Training and plasticity of working memory and attention

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Stockholm, Sweden

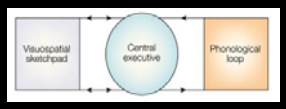
WM training improves WM and attention

- Underlying mechanisms
- Summary of evidence

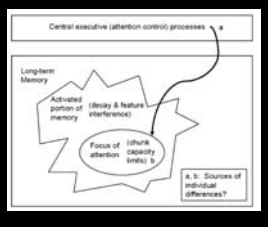
Outline

- Models of WM and attention
- WM and attention in ADHD
- WM training
  - Effects on WM and attention
  - Neural correlates

Working memory models

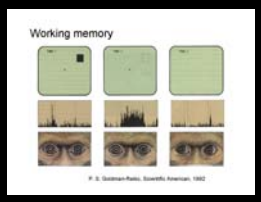


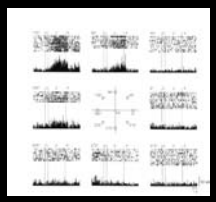
Alan Baddeley



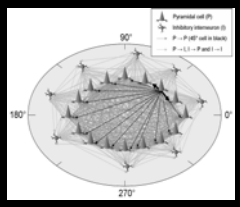
Nelson Cowan

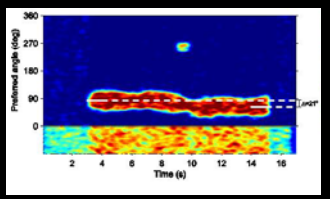
Neurophysiology of WM





A working memory model





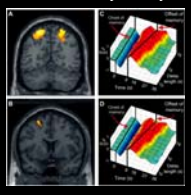
Compte et al. (2000)
Constantinidis, Wang (2004)

Edin et al. (2007) JOCN
Edin et al. (2009) PNAS

Sustained activity in WM tasks
Spatial code

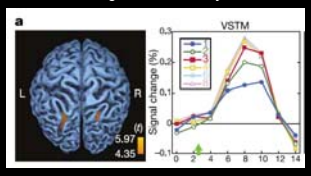
Storage and sustained activity in humans

Sustained delay activity



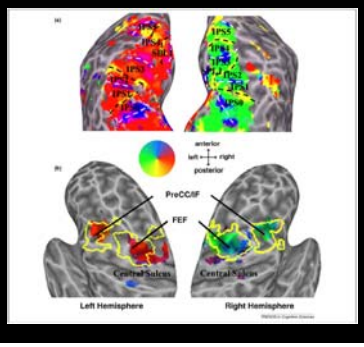
Rowe and Passingham (2000) Science

Storage related activity

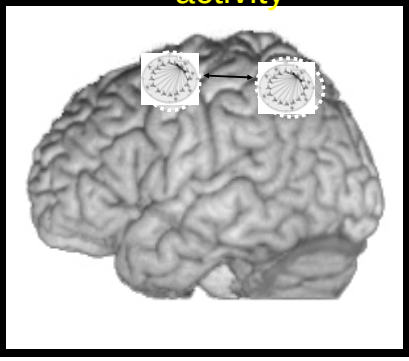


Todd and Marois (2004) Science

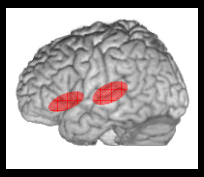
Spatially selective areas



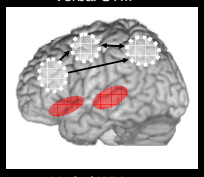
Spatial maps with sustained activity



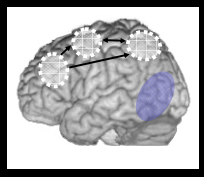
WM networks



Verbal STM

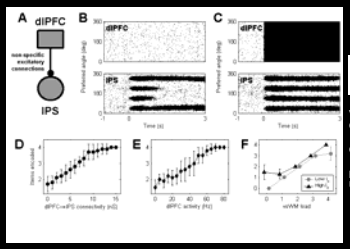


Verbal WM



Visuospatial WM and STM

Prefrontal boosting

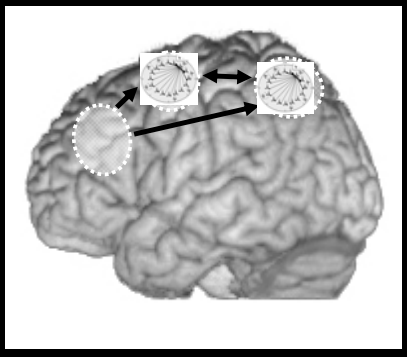


$$\nu = g([G^{+}+G^{-}(p-1)]\nu + \mu_X)$$

V = frequency
G+ = effective connectivity from neurones coding for the same item
G- = effective connectivity from neurones not coding for the same item (negati
p = number of maintained items
U = external input

