

This white paper provides an overview of working memory, its relation to attention deficits and research studies that confirm the effects of Cogmed Working Memory Training.

Training of Working Memory

By Torkel Klingberg, MD, PhD

Working memory is a key function that is necessary for many cognitive tasks. Working memory depends on the prefrontal cortex of the brain and memory deficits occur in several disorders that affect the prefrontal cortex, such as stroke, traumatic brain injury and ADHD. We have shown that systematic training can improve working memory. This improves attention and ameliorates the cognitive symptoms in both ADHD and stroke. Brain imaging studies indicate that training increases brain activity in the prefrontal cortex.

Working Memory is a key function necessary for many cognitive tasks

Working memory is the ability to keep information “online” for a brief period of time, typically a few seconds. In laboratory settings, working memory capacity can be measured by testing how many digits a subject can repeat back after hearing them once. In daily life, we use working memory to remember plans or instructions of what to do next, in problem solving, and for controlling attention, “remembering what to attend to.”

When people have deficits in working memory, it is often experienced as “inattention problems,” e.g. to have problems focusing on reading a text, or “memory problems,” e.g. forgetting what to do during the few second while walking from one room to the other. In children the problem is often remembering what to do next, which makes them unable to finish an activity according to plan.

The neuroscience of working memory has been studied for decades. Studies on both animals and humans have shown that the prefrontal cortex is essential for working memory performance as is correct dopaminergic transmission. Other important structures are the parietal cortex and the basal ganglia.

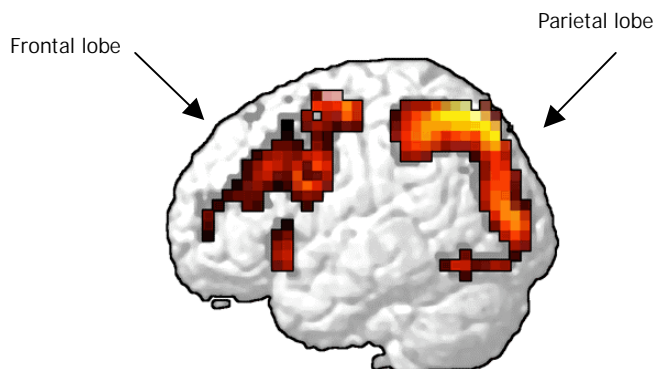


Figure 1. Colored regions show parts of the brain that are activated by a working memory task (from Klingberg et al. 2002).

Working memory deficits occur in many conditions

Working memory is impaired when the function of the frontal lobe or the dopaminergic systems are impaired. Stroke affecting the frontal lobe is associated with working memory deficits, as are traumatic brain injuries (Robertson and Murre, 1999). In these cases, the working memory deficits lead to attention and planning problems. Attention Deficit Hyperactivity Disorder (ADHD) is associated with disturbances of both the frontal lobe and the dopaminergic system, and is consequently also associated with working memory deficits. Learning disability is another prevalent condition that can be defined as academic difficulties that are not due to inadequate opportunity to learn, general intelligence, physical or emotional disorders, but to basic disorders in specific psychological processes. It has been shown that learning disability can be directly linked to deficits in working memory (Gathercole and Pickering, 2000).

ADHD is a widespread and serious disorder

ADHD is a disorder that includes severe problems of attention, impulsivity and hyperactivity. Centers for Disease Control and Prevention estimates as of 2003, 4.4 million young people ages 4-17 have been diagnosed with ADHD by a healthcare profession, while 2.5 million children are currently receiving medication for the disorder. In addition, CDC reports 7.8% of school-aged children in 2003 were reported to have an ADHD diagnosis by their parent. ADHD has a strong genetic component, with heritability estimated around 70%. Anatomical studies have shown that the frontal lobes, as well as the basal ganglia, are smaller in this group of children.

Deficits in working memory are thought to be of central importance in explaining many cognitive and behavioral problems in ADHD (Barkley, 1997; Castellanos and Tannock, 2002; Rapport et al. , 2000; Westerberg et al., 2004). Westerberg et al. (2004) compared working memory tasks with other tasks and showed that children had most problems with working memory tasks.

Can working memory be improved?

