COGMED

Training of Working Memory

By Torkel Klingberg, MD, PhD, Professor of Cognitive Neuroscience at the Karolinska Institute

Working memory is the ability to keep information online for a brief period of time, which is essential for many cognitive tasks such as control of attention and problem solving. 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 on several tasks that require working memory and control of attention and 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 in several ways – for example, by testing how many digits a subject can repeat back after hearing them once (verbal working memory), or by testing how many positions a subject can remember after seeing them once (visual working memory).

In daily life we use working memory 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 neuro-imaging 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 distracters (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.

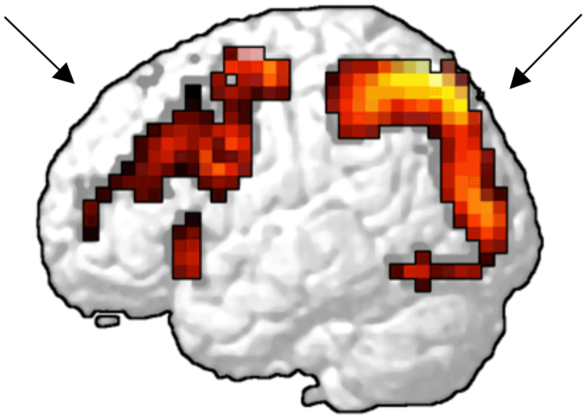

Figure 1. Colored regions show parts of the brain that are activated by a working memory task (from Klingberg et al. 2002).

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, impacting 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, and 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 working memory 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 working memory 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 Ph.D, has conducted research at Karolinska Institute 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.

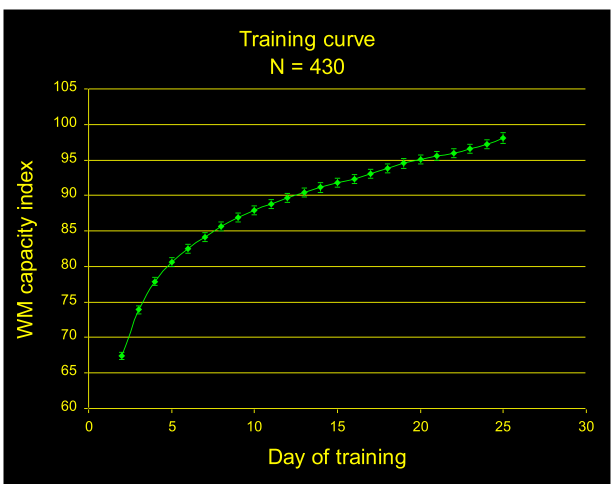

Figure 2. During training, performance is stored on the computer, and later uploaded via internet to a server. From this data, gradual improvement on working memory tasks can be seen. This figure shows improvement in 450 children, during 25 days of training.

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).

Replication of findings by independent research groups

In 2009, Joni Holmes and Susan Gathercole, at York University, UK, published a study of the effect on Cogmed RM in children with low working memory (Holmes et al., 2009a). A novel aspect of this study was to include children based on their working memory performance, rather than ADHD diagnosis. From 350 children, those children scoring below 15th percentile were included in the study and randomized to either the treatment group (receiving Cogmed RM), or the control group (receiving a low-intensity version of the computer program). After training the treatment group had not only improved on a set of working memory tasks but also on a test of working memory for instructions. This is an interesting and “ecologically” more valid test in that it closely resembles the kind of working memory challenges that children are exposed to in everyday life. At the six month follow-up, the treatment group did not only retain the significant improvement in working memory, but this had also translated into a significant improvement on a test of mathematical problem solving, which is known to be dependent on working memory capacity. This is the first time a published study documented the impact of working memory training on academic performance and the authors concluded: “These findings indicate that common impairments in working memory and associated learning difficulties may be overcome with this behavioral treatment”.