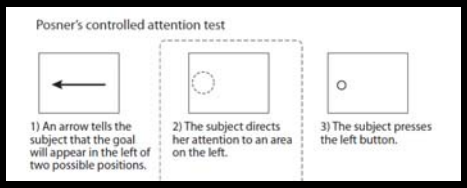
Edin et al. 2009 PNAS

PFC + spatial maps in WM

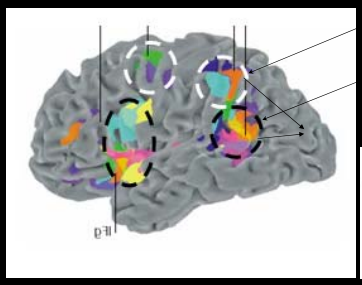


Attention

- The Attentional Network Task

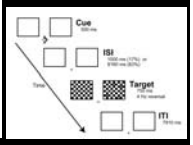


Attention systems



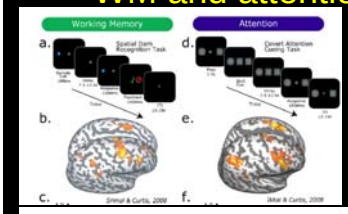
Controlled attention
= top-down attention

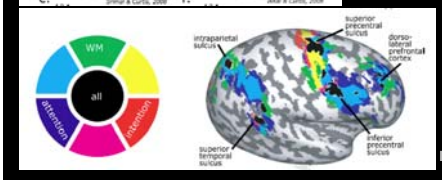
Stimulus driven attention



Corbetta and Shulman, 2002

WM and attention overlap





Ikkai and Curtis (2010)

WM and attention mechanisms

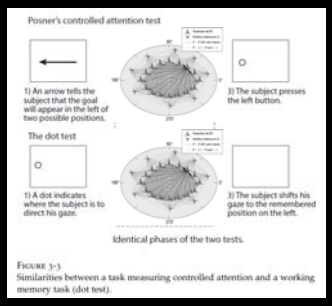
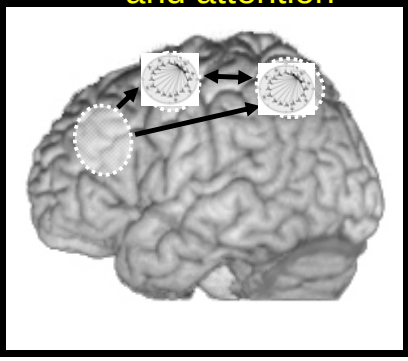


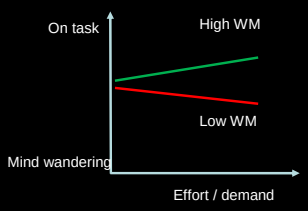
FIGURE 3-3
Similarities between a task measuring controlled attention and a working memory task (dot test).

Klingberg (2008) The Overflowing Brain

PFC + spatial maps in WM and attention



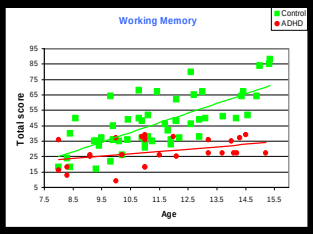
Inattention and WM



Kane et al., (2008) *Psychol Sci*

Clincial WM deficits

- ADHD
- Traumatic brain injury
- Stroke



Westerberg et al., 2004

WM deficit in ADHD

Memory Domain	Number of Studies	Number of Subjects ADHD	NC	Standardized Mean Difference	t	95% CI	I^2 (95% CI)$_a$
Verbal Storage	16	476	847	0.47	7.8***	0.36 – 0.59	0 (0 – 52)
Verbal C.E.	13	475	557	0.56	4.1***	0.29 – 0.83	76 (58 - 86)
	12$_b$	464	538	0.43	4.5***	0.24 – 0.62	49 (1.5 – 73)
Spatial Storage	9	318	304	0.85	7.2***	0.62 – 1.08	45 (0 – 75)
Spatial C.E.	8	161	166	1.06	6.2***	0.72 – 1.39	56 (5 – 80)
	7$_c$	151	156	1.14	7.0***	0.82 – 1.46	50 (0 – 79)

