White Paper Series, Issue 1

The cognitive comeback

New research with potential to end the debate
as to whether "cognitive training works"

Cogmed White Paper Series, Issue 1

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Different ways of asking whether "cognitive training works" have haunted educators, clinical psychologists, and neuroscientists alike for decades. The most recent research studies, however, make promising contributions to the field by covering a broader set of outcome variables, longer time spans, and larger populations than ever studied before.

Based on data from these trials a more nuanced picture emerges–and the state of the art can be thoroughly revised. As it turns out, the potential benefits from cognitive training can be both vast and long lived, in many cases larger than what was indicated by the early trials in the field.

At the same time, not all types of cognitive training have the same effect, and realizing the effects requires substantial effort from the person undergoing the training, as well as precise information, tools, and processes from the clinician providing it.

The last few years of evidence about cognitive training have potential policy impact in healthcare as well as education.

This whitepaper is arranged as follows: section 1 offers a brief summary of how the field's state of the art has swung from seeing the mind as non-malleable, to malleable, and then back again. In section 2 we present three recent research projects and discuss how each of them add to the knowledge and understanding of cognitive malleability. Section 3 synthesizes and frames the current state of the art, with a focus on the application and real world use of the methods and techniques being investigated. In section 4 we bring the observations together and suggest a new conceptual framework, one that fits the research data as well as the clinical experience. Lastly, in section 5 we point to areas where more research is needed in order to further the understanding in this fascinating, and promising, field.

1. Background

1.1. The static mind

Cognitive capability is a broad set of skills and abilities associated with conscious mental effort; in daily life these are sometimes referred to simply as *intelligence*. During the early 20th century the German psychologist Willam Stern tried to pin down intelligence to a single number: an *Intelligenzquotient*[1], or *IQ*. A person's IQ has since then been widely treated as an observable and objectively measurable quantity that is highly heritable[2] and largely stable over a lifetime[3].

Still, measuring intelligence is a complex task. The subject typically goes through a wide range of different tests, the results of which are then combined into a unitary IQ score. The most widely used measure of IQ, the *Wechsler Adult Intelligence Scale (WAIS)*[4], consists of four subscales with a total of 15 different tests, and takes several hours to complete.

A more specific cognitive capability than intelligence, one that is much easier to measure, is *working memory*: "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning"[5].

Working memory is not separate from intelligence, but rather one aspect of it[6]. One of the four subscales of the WAIS (and three of the 15 tests) is specifically dedicated to measuring its capacity.

Just like intelligence, working memory was for a long time seen as a stable trait, with a maximum capacity given at the time of birth[7, 8, 9]. Both working memory and intelligence are found to be strong predictors of many positive outcomes in life, such as verbal fluency[10], reading comprehension[11], mathematical skills[12,13], reasoning[14], the learning of new languages[15], general academic performance[16], and even entrepreneurship[17]. Therefore, the notion of it being strictly heritable, and non-malleable through life, can lead to the deterministic conclusion that *some have it and some don't, and there is nothing you can do about it*.

In the popular press, hopeful claims were repeatedly made that by solving sudoku, crossword puzzles, or other pastimes, one would also rejuvenite the brain and increase cognitive performance. As tempting as these claims were, however, any rigorous test of them always led to the same conclusion: if you practice sudoku, you get better at sudoku–not at anything else[18]. The chances of improving one's cognitive performance indeed appeared glum.

1.2. The malleable mind

Then, in the early aughts, a glimmering light of hope was lit. Maybe there was some way a person could influence cognition–at least the working memory portion of it–beyond what was already written into their genetic makeup at birth.

