Training of Working Memory

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Working memory is the ability to keep information on-line for a brief period of time, which is essential for many complex cognitive tasks such as reading comprehension, problem solving and control of attention. In contrast to what was previously assumed, we have shown that systematic training can improve working memory capacity, in both children and adults. Brain imaging studies also show that working memory training leads to increased brain activity in the prefrontal and parietal cortex. Improving working memory capacity leads to better performance of a range of tasks that require working memory, such as problem solving and reading comprehension. Moreover, it translates to increased attentiveness in everyday life.

Working Memory is a key function necessary for critical cognitive tasks

Working memory is the ability to keep and manipulate information “online” for a brief period of time. This ability can be measured for example by testing how many digits a subject can repeat back after hearing them once (verbal working memory) or how many positions a subject can remember after seeing them once (visual working memory).

In daily life we use working memory, for example, to remember plans or instructions of what to do next. But keeping information online is a very basic function that has proved to be of central importance in a wide range of cognitive tasks. Verbal working memory is necessary for comprehending long sentences; and verbal working memory capacity predicts performance on reading comprehension in the scholastic aptitude test (SAT) (Daneman and Carpenter, 1980). Working memory is also important for control of attention, and to maintain task-relevant information during problem solving. More generally, working memory has been suggested to be the single most important factor in determining general intellectual ability (SüB et al., 2002). About 50% of differences between individuals in non-verbal IQ can be explained by differences in working memory capacity (Conway et al., 2003).

More recently, it has also become clear that there is a strong link between working memory capacity and the ability to resist distractions and irrelevant information. One study used the so called “cocktail party effect”, i.e. our ability to focus on one voice despite noisy surroundings, and showed that this ability is related to working memory capacity (Conway et al., 2001). Recent studies have also shown that low working memory is related to being “off-task” and daydreaming (Kane et al., 2007). These psychological studies are consistent with neuroimaging studies, which have shown that subjects with higher working memory capacity are less likely to store irrelevant information (Vogel et al., 2005). The prefrontal cortex is important in providing this “filtering” of irrelevant information, and subjects with higher working memory capacity have a higher prefrontal activity and are better at filtering out distractors (McNab and Klingberg, 2008).

When people have deficits in working memory, they are often experienced as "inattention problems", e.g. to have problems focusing on reading a text; or "memory problems", e.g. forgetting what to do in the few seconds of walking from one room to the another, or being easily distracted while trying to focus on a task. In children the problem is often remembering what to do next, which makes them unable to finish an activity according to plan.

In conclusion, working memory allows us to hold on to information in order to complete a task, and is especially important in any cognitively demanding environment with irrelevant distractions.

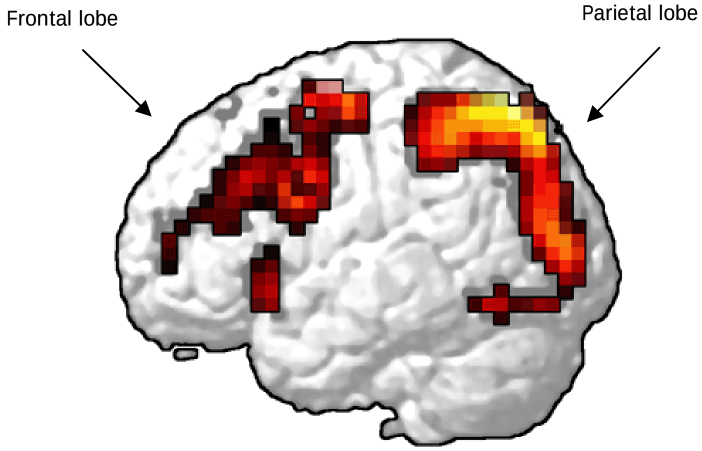

Figure 1. Colored regions show parts of the brain that are activated by a working memory task (from Klingberg et al. 2002).

Working memory deficits occur in many conditions

There is a normal variability from individual to individual in working memory capacity. In the individual, capacity can also be temporarily decreased due to stress or lack of sleep. Moreover, there is a normal decline in capacity with aging, starting around 25-30 years of age, with a decline of about 5-10% per decade.