Torkel Klingberg, MD, PhD, has conducted research at Karolinska Institute, and at Stanford University for several years concerning the neural basis of working memory and working memory deficits in children. Working memory capacity has generally been held to be a fixed property of the individual. However, Klingberg, Helena Westerberg and others at the Department for Neuropediatrics at Astrid Lindgren's Children's Hospital (part of Karolinska University Hospital), recently started to develop methods for improving working memory. These methods are influenced by animal research on mechanisms for training induced plasticity (Buonomano and Merzenich, 1998). Development was conducted in collaboration with Jonas Beckeman and David Skoglund, professional game developers who helped solve technical issues and helped make the training more rewarding.

The training consists of a specific set of working memory tasks that are performed on a computer, where the difficulty level is adjusted according to a specific algorithm. The children complete a fixed number of trials every day, taking about 30-40 minutes daily. This is done for five days a week over five weeks. During training, performance results are saved and can be used for later analysis.

The program is called RoboMemo, and has been developed by Cogmed Systems AB. Figure 2 show how performance increases gradually during training.

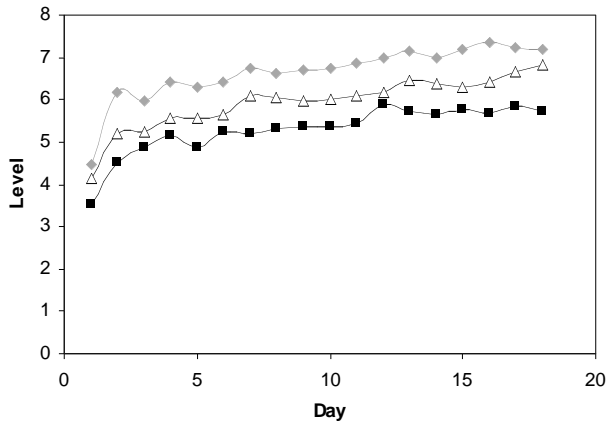


Figure 2. During training, performance is stored on the computer, and later uploaded via internet to a server. From this data gradual improvement on working memory tasks can be seen. This figure shows improvement on three different working memory tasks during 18 days of training (from Olesen et al. 2004).

The first training study with ADHD: promising results

A first double-blind, placebo-controlled study of the clinical effect of the training included children with ADHD aged 7-13 years (Klingberg et al., 2002). Two groups were compared: a treatment group and a comparison group. Children in the treatment group practiced working memory tasks where the difficulty level was adjusted to closely match the working memory capacity of the child. This procedure was hypothesized to optimize the training effect. In the comparison condition, the same tasks were used but the working memory load, i.e. number of items that should be remembered, was low, thus resulting in easy tasks which were expected to result in only small training effects. By having two similar versions we intended to control as much as possible for non-specific effects of the training procedure, and specifically estimate the effect of improvement of working memory. Both groups were evaluated with neuropsychological tasks before and after training.

When the results from the two groups were compared, we could show that the treatment group had improved significantly more than the comparison group on working memory tasks. Moreover, they had also improved on a task measuring response inhibition, which is something children with ADHD have serious problems with. Somewhat unexpectedly, the children in the treatment group had also improved on a reasoning task known to have a high correlation with IQ.

The second training study with ADHD: confirmation in a multi-center trial

A main shortcoming of the first study was the low number of subjects (N = 7 in both the treatment and in the comparison group). Moreover, ratings of ADHD symptoms were not performed, only one clinical center was involved and there was no follow-up measurement of both groups to estimate the extent to which training effects lasted. A second study was therefore conducted at four clinical sites in Sweden, evaluating the effects of practicing working memory tasks in a randomized, double-blind, controlled design (Klingberg et al., 2003). In the multi-center study we compared two similar versions of the same training program, exactly as in the first study. Executive functions (working memory, response inhibition and reasoning) were measured and ADHD symptoms were rated by parents and teachers before, directly after and 3 months after training.

The results were very clear. There was a significant treatment effect for non-trained tasks measuring visuo-spatial and verbal working memory, response inhibition and complex reasoning. Three months after the intervention, on average more than 90% of the training effect for the working memory tasks remained. Parent ratings showed significant reduction in symptoms of inattention and hyperactivity/impulsivity, both post-intervention and at follow-up. Combined ratings from teachers and parents showed significant reduction of symptoms related to inattention post-intervention (1 SD reduction in scores, 0.9 SD at follow-up).