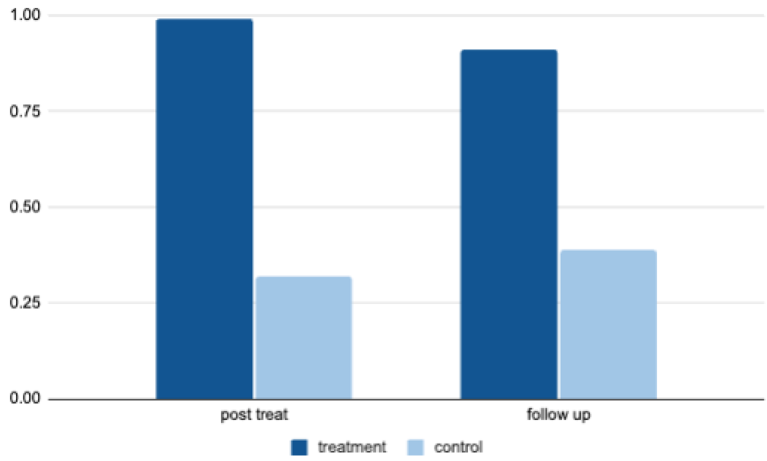
A team of researchers at the Karolinska Institute, led by Torkel Klingberg, noted that previous attempts to stimulate an increase in working memory capacity had been done with a low number of repetitions and a static workload. They hypothesized that in order to get any meaningful effect from cognitive training, the intensity, frequency, and effort required ought to be at least on par with what is needed when working to increase one's physical fitness. To create training conditions that fit this hypothesis, they developed a computer program that continuously adjusted its level of difficulty based on the subjects' performance, aiming to stay near the test subject's maximum capacity, and set the amount of training to 25 minutes per day, five days per week, for five weeks[19].

Fourteen children with ADHD were selected as subjects for the trial, since low working memory had already been identified as a potential underlying factor of the condition[20]. Albeit a small sample population, the results were clear: not only did the participants improve their performance in the working memory tasks that were trained, but also in non-trained tasks that measured working memory capacity by different means. Additionally, the treatment group saw a significant increase in fluid intelligence after the treatment, as measured by Raven matrices.

The significance of this can hardly be overstated. For the first time ever, there was methodologically robust evidence in support of cognitive malleability, with working memory identified specifically as the faculty showing plastic properties. The previously settled truth that "if you practice sudoku, you get better at sudoku", could now be accompanied by a new claim: "if you practice working memory (intensively, frequently, and in large amounts), you get better at fluid reasoning." This was the first firm proof that the effect of training one cognitive capacity had the potential to *transfer* to other capabilities–in this case, a non-trained working memory task, and Raven matrices.

While several other research teams took the challenge of replicating and expanding on the trials made, Klingberg et al followed up their seminal paper from 2002 with a trial of a larger cohort (N=44) of children with ADHD[21], and included two additional features. First, in addition to their objective measurements of improvement in working memory and other cognitive metrics, the researchers also gathered assessment data from teachers and parents in order to capture observable improvements in ADHD behaviors. Secondly, the researchers added a follow-up, three months after the intervention, to see to what extent the results were retained over time.

The first of these additions was carried out by having parents and teachers assess the children's ADHD symptoms on the Conners Rating Scale before the treatment (T1), immediately after (T2), and at the three-month follow up (T3). Overall, the symptoms were rated as lower at T2 and T3 compared to T1, both for the control group and the treatment group, but the treatment group had reduced their symptoms significantly more.

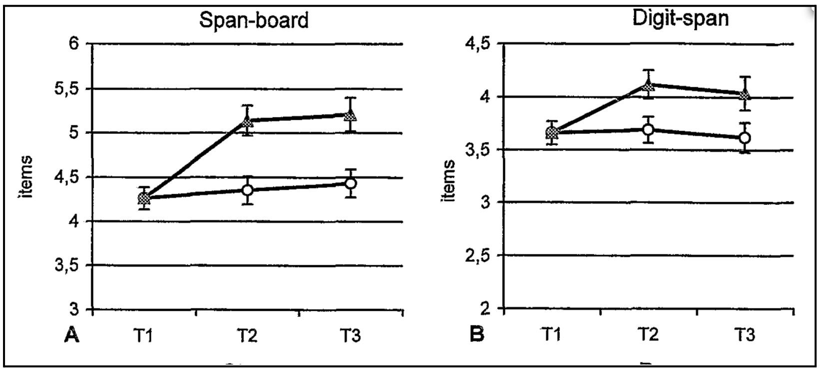


Change in parents' and teachers' assessment of ADHD symptoms immediately after and three months after treatment.

