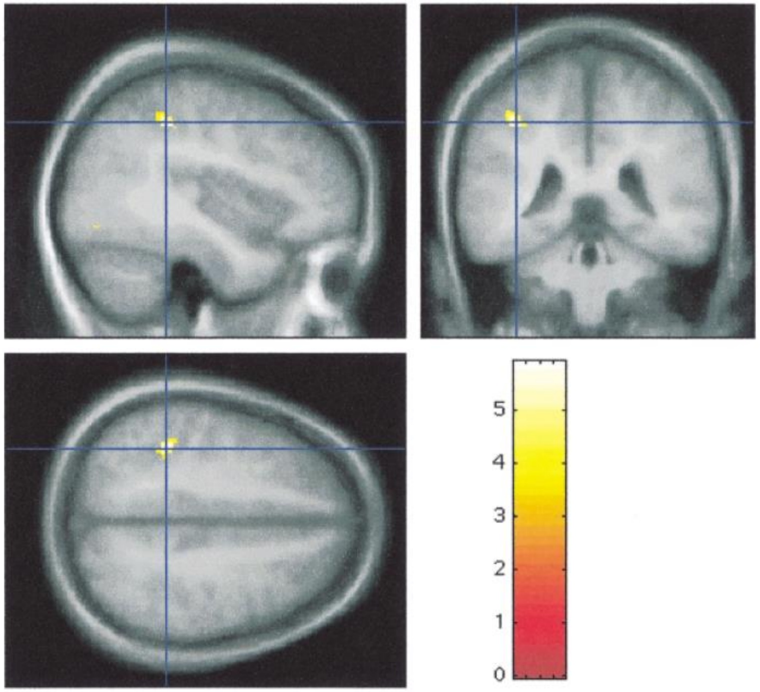


Monkeys, human adults, and human children exhibit similar activation in the IPS during analog numerical processing.

Cantlon, PNAS 2012

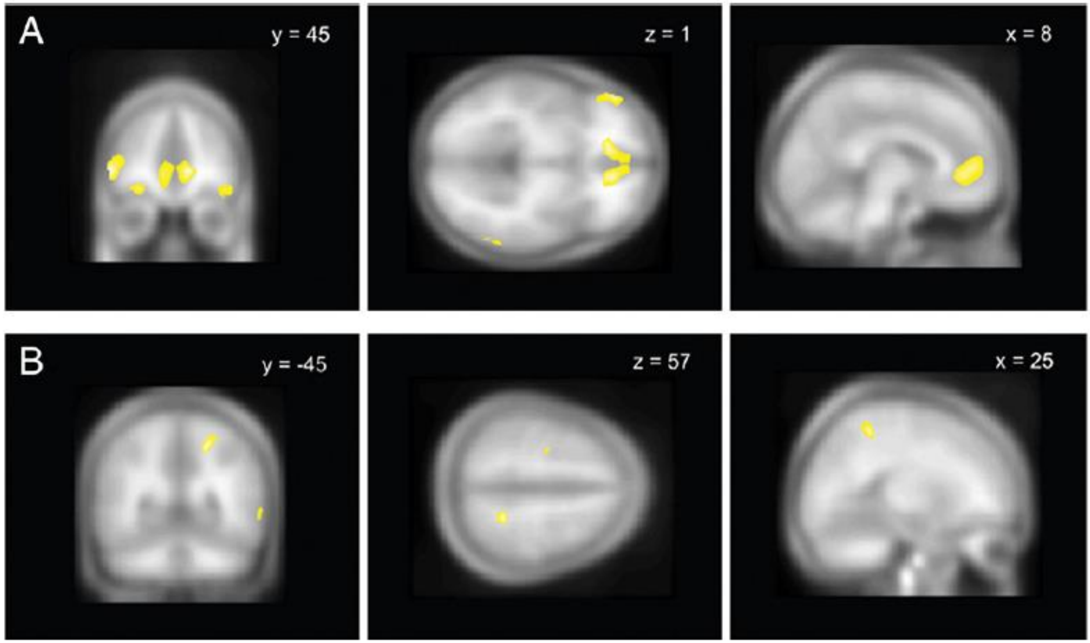
Reduced grey matter density in the IPS in dyscalculia

Teens (age 15) with "numerical operations deficit" (N=12) vs. Control (N=12), all very low birth weight.