In a second study by the same research group (Holmes et al., 2009b) they investigated the effect of working memory training on children with ADHD, and compared the effect with medication. Children were assessed with a battery of working memory tests (the Automated Working Memory Assessment) at four time-points: 1) without medication, 2) with medication, 3) with medication and training, and 4) 6 months after training. Their conclusion was that "While medication significantly improved visuo-spatial memory performance, training led to substantial gains in all components of working memory across untrained tasks. Training gains associated with the central executive persisted over a 6-month period. IQ scores were unaffected by either intervention."

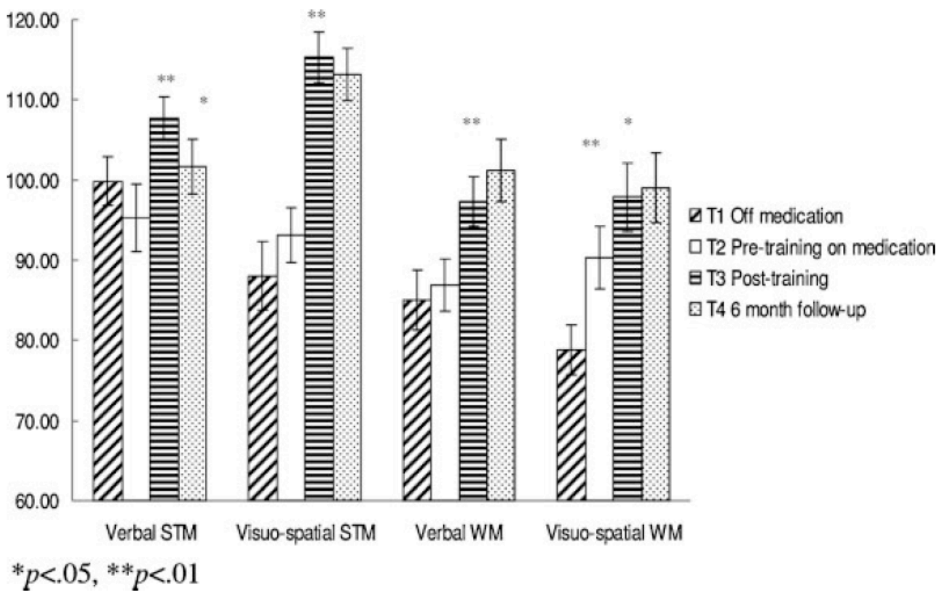

Figure 3. From Holmes et al. (2009b). Impact of training and medication on working memory component scores. *p<.05, **p<.01. NB. Asterisk above a bar denotes a significant change in score from the previous testing point.

A 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).

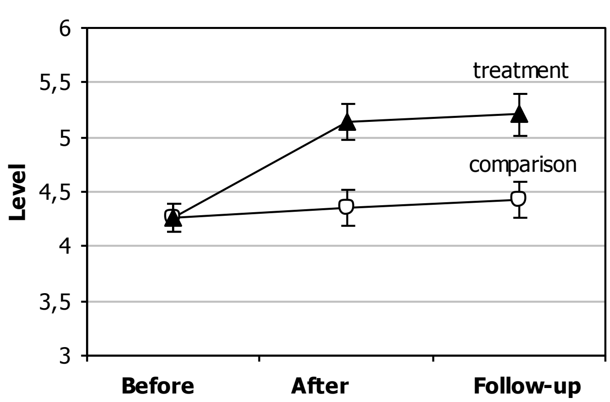

Figure 4. This figure shows performance of a working memory task before training (T1), after training (T2) and three months after training (T3). Although both groups improve somewhat from taking the test repeatedly, the treatment group improved significantly more. The difference between the groups remained after three months (from Klingberg et al. 2005).

A study lead by Chris Lucas at New York University Child study center (Lucas et al., 2008) investigated the effect of Cogmed Working Memory Training on 46 children with ADHD who participated in a summer camp. Children either received the Cogmed Working Memory Training, or a control program. A novel aspect of this study was to have raters, blinded to group assignment, performing weekly ratings of the children's behavior. After three weeks of training, a significant improvement emerged, which was retained throughout the training period. This again confirms the effect of working memory training on everyday functioning.