ADHD = attention deficit hyperactivity disorder; NC = normal controls; C.E. = central executive;

46 studies on WM in ADHD Review by Martinussen et al. 2005

WM and ADHD review

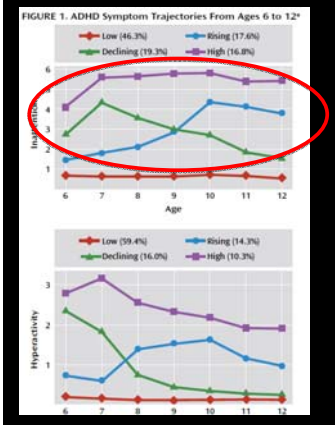
Chamberlain et al. Biol. Psychiatry, 2011

	Effect size
Spatial working memory	0.9
Response inhibition	0.8
Executive planning	0.5
Attentional set-shifting	0.2

WM deficit (ES) span-board like tasks

	CANTAB WM	WAIS span-board
Dowson -04	1.15	-
Kempton -99	1.33	1.22
Barnett -01	1.45	1.06
Westerberg -04	-	1.34

Mean = 1.26 SD



Impair chances of high-school graduation

Inter-individual differences

WM capacity

- WM tasks
- Inattentive behavior
  - "Normal" distractability
    - Kane et al. 2007
    - Vogel et al. 2005
    - McNab and Klingberg 2008
  - ADHD inattentiveness
    - Barkeley 1997
    - Castellanos, Tannock (2002)
    - Martinussen et al. (2005)

Improving WM

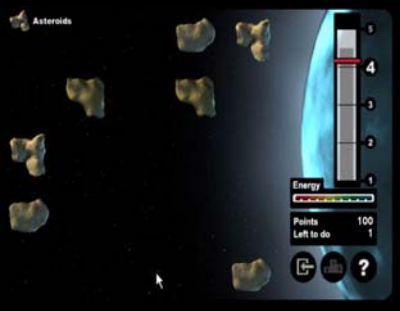
- Teaching of rehersal
  Butterfield et al. (1973)
  "On the theory and practice of improving short-term memory"
- Chunking and association to LTM
  Ericsson et al. (1980)
  "Acquisition of a memory skill"

Explicit

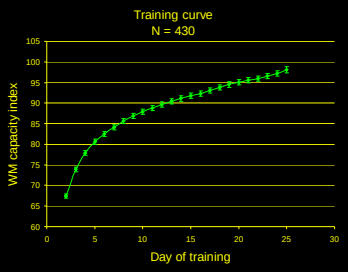
Implicit ?

WM training (Klingberg et al. 2005)

- Repeated performance with feedback (no strategy instruction)
- Adaptive difficulty close to capacity limit
- Mainly visuo-spatial WM tasks
- Intense and extensive
  - 35 min per day
  - 5 days/week
  - 5 weeks



Improvement on trained tasks



Transfer from training?

WM training

?

- WM tasks
- Inattentive behavior
  - "Normal" distractability
  - ADHD inattentiveness
- Other cognitive tasks
  - Reasoning, problem solving
  - Inhibitory functions

Journal of Clinical and Experimental Neuropsychology
2002, Vol. 24, No. 6, pp. 781–791

1380-3395/02/2406-781$16.00
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Training of Working Memory in Children With ADHD

Torkel Klingberg, Hans Forssberg, and Helena Westerberg
Department of Neuropediatrics, Karolinska Institute, Stockholm, Sweden

Improvement in:

- Non-trained VSWM task (span-board)
- Problem solving (RPM)
- Response inhibition (Stroop)

- N = 14

Klingberg et al. 2002

Computerized Training of Working Memory in Children With ADHD—A Randomized, Controlled Trial

TORKEL KLINGBERG, M.D., PH.D., ELISABETH FERNELL, M.D., PH.D., PERNILLE J. OLESEN, M.SC., MATS JOHNSON, M.D., PER GUSTAFSSON, M.D., PH.D., KERSTIN DAHLSTRÖM, M.D., CHRISTOPHER G. GILLBERG, M.D., PH.D., HANS FORSSBERG, M.D., PH.D., AND HELENA WESTERBERG, L.P., PH.D.