Isaacs et al. *Brain* 2001

Children (age 9) with DD (N=12) vs. Control (N=12).

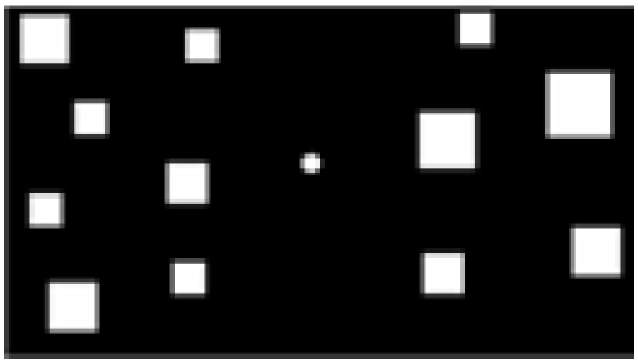


Rotzer et al. *Neuroimage* 2008

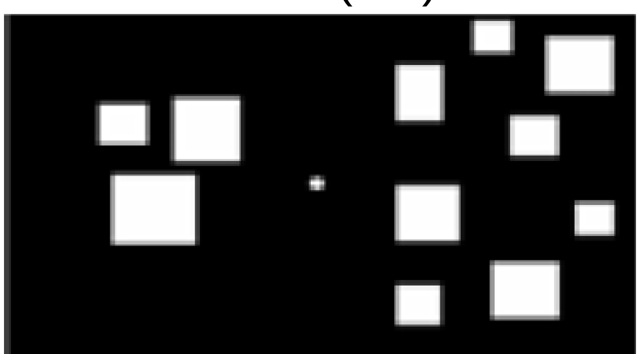
Right IPS differences during non-symbolic number comparison

Children with DD (N=8) vs. controls (N=8), age 11-12y.

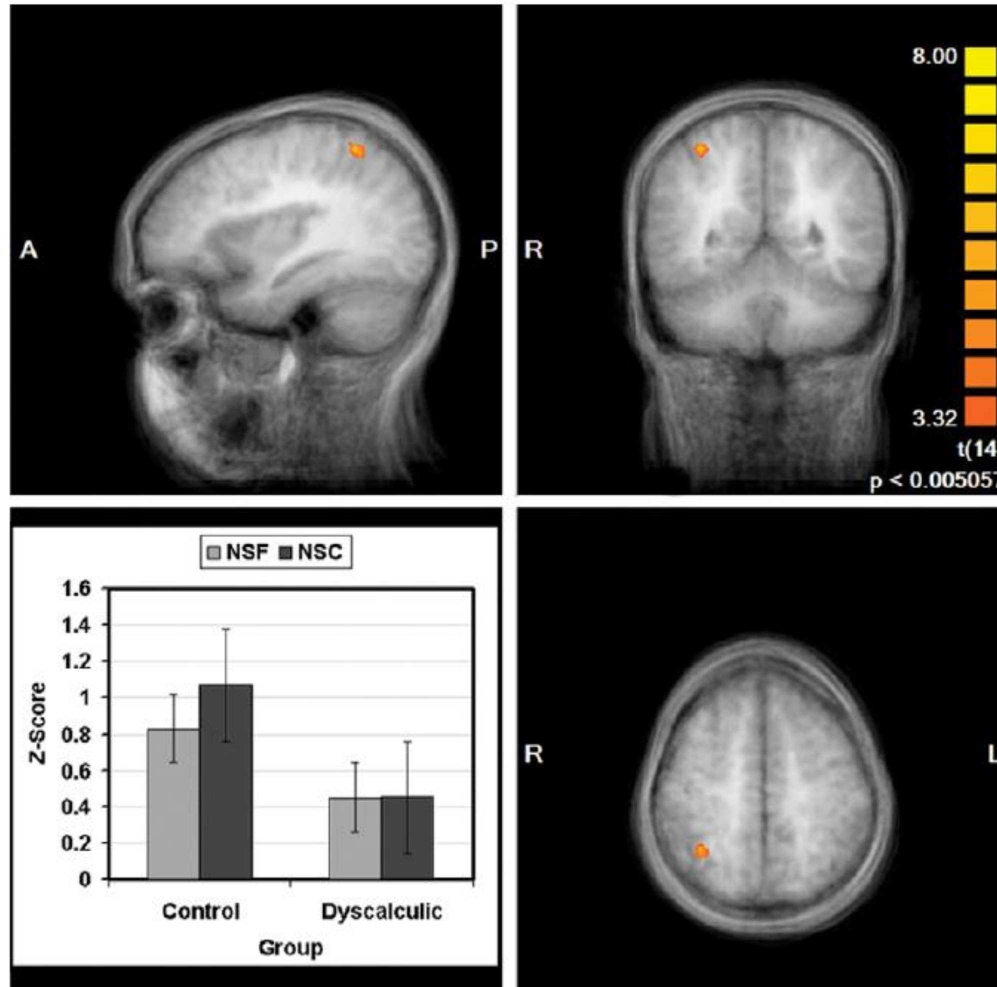
Near (1-3)