The second extension of the experiment, the follow-up, enabled the researcher's to capture a similar set of outcome variables as used in the 2002-study, both right after the intervention and then again three months later. This follow-up showed that the treatment group outperformed the control group by a significant margin in both of the non-trained tests of working memory (Span-board and Digit-span), and that the improvements were still significant at the 3-month follow-up.

The 2005 study clarified two more aspects, valid for this cognitive training program:

- The improvement in cognitive capacity does transfer to improvements of behaviors characteristic to ADHD
- The effect of working memory training does persist to a substantial degree over time



Results of the control group (circles) and treatment group (triangles) in two outcome measures.

As the interest for *neural plasticity* grew rapidly, some researchers carried out trials using the same training program as Klingberg and his team, while others experimented with different regimens. One type of cognitive training that drew praise after having shown strong results was the *N-Back training program*, based on a task originally developed in the 1950:s[23]. In 2008, Susanne Jaeggi and her team at the University of Michigan published some astonishing results: 34 subjects who had undergone an intensive N-Back training program for up to 19 days, outperformed the control group and increased their fluid intelligence by 0.65 standard deviations[24]. This was a substantial improvement of a cognitive metric that had been, until recently, considered mainly non-malleable.

While the first successful trials of working memory training focused on children with ADHD, researchers soon discovered that other groups of patients could benefit from this type of intervention as well. This included children recovering from cancer treatment,[25,26,27] as well as patients in rehabilitation after a stroke or traumatic brain injury.[28,29,30] The confirmatory replications grew in number and scope, and it seemed that the evidentiary support for working memory training had gone from groundbreaking to beyond dispute in just 10 years.

1.3. Boom and bust

As the stack of evidence in favor of working memory training grew, so did the number of commercially available programs, apps, and computer games claiming to deliver the benefits. In 2007, the Harvard Business Review published a long article wholeheartedly embracing the pursuit of deliberately training one's mind to achieve cognitive growth.[31] Titles such as Lumosity, HappyNeuron, and Nintendo BrainAge appeared frequently in ads and app stores. Just five years after Klingberg's first article was published, "brain training" had grown to be a multi-million dollar industry in the United States, with turnover estimated to be 80 million.[32]

However, the scientific backing of many of these new programs was typically weak, if at all present. If the early effort of developing cognitive training was based on modest claims and rigorous science, then this was the era of bold claims and weak evidence. One 2010 article published in Science concluded, based on a trial including more than 11,000 test subjects, that

> *[t]he central question is not whether performance on cognitive tests can be improved by training, but rather, whether those benefits transfer to other untrained tasks or lead to any general improvement in the level of cognitive functioning.*[33]

In 2013, the New Yorker magazine bluntly concluded that *Brain games are bogus*,[34] pointing out several examples of unsubstantiated claims made by companies in the industry. Shortly thereafter, the Stanford Center for Longevity published a letter signed by 75 prominent researchers titled: *A Consensus on the Brain Training Industry from the Scientific Community*.[35] This was followed by an article in *Psychological Science in the Public Interest*, which rhetorically asked: *Do Brain-Training Programmes Work?*[36] Both these letters declared that there was little evidence to support the claim that the brain could be trained in any general way, beyond just increasing the performance of the very same task that was being practiced.

Among the scientific publications, too, more skeptic opinions started to be voiced. In medical research, *meta studies* are given a lot of attention–and for good reason. If a single clinical trial with 100 participants finds that a treatment is effective, and that the results are statistically significant, it is an indication that the treatment in question indeed does what it is supposed to. But if 100 clinical trials of the same treatment are carried out, measuring the same outcome variables, and the combined results of all 100 trials indicate that no, the treatment is in fact not more effective than placebo, then the latter is more likely to be the correct conclusion. Properly produced meta analyses are thus powerful tools for creating evidence-based knowledge.

