Effects of working memory training on cognition and white matter microstructure: Does brain training work?

Claudia Metzler-Baddeley[1], Karen Caeyenberghs[2], Sonya Foley[3], and Derek K Jones[3]
[1]CUBRIC, Cardiff University, Cardiff, United Kingdom, [2]University of Ghent, Ghent, Belgium, [3]CUBRIC, Cardiff University, Wales, United Kingdom

Purpose: Computerised brain trainings are very popular and widely in use. However, the effects of such trainings in terms of enhancing brain structure and mental capacity remain controversial due to limited scientific evidence and methodological weaknesses and poor reproducibility of past studies[1]. The present research employed a well controlled experimental design to investigate the effects of a two month working memory training[2] on white matter microstructure in pathways thought to mediate working memory i.e. the superior longitudinal fasciculus, the arcuate, and the cingulum. Post- relative to pre-intervention cognitive and microstructural changes in the training group were compared with those in a matched active placebo control group.

Materials and Methods: Participants: 40 healthy adults (20– 40 years of age) were pseudo-randomly allocated to the two groups so that they were matched for age and IQ. Diffusion MRI: Data were acquired using a 3T GE HDx MRI system. Cardiac-gated HARDI diffusion MRI employed an optimised 60 direction gradient vector scheme and b-value 1200s/mm^2, 60 slices (2.4mm), FoV 24 cm, matrix 96x96, TE 87ms. Images were corrected for EPI distortions and motion with re-orientation of gradient directions[3]. The tensor was estimated in each voxel using RESTORE[4], and damped Richardson-Lucy spherical deconvolution[5] was used to extract voxelwise peaks in the fibre orientational density function (fODF). Data were corrected for CSF partial volume artefacts with the Free Water Elimination method[6]. Deterministic tractography was performed by seeding in all voxels and following the fODF peaks using *ExploreDTI*[7]. Putative 3D pathways belonging to the cingulum, the superior longitudinal fasciculus, and arcuate (Fig. 1) were selected from the whole brain tracking results using 'waypoint' regions of interest and reproducible landmarking techniques[8,9]. Tract-specific measures of average fractional anisotropy (FA) and radial diffusivity (RD) were subsequently generated.

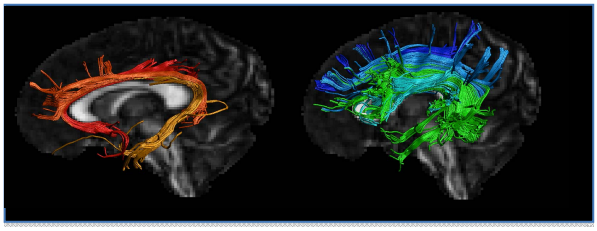

Figure 1: Sagittal view of the cognitive control pathways studied here: Subgenual (red), retrosplenial (orange) and parahippocampal fascicles (light orange) of the cingulum, superior longitudinal fasciculus I (dark blue), II (blue), III (light blue) and the arcuate fasciculus (green).

Results: Large training specific improvements were observed in working memory span performance (Fig. 2) together with an average decrease in FA and increase in RD in the parahippocampal cingulum for the training relative to the control group (Fig. 3). Training related cognitive changes correlated with microstructural changes in the parahippocampal cingulum (Fig. 4c) and the arcuate and were dependent on inter-individual variation in baseline microstructural measures (Fig. 4a,b).

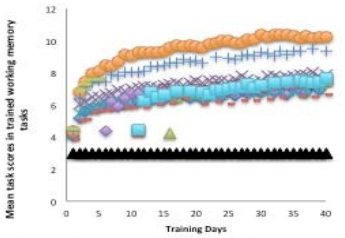

Figure 2: Performance improvements in the seven trained working memory tasks across 40 training days in the training group (coloured markers) compared to the active placebo control group (black markers).

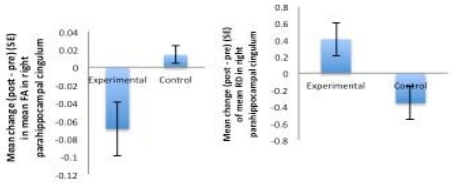

Figure 3: Training induced mean decrease in fractional anisotropy (FA) and increase in radial diffusivity (RD) **(x10^{-4} mm^2.s^{-1})** in the right parahippocampal cingulum.

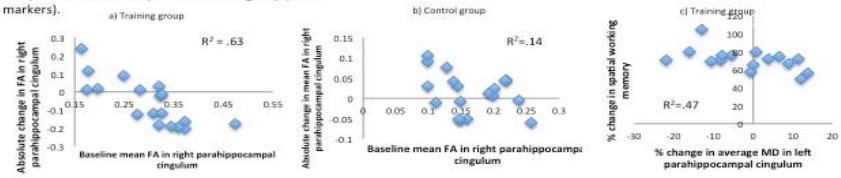

Figure 4: a + b Relationships between absolute FA change and baseline FA level in right parahippocampal cingulum. In the training group the change in FA was related to the baseline level of FA (a) whereas the control group did not show such a relationship (b). c correlation between improvements in spatial working memory capacity and microstructural change in parahippocampal cingulum in training group.

Conclusion: Our study demonstrates that intensive exercise of working memory capacity leads to focal and localized white matter microstructural changes in cognitive control pathways, which were related to training specific cognitive improvements. Moreover, the amount and the direction of observed microstructural changes after the training were determined by an individual's baseline microstructure. These results are important for our understanding of the mechanisms and limitations of environmentally induced neuroplasticity and its potential applications to aging and neurodegeneration.

References: [1] Thomas C, Baker, C (2013) *NeuroImage* 73:225-36. [2]Cogmed and Cogmed Working Memory Training are trademarks, in the U.S. and/or other countries, of Pearson Education, Inc. or its affiliate(s). [3] Leemans A, Jones DK (2009) *Magn Reson Med* 61:1336-49. [4] Chang et al (2005) *Magn Reson Med* 53:1088-95. [5]DellAqua et al (2010) *NeuroImage*.49:1446-58. [6] Pasternak et al (2009) *Magn Reson Med* 62:717–730. [7] Leemans et al (2009) ExploreDTI *Proc ISMRM 17th Ann Meetg*, p 3537, Hawaii. [8] Jones DK et al. (2013) *Neuropsychologia* 51: 67-78. [9] Thibaut de Schotten et al (2011) *Nature Neuroscience* 14:1245-6.

Target audience: Cognitive neuroscientist, Imaging scientist, Psychologists, Clinicians