Far (5-8)



Group x



Price et al. *Curr Biology* 2007

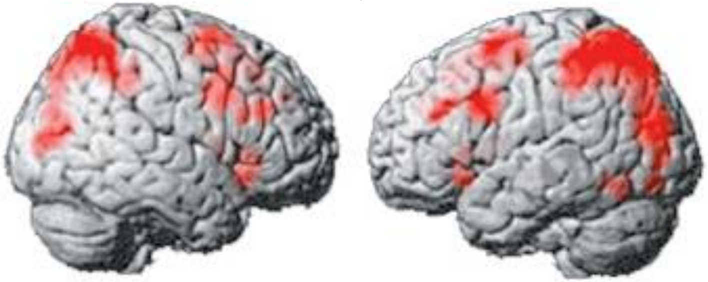
Can neuroscience inform our understanding of educational performance?

Training

Learning

(Arithmetics)

Working memory



Can working memory deficits be overcome?

- Explicit strategy learning – task specific
- Repetitive practice – neural plasticity

Boosting of neural activity?

Klingberg, *TICS* 2010

Can neuroscience inform our understanding of educational performance?

Training

Working memory

Learning

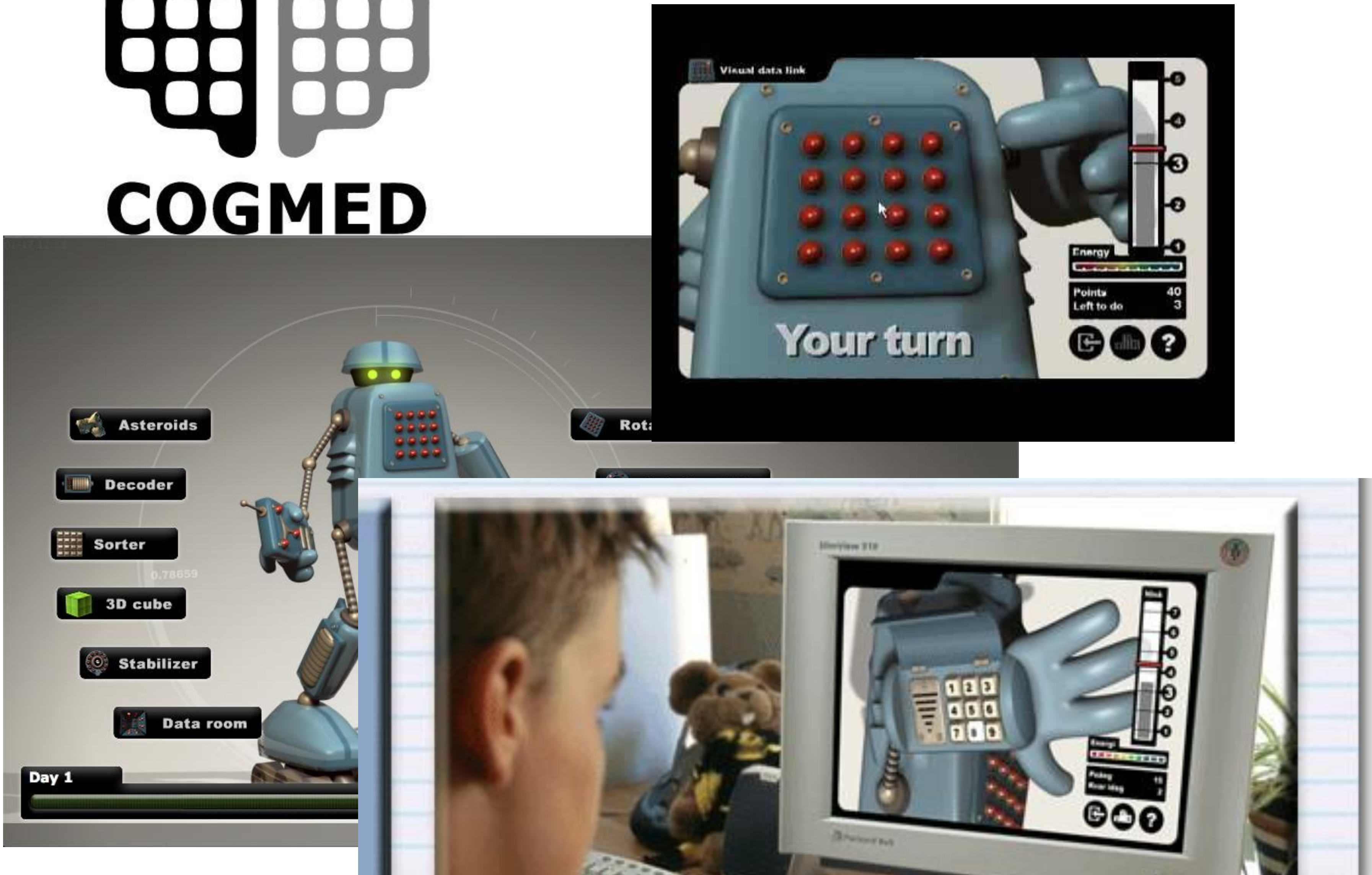
(Arithmetics)