However, they are also subject to a number of weaknesses. These weaknesses can lead to over-confident results that are difficult to identify without detailed investigation of each of the trials included in the analysis, as well as of those that were excluded from it.

In 2013, two Norwegian researchers attempted to summarize the then-available research in a meta study, and concluded that

> *the programs produced reliable short-term improvements in working memory skills. For verbal working memory, these near-transfer effects were not sustained at follow-up, whereas for visuospatial working memory, limited evidence suggested that such effects might be maintained. More importantly, there was no convincing evidence of the generalization of working memory training to other skills (nonverbal and verbal ability, inhibitory processes in attention, word decoding, and arithmetic). The authors conclude that memory training programs appear to produce short-term, specific training effects that do not generalize.*[37]

At the same time, researchers who had tried to replicate Susanne Jaeggi's results (where N-Back training appeared to offer improved fluid intelligence) found that they could not recreate the positive effects at all.[38, 39]

Then, a team of researchers working for the European ADHD Guidelines Group conducted another meta study, and similarly concluded that

> *[d]espite improving working memory performance, cognitive training had limited effects on ADHD symptoms according to assessments based on blinded measures. Approaches targeting multiple neuropsychological processes may optimize the transfer of effects from cognitive deficits to clinical symptoms.*[40]

In 2016, the results of an Australian clinical trial, led by Gehan Roberts at the Royal Children's Hospital in Melbourne, were published. The research team had identified just over 400 children who scored below the 15th percentile in working memory, and assigned half of them for treatment and half for control. When the subjects had gone through the majority of a working memory training program, their working memory capacity was assessed, together with a range of other outcome variables. New data was then collected in follow-ups after 6, 12, and 24 months. Even though working memory had indeed increased by a significant margin immediately after the intervention–and even further a full year later–the authors concluded that

> *[w]orking memory screening of children 6 to 7 years of age is feasible, and an adaptive working memory training program may temporarily improve visuospatial short-term memory. Given the loss of classroom time, cost, and lack of lasting benefit, we cannot recommend population-based delivery of [the working memory training program] Cogmed within a screening paradigm.*[41]

And if this was not enough to kill off the entire field on its own, the company behind the brain training app Lumosity lost a legal battle and agreed to pay a 50 million dollar settlement (later reduced to 2 million), after being found to have "preyed on consumers' fears about age-related cognitive decline, suggesting their games could stave off memory loss, dementia, and even Alzheimer's disease." [42]

1.4. A method worth pursuing?

Collectively, these events shifted the needle of academic consensus back toward the axiom "working memory is fixed and cannot be influenced by training." Was neural plasticity a dead end, and working memory training a waste of time? Should scientists move on to other, more promising, pursuits? Or was it worth it to stick with the field and work on gaining a better understanding of what, exactly, was going on inside the brain when it was subjected to intensive and frequent cognitive workouts?

The answers to these questions would have vast implications. If people kept their neuroplastic mindset, spent more time on more research and interventions, and it turned out the critics were right, then this would mean wasting valuable resources that could have been put to more productive uses elsewhere.

On the other hand–if they were to abandon cognitive training altogether and return to the old fixed-capacity mindset, and it turned out the critics were wrong, then the world would lose out on an effective, low-cost, non-pharmacological treatment option for medical conditions that affect a substantial share of the world's population.

To settle this, the researchers needed to go beyond the simplified question of "does cognitive training work" and examine detailed, specific aspects of the field; because even the research papers that were most critical of the method did recognize improvements in at least some of the measured outcomes. In fact, virtually all of them confirmed that yes, working memory training does lead to increased working memory, even if it is assessed by other means than those tasks that are being trained. In other words, the capacity for *near transfer* was almost universally supported. Additionally, several of the critics also confirmed the presence of some *far transfer* effects, even if they were deemed to be too short lived to be clinically relevant.