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 function, 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.

Another aspect of brain functioning is the receptor systems of the brain. It is known that especially the dopamine receptors are important for working memory performance, and disturbances of the dopamine systems are thought to partly explain the working memory deficits in disorders such as ADHD. To study the effect of working memory training on the dopamine system, a group of researchers, including Fiona McNab and Torkel Klingberg at the Karolinska Institute, used positron emission tomography to measure the density of dopamine D1 and D2 receptors in the brain, before and after training. The participants in this study were young, healthy adults, who all performed five weeks of working memory training. It was found that the density of dopamine D1-receptors, but not of D2-receptors, was significantly associated with the change in working memory capacity. The change in absolute terms depended on the initial receptor density of the subjects, with some subjects increasing their number of receptors, while the majority of subjects decreased their number of receptors. The mechanisms behind this finding are as yet unclear. It is not known whether the change in dopamine receptors is the reason for the change in capacity, or if it is a side effect of increased dopamine release during working memory training. However, it clearly shows that the dopamine receptor system of the brain is plastic, and that the training of working memory involves changes relating to the dopamine system. This is especially interesting in the light of the dopamine hypothesis of ADHD, i.e. the idea that the behavioral and cognitive impairments are related to disturbances of the dopamine system, which is also affected by the drugs used in treating ADHD.

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 to a comparison group 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 arithmetic). Furthermore, self-ratings (using the Cognitive Failure Questionnaire), indicated that the treatment group experienced significant improvement in their everyday cognitive functions, 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 both the studies by Holmes et al. (2009a, 2009b) significant improvement was retained six months after training. Furthermore, in the first study (2009a) additional effects on mathematical reasoning, which were not significant directly after training, had emerged.

In a survey conducted by Cogmed, parents of 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.

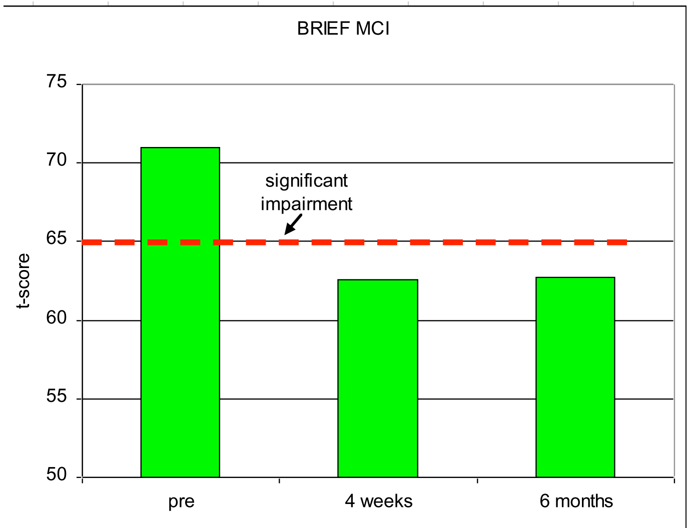

Figure 5. Effects of working memory training on the BRIEF metacognition index, 4 weeks after training and 6 months after training (Bozylinski, 2007).

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., 2008) 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 transfer to improvement of non-trained tasks. Neither the inhibitory group, nor the group playing commercial computer games improved on any of the cognitive transfer 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.

2010 research update

In 2010 there were several studies published adding to Cogmed's solid research base. The studies examined the benefit of Cogmed training with various populations across all age groups – and showed very positive results in keeping with those seen in previous research. Below is a breakdown of the studies published in 2010 and a brief summary describing each one.

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Title: Computer Training of Working Memory for Children with ADHD: A School-Based Feasibility Pilot Study

PI: Enrico Mezzacappa, M.D.