?

?

?

COGMED


Asteroids
Decoder
Sorter
3D cube
Stabilizer
Data room
Day 1
Visual data link
5
4
3
2
1
Energy
Points 40
Left to do 3
Your turn

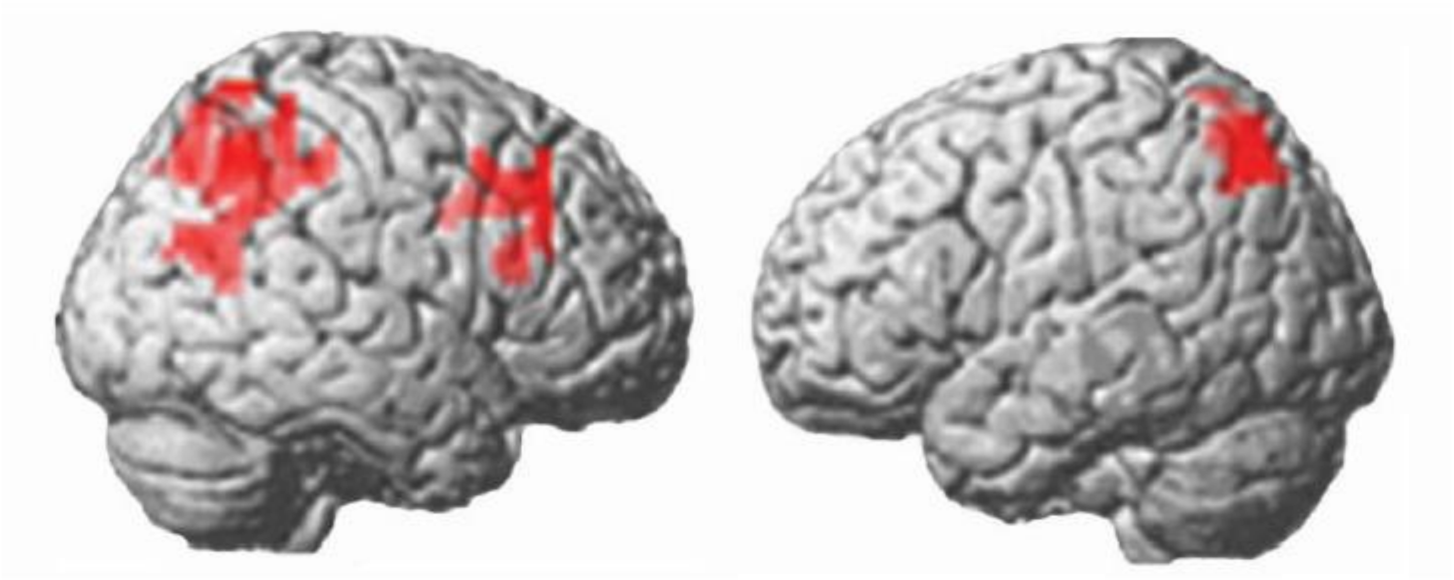
Can working memory be trained?