So, there were two fundamental aspects of working memory training where the science had produced contradictory results, leading to the questions: to what extent do the effects transfer to other relevant areas, and how long-lived are the results? In order to answer them the researchers needed to study larger groups of people, follow them for a longer period of time, and capture a wider set of relevant outcome variables.

2. New evidence emerges

The researchers who remained engaged in the field were up for the challenge and began designing trials to answer the remaining questions. As results from these larger, longer, and wider trials started trickling in, the consensus began to move back toward accepting the mind as malleable–but this time with more nuance, and balanced expectations.

This section presents, in some detail, a selection of three of those larger, longer, and wider trials, followed by a comparison of this development to the phases of a popular model for how technology-enabled innovations are often received by the public.

2.1. A study of far transfer effects in children with ADHD[43]

The first clinical trial to publish results tackling these two key questions–far transfer and longevity–in a large enough scale to shed new light on them, was carried out by Aitana Bigorra and her team at the University Hospital in Barcelona, Spain. They carried out a randomized, double-blind, placebo-controlled trial of children with ADHD (N=66, 7-12 YOA).

As outcome variables for far transfer they captured 30 different measures of executive function, assessed by blinded parents and teachers. In addition, nine different objective metrics of cognitive performance were evaluated. These included auditory and visuospatial working memory, attention, impulse inhibition, flexibility, task switching, and reading comprehension. Each metric was assessed at three different occasions: baseline, one to two weeks after completed intervention, and six months after.

In addition to a large and persistent increase in working memory capacity (more than 0.8 standard deviations), the results showed a broad pattern of improvements across most of the executive function measures captured. The largest statistically significant improvements were made in self-monitoring, in the ability to initiate activities, and in school learning behavior. For the other measures of executive function, a positive effect was indicated, but with a lower level of statistical significance ($p > 0.05$).

Additionally, the ADHD composite index was assessed by teachers to have improved by a moderate amount immediately after the intervention, and increased by 0.7 standard deviations at the six-month follow up.

In summary, the Spanish study showed that:

- Completing a 25 session intervention of Cogmed working memory training typically leads to a large and sustained increase of working memory capacity, as measured by other metrics than the ones being trained.
- The increase in working memory capacity readily transfers to many important areas of executive functioning, including initiation, monitoring, and learning behavior.

- Teachers in general assess the improvements as larger and more persistent than parents, which may indicate that the more structured nature of the school environment is more conducive to utilizing the acquired cognitive improvements.
- The positive effects are typically detected immediately after the intervention, and then increase in magnitude and significance at the six-month follow-up, indicating that complex behavioral effects take time to develop but then grow as they are practiced, as opposed to the notion that the results would fade away with time.

The authors conclude that training working memory using the Cogmed program had "had a significant impact on ADHD deficits by achieving long-term far-transfer effects."

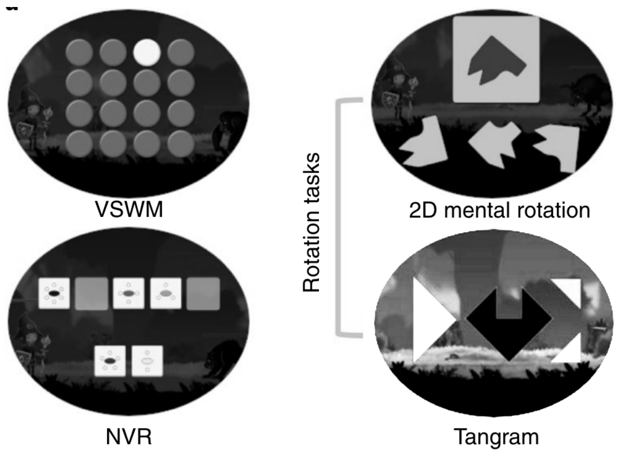
2.2. An experimental study of math learning in 17,000 students[44]

The next study that took on the question of far transfer looked at how working memory training influences mathematical abilities. The study was led by Nicholas Judd, working at the same lab where Klingberg's first trials were carried out. The article, published in 2021, describes a randomized controlled experiment involving more than 17,000 students, a number of research subjects vastly larger than that of all other experiments in the field combined.