- 53 children (9 girls, 44 boys)
- 7-12 years of age (mean 9.9 years)
- ADHD

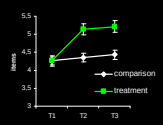
Klingberg et al. 2005

Randomized, double blind design
Active control group

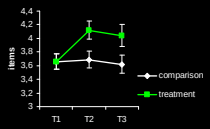
Treatment
- Adaptation of difficulty level

Control
- Easy trials (level 2)

Transfer to working memory



Span-board

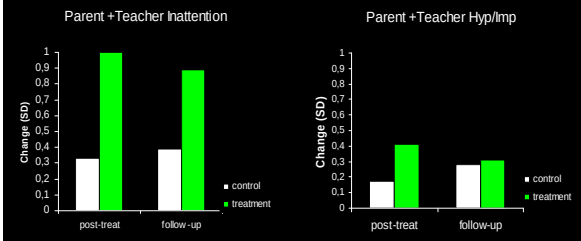


Digit-span

"2 8 4 7 2 9"

"9 2 7 4 8 2"

Inattentive symptoms (DSM-IV)



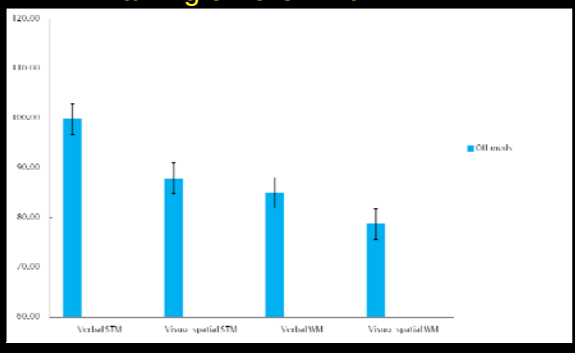
Effect size (Cohen's delta) inattention = 0.7

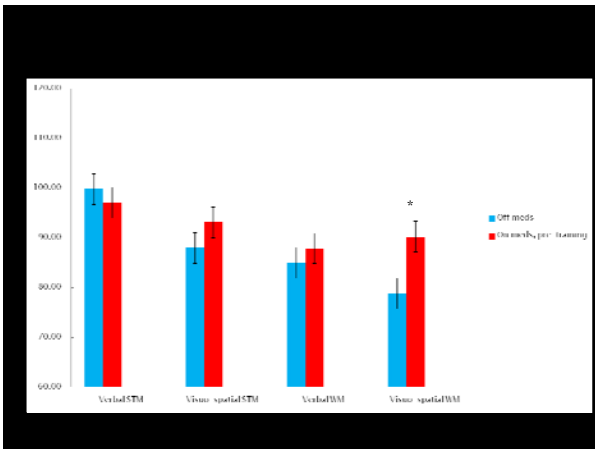
Working memory deficits can be overcome: impacts of training and medication on working memory in children with ADHD

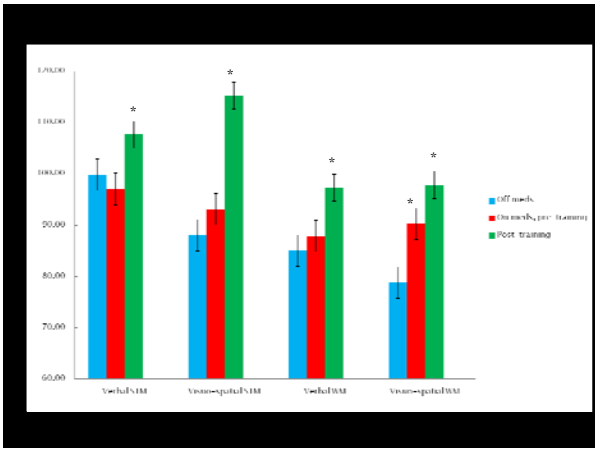
Holmes, J, Gathercole, et al. (2009) App. Cogn. Psych.