Except for this normal variability, working memory capacity is also affected in a range of clinical conditions, affecting the neural systems underlying working memory. Studies on both animals and humans have shown that the prefrontal and parietal cortexes are essential for working memory performance; as is the basal ganglia, as well as correct dopaminergic transmission. When these systems are affected, working memory is 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 and ADD) 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, in children and in adults, which can be defined as academic difficulties that are *not* due to inadequate opportunity to learn, general intelligence, nor to physical/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 with a key WM component

ADHD is a disorder which includes severe problems of attention, impulsivity and hyperactivity. ADHD affects 3-5% of children between 6-16 years, which makes it the most common neuropsychiatric disorder. When children with ADHD grow older, the hyperactivity decreases, but problems of inattention, which often lead to academic and occupational failure, remain in the majority of cases. ADHD has a strong genetic component, with heritability estimated around 70%. 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. A meta-analysis of 46 studies (Martinussen et al., 2005) confirmed the WM deficits in ADHD, and also showed that the deficits are most pronounced in the visuo-spatial domain.

Can working memory be improved?

Torkel Klingberg, MD PhD, has conducted research at Karolinska Institutet 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, Ph.D., and others at the Department for Neuropediatrics at Astrid Lindgren's Children’s Hospital (part of Karolinska University Hospital), started to develop methods for improving working memory in 1999. 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 users 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 Cogmed RM, and has been developed by Cogmed Systems AB. Figure 2 shows 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 in 450 children, during 25 days of training.

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 training working memory tasks in a randomized, double-blind, controlled design (Klingberg et al., 2005). 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 (Klingberg et al., 2005) .

Recently, an independent research group at Notre Dame University, USA, lead by Dr. Bradley Gibson, tested the Cogmed working memory training method in a group of thirteen children with ADHD (Gibson et al. 2006). They found significant pre-post improvements for both working memory tasks and a problem solving task. Moreover, ADHD symptoms decreased as rated by both parents and teachers, with the magnitude of improvement even larger than those previously reported by Klingberg et al. (2005). Further studies are also being conducted by Susan Gathercole and colleagues at York University, UK.

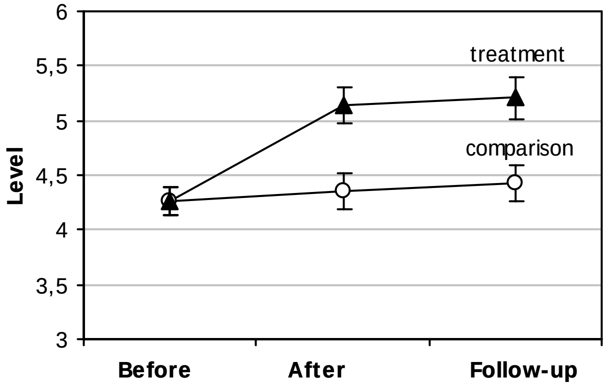

Figure 3. This figure shows performance of a working memory task before training (T1), after training (T2) and three months after training (T3). Although both groups improve somewhat from taking the test repeatedly, the treatment group improved significantly more. The difference between the groups remained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

A later study by Dahlin, Myrberg and Klingberg (data presented at Nordic Conference on Dyslexia, 2005) studied the effect of working memory training in children with special education needs, in order to investigate the effect on academic performance. Forty-five children performed five weeks of working memory training. Compared to the control group, who only received ordinary special education activities, the children in the training group improved significantly on non-trained working memory tasks and problem solving tasks, confirming previous results in children with ADHD. In addition, the children improved significantly on a standardized test of reading comprehension (PIRLS) as well as on a test of mathematical reasoning. This effect was also significant at the six month follow-up measurement. This suggests that working memory training could be a useful tool in order to improve academic abilities in children with special education needs.

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 remediate the cognitive problems. We therefore wanted to test if training of working memory could help persons who had suffered from stroke (Westerberg et al., 2007). The same training program as in the studies on children with ADHD was used. 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 completed a questionnaire rating their cognitive problems in everyday life.

When the results from the two groups were compared, 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.

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 note 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 brain region could explain how training could benefit several neuropsychological functions, as shown by the improvements in the behavioral tests in the training studies involving children with ADHD.

Further analysis of brain activity changes also suggested that differences are due to slight increases in the extent of activity (Westerberg and Klingberg, 2007). This could be interpreted as increases in the total number of neurons that are devoted to keeping information in working memory.

Working Memory Training in older individuals

Working memory capacity decreases with normal aging. Starting from around 25 years of age, the capacity decreases with 5-10 % per decade. In order to investigate whether this decline can be compensated by training, Westerberg and colleagues (Westerberg et al., 2007) undertook a training study with 50 older adults (age 60-70) and 50 younger adults. Within each age-group, subjects were randomized to either working memory training, or a comparison groups using a “low-dose” version of the training program, with easy trials that were not expected to have any training effect. The trial was conducted as a double blind study, where the testing psychologists as well as subjects were blind to grouping.