Institution: Harvard University

Published: School Mental Health, February 2010

Summary: This study was conducted by researchers at Children's Hospital, Harvard University. 8 children from one school in a low SES environment, all qualified for free breakfast and lunch at school, trained with Cogmed RM at school for five weeks. After training they improved significantly on measures of verbal and visuo-spatial working memory and symptoms of ADHD as rated by teachers decreased. This study is important in that the training took place in a school setting.

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Title: Effects of working memory training on reading in children with special needs

PI: Karin Dahlin

Institution: Stockholm University

Published: Reading and Writing, May 2010

Summary: This study examined the efficacy of Cogmed training in improving reading comprehension development in 57 Swedish children with special needs. The study showed specific improvements in reading comprehension. The researchers concluded that "the training of working memory may be useful for children with reading comprehension problems, special-education needs, and attention problems". The researchers also concluded that screening for working memory deficits would be valuable for identifying those at risk to struggle academically.

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Title: Computerized training of working memory in a group of patients suffering from acquired brain injury

PI: Anna Lundqvist, Ph.D.

Institution: Linköping University

Published: Brain Injury, September 2010

Summary: This study examined the efficacy of Cogmed training on 21 subjects (mean age 43.2 years) with a working memory deficit caused by an acquired brain injury or stroke. The study showed that there was significant improvement in working memory in both the trained working memory tasks and in non-trained neuropsychological assessments. Rating scales also showed better performance at work with noticeable improvement in pre-defined occupational problems. The researchers concluded that Cogmed training is an effective intervention to improve working memory capacity in people with an acquired brain injury or stroke - most likely leading to improved performance at work and other daily activities.

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Title: A Controlled Trial of Working Memory Training for Children and Adolescents with ADHD

PI: Steven Beck, Ph.D.

Institution: Ohio State University

Published: Journal of Clinical Child & Adolescent Psychology, November 2010

Summary: This study examined the efficacy of Cogmed training on 52 children with ADHD and other comorbid diagnoses. The children ranged in age from 7-17 and all attended a private school for children with ADHD and other learning disabilities. The researchers found significant improvement in ADHD symptoms and executive functions as well as inattention, organization, and working memory. This improvement was noted, in addition to various neuropsychological assessments, by rating scales filled out by both the parents and the teachers of the participants. The researchers concluded that Cogmed training may be effective in improving core cognitive deficits underlying ADHD and thus improve ADHD symptoms.

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Title: A Controlled Trial of Working Memory Training for Children and Adolescents with ADHD
Researchers: Gro C. C. Løhaugen, Ida Antonsen, Asta Haberg, Arne Gramstad, Torstein Vik, Ann-Mari Brubakk, and Jon Skranes
Institution: St. Olav's University Hospital, Trondheim, Norway
Published: The Journal of Pediatrics, December 2010

Summary: This study examined the efficacy of Cogmed training on children and adolescents who were born preterm with extremely low birth weight (ELBW). These children usually have a working memory deficit which contributes to the problems they have later in life. The results showed that the children examined were able to improve non-trained working memory tasks following the program. They also found the training to generalize to verbal learning ability and that the results remained stable six months after training. The researchers concluded that Cogmed was an "effective intervention tool for improving memory and reducing core learning deficits in adolescents born at ELBW".

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Title: Working Memory Training for Children with Cochlear Implants: A Pilot Study
PI: William Kronenberger, Ph.D.
Institution: Indiana University
Published: Journal of Speech, Language, and Hearing Research

Summary: This study investigated the efficacy of Cogmed training for improving memory and language skills in a sample of deaf children with cochlear implants (CIs). The study examined 9 children ages 7-15 and results showed significant improvement on measures of verbal and nonverbal working memory, parent-reported working memory behavior, and sentence repetition skills. The study included a six month follow up which showed a slight drop in working memory, but continued improvement in sentence repetition.

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

Cogmed Working Memory Training is perhaps the most scientifically well documented cognitive training program currently available. The training improves performance on cognitive tasks requiring working memory and attention, and also improves attention in everyday life. The effects are clinically strong, long lasting, and seem to be prevalent in most age-groups, including children as well as young and old adults.

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