These results thus confirmed the findings from the first study. Moreover, they showed that the very symptoms that define ADHD decreased (Klingsberg et al., 2005) .

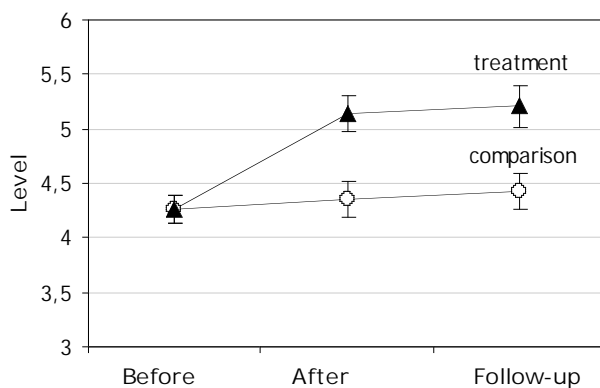


Figure 3. This figure shows performance of a working memory task before training (T1), after training (T2) and three months after training (T3). Although both groups improve somewhat from taking the test repeatedly, the treatment group improved significantly more. The difference between the groups remained after three months (from Klingberg et al. 2005).

Training of working memory after stroke

Working memory is often affected after stroke and traumatic brain injuries (Robertson and Murre, 1999). These deficits are often subjectively experienced as problems with attention and planning. Following stroke, one of the main reasons for not being able to return to work

is the cognitive problems. While there are many therapies addressing problems with motor functions and language, there is currently no satisfactory way to treat the cognitive problems.

We therefore wanted to test if training of working memory could help persons who had suffered from stroke (Westerberg et al., 2003). Eighteen persons aged 34-65 years were included in the study. They had all suffered from stroke 1-3 years prior to the study. Subjects were randomized into a treatment group or a wait-list control group. Both groups were tested with neuropsychological tests twice with a five-week interval. In addition, they filled out a questionnaire rating their cognitive problems in everyday life.

When the results from the two groups were compared, we could show that the treatment group had improved significantly on several neuropsychological tasks measuring working memory and attentive ability (the span board task, the PASAT and Ruff 2 & 7). In addition, the subjects in the treatment group reported significantly fewer symptoms of cognitive problems. The reduction of symptoms was also correlated with the improvement on the neuropsychological tasks.

Although the study was small and needs to be replicated, these results could be important from both a clinical and a scientific viewpoint. Clinically, it shows that working memory training could be a useful method in stroke rehabilitation. Scientifically, it shows that not only children can improve their working memory functions but that the ability to improve working memory could be a general capability that is retained throughout life.

Based on the experience from this study and additional cases, a specific training program for stroke patients has been developed in collaboration with the stroke clinic at Danderyd Hospital.

Training changes brain activity

What, then, is the basis for the improvement of working memory that we have observed? To investigate the neural basis of the training effect we used functional Magnetic Resonance Imaging (fMRI) to measure brain activity in healthy, young adults while they performed a working memory task (Olesen et al., 2004). These measurements were done before, during and after training. We performed two different studies with slightly different designs. Both studies confirmed each other in showing that after training, the brain activity in the prefrontal and parietal areas increased.

These studies indicate that the neural systems underlying working memory are plastic, i.e. they can change. It is also interesting to notice the specific regions in which these changes occur. They occur in the so-called multimodal association cortices. This is a part of the brain that is not tied to any particular sensory modality of the brain, such as vision, but regions that are active in a wide range of cognitive functions that involve working memory. Improvement of function in such a region could explain how training could benefit several neuro-

psychological functions, as shown by the behavioral tests in the training studies involving children with ADHD.

Constant improvements

Part of our current research concerns the link between learning disability and working memory deficits. Preliminary data suggests that working memory training does improve reading comprehension and mathematical problem solving ability (data presented at Nordic Conference on Dyslexia, 2005).

The Cogmed training method is under constant improvement. We do this by evaluating the effect modifying the current training program. The fact that all training data in all studies and clinical work are recorded and available means that we are constantly adding to a database that we can analyze to deepen our knowledge about how children and adults improve learning most effectively.

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Dr. Klingberg is active as a consultant to Cogmed in matters of research and development.

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