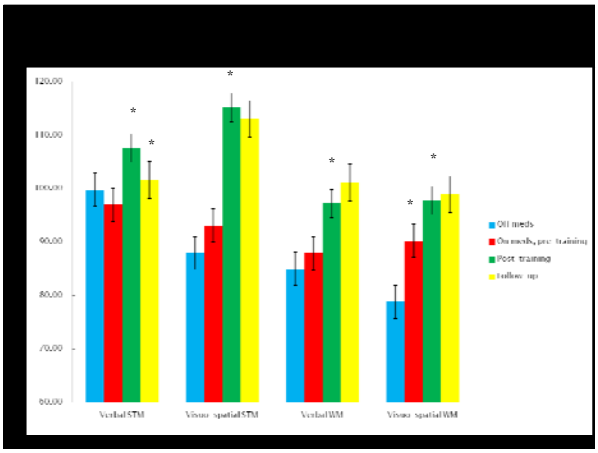
Children with ADHD, off or on medication
Automated working memory assessment (AWMA)

Training children with ADHD




120,00
110,00
100,00
90,00
80,00
70,00
60,00
*
Off meds
On meds, pre- training
Verbal STM
Visuo- spatial STM
Verbal WM
Visuo- spatial WM


120,00
110,00
100,00
90,00
80,00
70,00
60,00
*
Off meds
On meds, pre- training
Post- training
Verbal STM
Visuo-spatial STM
Verbal WM
Visuo-spatial WM


120,00
110,00
100,00
90,00
80,00
70,00
60,00
*
Off meds
On meds, pre- training
Post- training
Follow- up
Verbal STM
Visuo- spatial STM
Verbal WM
Visuo- spatial WM

Adaptive training leads to sustained enhancement of poor working memory in children

Joni Holmes,[1] Susan E. Gathercole[2] and Darren L. Dunning[2]

1. Division of Psychology, University of Northumbria, UK
2. Department of Psychology, University of York, UK

Developmental Science 2009

Subjects

- 345, 9-10 year old children screened with WM tests
- <15th percentile included
- N = 42

Randomized, controlled, blinded design

Intervention

- Training group, (Klingberg, 2005) (n=22)
- Control group (easy WM tasks) (n=20)

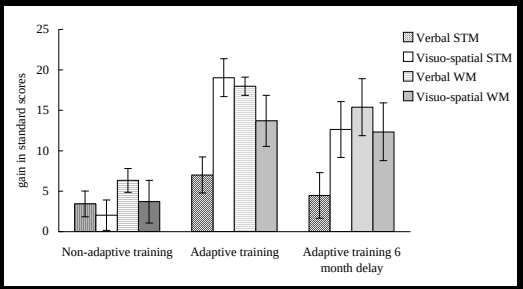
- Both groups receive 25 days of training over 5-6 weeks

Outcome measures

pre, post, 6 month follow-up

- Working memory (AWMA, 8 subtests)
- Instruction WM
  - *"Put the blue ruler in the red folder and touch the yellow pencil "*
    - Gathercole et al. (in press) Appl. Cogn. Psych.
- IQ
  - *Wechsler Abbreviated Scale of Intelligence*
- Mathematical reasoning
  - *Wechsler Objective Number Dimensions*
- Word reading
  - *Wechsler Objective Reading Dimensions*

Transfer to WM



Holmes, Gathercole & Dunning 2009.

Results

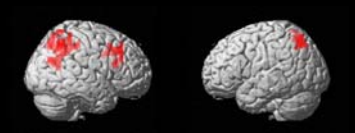
	Post training	6-month followup
AWMA (verb WM+VS)	☑	☑
Instruction WM	☑	☑
IQ Wech. Abbr.	—	—
Word reading	—	—
Mathematics	—	☑

Neural correlates of WM training

Experiment 1

fMRI

WM training

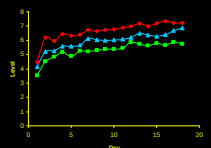


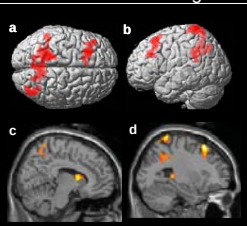
Olesen, Westerberg, Klingberg (2004) Nature Neurosci.