Meta-analysis

- programs produced reliable short-term improvements in working memory skills
- for verbal working memory, these near-transfer effects were not sustained at follow-up
- for visuospatial working memory, limited evidence suggested that such effects might be maintained

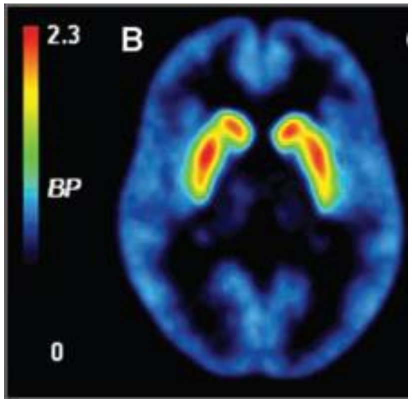
Melby-Lervag & Hulme, *Developmental Psychology,* 2012

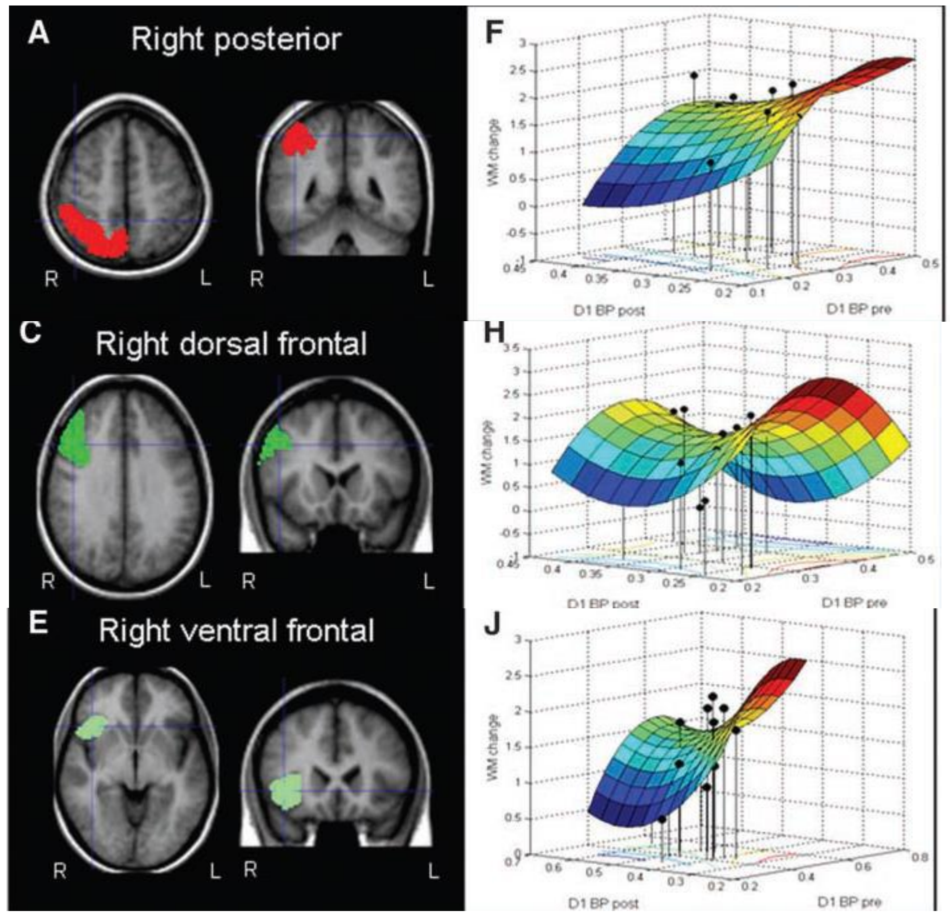
Increased prefrontal and parietal activity after training of working memory



Olesen et al., *Nature Neuroscience,* 2004

Changes in dopamine receptor density associated with WM improvements during training