Testing before and after training showed that the training group improved significantly on non-trained task measuring working memory capacity (span-board and digit span), as well as sustained attention (the paced auditory serial addition task, requiring subjects to perform mental arithmetics). Furthermore, self-ratings of everyday cognitive functions (using the Cognitive Failure Questionnaire), showed that the treatment group experienced significantly less everyday cognitive problems, such as being better at remembering instructions.

Durability of effects

The long-term effects of training are more difficult to study than immediate effects, because of drop-outs, and the problem of retaining a control group blinded and non-treated for a long time. However, in two randomized, controlled studies (Klingberg et al., 2005; Westerberg et al., 2007) training effect were significant at the three-month follow-up. In the study by Dahlin et al., follow-up measurements in both trained subjects and controls, conducted six months after training, showed that improvements in reading comprehension and mathematical problem solving were still significant.

In a survey conducted by Cogmed, parents to children who had undergone working memory training were interviewed five months after training. They were asked, “Do you experience the effect on your child as smaller, equally strong, or stronger now, compared to directly after training?” Out of 50 families, 82% experienced the effect to be equally strong or stronger 5 months after training. This finding is also consistent with a study by Steven Bozylinski (2007) in 16 children and adolescents with ADHD which showed that the significant effects on the BRIEF metacognition index where virtually undiminished 5 months after training.

The results above thus suggest a long-lasting effect of working memory training. Possibly these long-term effects are mediated through positive feedback, in that an initial improvement in working memory leads to increased participation in mentally demanding activities in everyday life, which in turn sustains the training effect. Similar examples of positive feedback have been noted after interventions aimed at improving reading.

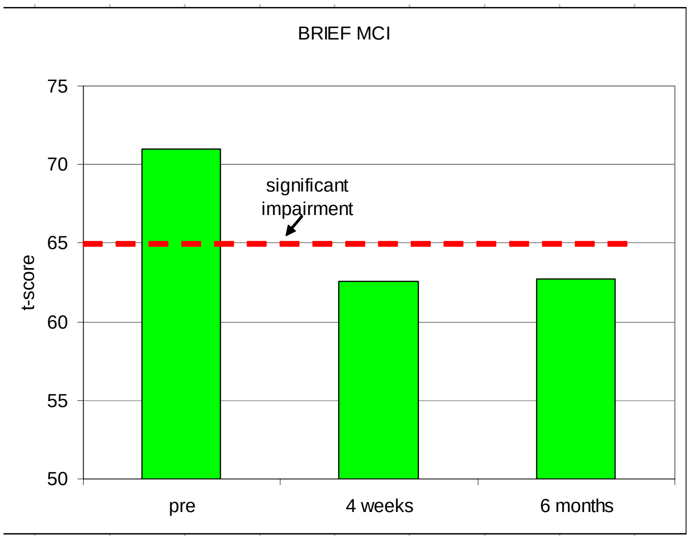

Fig. 3. Effects of working memory training on the BRIEF metacognition index, 4 weeks after training and 6 months after training (Bozylinski, 2007).

Training of working memory in relation to other types of cognitive training

Studies of the effectiveness of working memory training raise the question of whether other cognitive functions are also possible to improve by training. In one recent study (Thorell et al., in press) working memory training was compared to training of inhibitory functions, which are also suggested to play a role in ADHD, particularly at younger ages. Children aged 4-5 years participated in the study, and were randomized into one of four groups: 1) Cogmed working memory training; 2) Computerized training of inhibitory functions; 3) Performance of a commercial computer game, and 4) Passive control. Both the working memory group and the inhibitory group improved on the tasks performed as part of the training regime. However, when the children were tested before and after on cognitive tasks that were different from those in the training program, only the working memory group showed a significant improvement compared to the control group. Neither the inhibitory group, nor the group playing commercial computer games improved on any of the cognitive tasks. This study illustrates two important points: Firstly, it is not enough to show improvement on trained tasks, as is often done in pseudo-scientific studies of cognitive training. Transfer to non-trained tasks has to be shown, and this requires scientific studies. Secondly, cognitive abilities seem to differ in the extent to which training generalizes to other cognitive functions, and working memory seems to be especially amenable to improvement by training.

Constant improvements

Part of our current research concerns the link between learning disability and working memory deficits. The Cogmed training method is under constant improvement. We do this by continually evaluating the effects of 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.

Conclusions

The Cogmed working memory training is scientifically well documented and further studies are ongoing. The training improves performance on cognitive tasks requiring working memory and attention, and also improves attention in everyday life. The effects are clinically strong, lasting, and seem to be prevalent in most age-groups, including children as well as young and old adults.

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