Experiment 2

fMRI

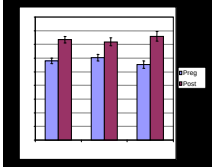
WM training



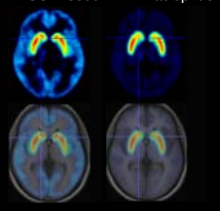


Dopamine and WM training

- 13 healthy, young adults
- 5 weeks of training (Klingberg et al., 2005)
- Measurement of verbal and visuospatial WM
- fMRI during performance of WM tasks
- PET of D1 and D2 binding, before and after



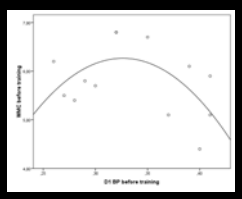
D1 SCH23390 D2 Raclopride

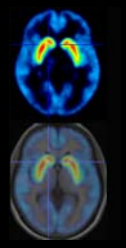


McNab et al. Science 2009

D1 BP vs WM at baseline

Linear model: $y = a + \beta_1 x$ r^2=0.09; p = 0.33
Quadratic model: $y = a + \beta_1 x + \beta_2 x^2$ r^2=0.34; p = 0.12
b_2 estimate p = 0.08

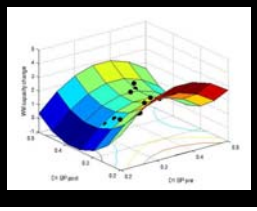




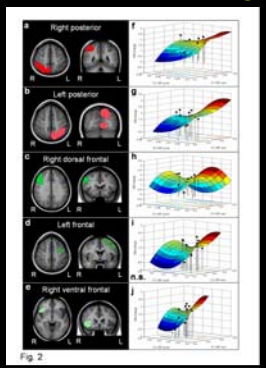
DA1 BP change vs WM change

Linear model:
$y_2 - y_1 = (a + \beta_1 x_2) - (a + \beta_1 x_1) = \beta_1 (x_2 - x_1)$ r^2=0.42; p=0.016

Quadratic model:
$y_2 - y_1 = (a + \beta_1 x_2 + \beta_2 (x_2)^2) - (a + \beta_1 x_1 + \beta_2 (x_1)^2)$ r^2=0.75; p=0.001
β_1 estimate p = 0.002
β_2 estimate p = 0.005



DA1 BP change vs WM change



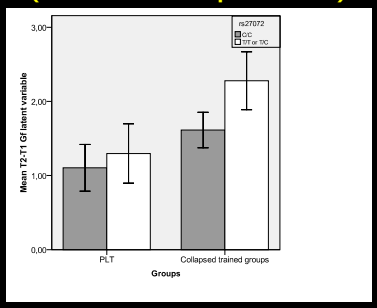
DA release

training ↔ WM improvement

D1 rec changes

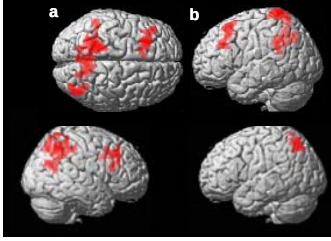
McNab et al. 2009

DAT1 and plasticity (and development?)

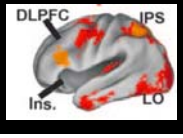


Söderqvist et al. (in press)

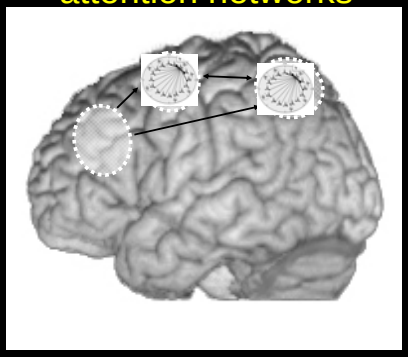
Working memory training
(Olesen, Westerberg, Klingberg, 2004



Expert "concentration" meditation
Brefczynski-Lewis, Davidson et al. 2007



Plasticity of the WM and attention networks



Conclusions

Training of working memory:

- Improves non-trained measures of WM capacity
  - Klingberg et al. 2002, Klingberg et al. 2005, Gibson et al. 2007, Lucas et al. 2008
  - Westerberg et al. 2007, Westerberg et al. (2008); Holmes et al. (2009)
- Decreases inattentive symptoms
  - Klingberg et al. 2005, Gibson et al. 2007, Lucas et al. 2008
  - Westerberg et al. 2008, Green et al. 2009, Hardy et al. 2009
- Is associated with plasticity of parietal and prefrontal cortex, possibly including D1
  - Olesen et al. 2004; Westerberg and Klingberg 2007; McNab et al. (2009)

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