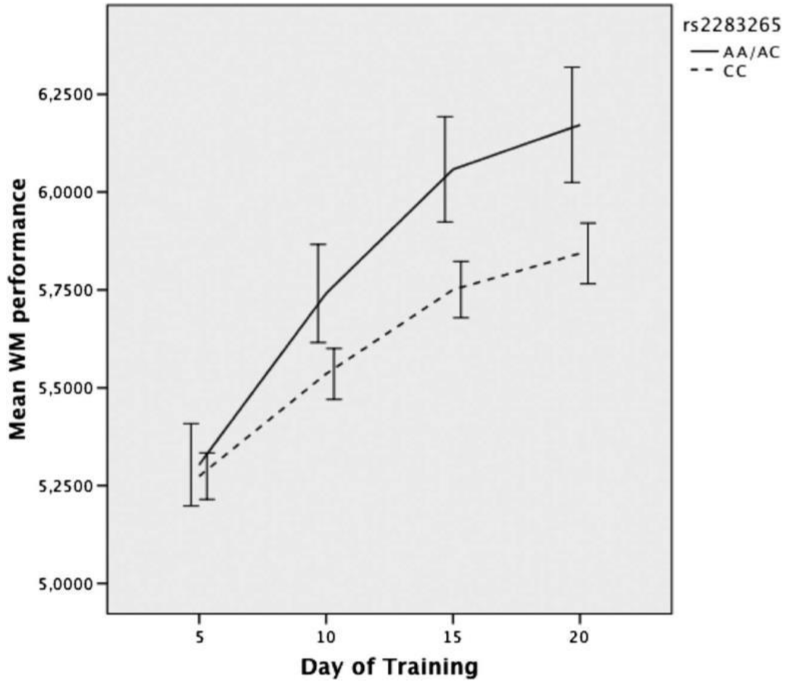




McNab et al. *Science* 2009

Individual differences in susceptibility to training

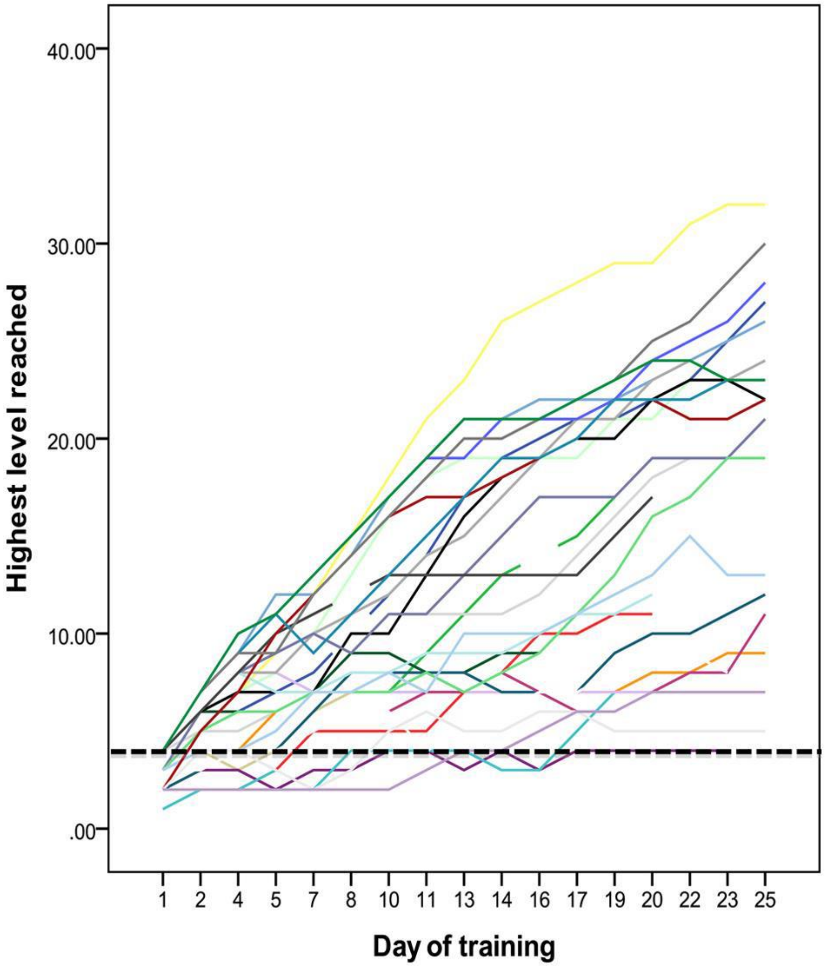
Genetic variation in the dopamine receptor 2 (DRD2) gene region influences improvements during working memory training in children and adolescents



Soderqvist et al. *J of Cogn Neuro* 2013

Individual differences in susceptibility to training

Children with intellectual disabilities show variability in their training curves – not benefits



Soderqvist et al. *Frontiers in Human Neuroscience* 2012

Can working memory be trained?

Meta-analysis

- programs produced reliable short-term improvements in working memory skills
- for verbal working memory, these near-transfer effects were not sustained at follow-up
- for visuospatial working memory, limited evidence suggested that such effects might be maintained
- there was no convincing evidence of the generalization of working memory training to other skills (nonverbal and verbal ability, inhibitory processes in attention, word decoding, and arithmetic)

Melby-Lervag & Hulme, *Developmental Psychology,* 2012

Can neuroscience inform our understanding of educational performance?

Training

Working memory

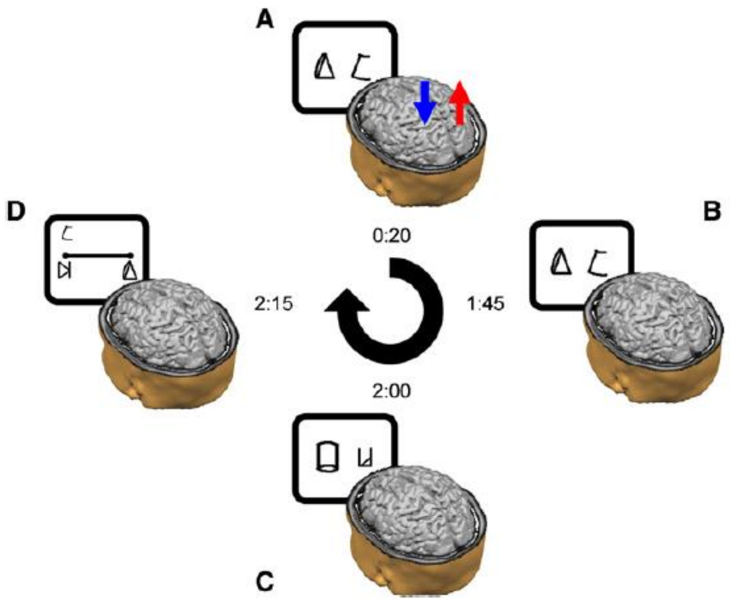
✓

Learning

(Arithmetics)

Other types of training?

tDCS stimulation in the right, but not left, IPS leads to enhance acquisition of automatic number processing and the mapping of number into space



Cohen Kadosh et al. *Current Biology* 2010

Conclusions

- Working memory is an important cognitive marker predicting educational achievements
- The neural basis of working memory has been extensively studied, and shows overlap with e.g. numerical processing
- Working memory training leads to neural and performance changes in working memory tasks
- And is sensitive to individual differences
- BUT far transfers effects to other aspect of cognition and to educational practice have not been reliably demonstrated

What next?

- Individual differences
- Combination of task practice and neural stimulation
- Combination of task practice and training in how to use these skills in a more ecological environment (Gathercole et al.)
- Making the game more exciting?

Use of technologies

- Video games are very engaging. Neuroimaging has revealed they stimulate our brain's reward system as much as methylphenidate (Ritalin) and some amphetamines (Weinstein, 2010). This response, involving dopamine uptake in the mid-brain region, is not just associated with attention but also with synaptoplasticity (the brain basis of learning) in a range of cortical regions (Shohamy & Adcock, 2010).
- This may help explain why action video games enhance a range of cognitive functions (Bavelier, Green & Dye 2010) and can also teach affective response, whether this involves the teaching of empathy via prosocial gaming or our aggressive tendencies via violent video games (Howard-Jones, 2011).

Institute of Cognitive Neuroscience
Sarah-Jayne Blakemore

Neuroscience Department
Torkel Klingberg
Chantal Roggeman
Tim Ziermans
Stina Soderqvist

Department of Psychological Sciences
Michael Thomas
Denis Mareschal