For this study, the researchers had access to an online working memory program used in schools, which combined Cogmed-based working memory exercises with other cognitive training tasks as well as a set of purely mathematical activities. With this large number of observations, the researchers could afford to split the subjects into five separate groups, making only subtle changes to the type of cognitive training treatment in each group, without any loss of statistical significance.

The mathematical tasks, taking up half of the time spent with the program, were mainly focused on arithmetic and use of the number line. This portion of the program was identical in all five groups, so that its results could be used as the outcome metric.

One aspect that makes this experiment special, in addition to the sheer size, is the precision of the analysis. This was made possible by comparing slightly different variants of cognitive training to one another, as opposed to comparing the difference between training and no training. A superficial look at the different training tasks would not reveal any obvious differences in expected results. All tasks look and feel like they belong to an IQ test; they are made up of non-verbal puzzles, which get progressively more challenging the better you perform in solving them.



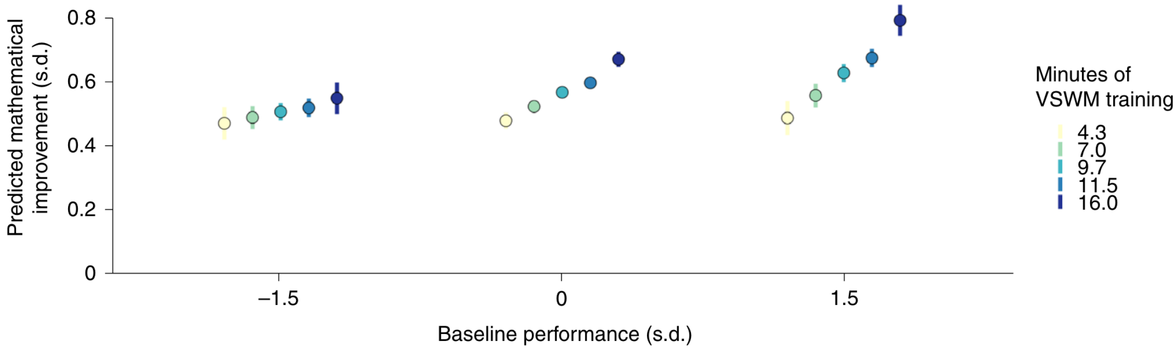
Four different types of puzzles combined in different ways to create five training plans.

Still, the difference between the training tasks with the weakest versus the strongest effect is large. The outcome of this trial shows that training visuospatial working memory improves mathematical ability more than twice as much as training tangram puzzles, a difference that increases further by mixing in non-verbal reasoning exercises into the treatment.

This is an important observation to keep in mind whenever the question "does cognitive training work?" is brought up. All cognitive training is not equal, and even tasks that are perceived as equally difficult by the user, and are designed with the same purpose by the same scientists, can differ substantially in efficacy.

This observation, that different tasks have drastically different performance, is true on an aggregate level, averaged across all 17,000 students. But what if some students are more helped by some form of training than others, and that is different from the average? The researchers tested clustering students by their baseline performance in various dimensions to see if they reacted differently to the training, and thus by extension, if some forms of cognitive training suit some people better than others.

In the below graphic, the results from the experiment shows how each minute of additional training of visuospatial working memory predicts increase in mathematical ability. The color of the dots represent the amount of daily training. In the middle group, where baseline working memory was at average level, the benefit of the treatment starts at 0.45 standard deviations with just over four minutes of training per day, and then increases as the training volume increases, to roughly 0.65 s.d. at 16 minutes per day of training. So, working memory training is beneficial for math performance, even in small amounts, and more training leads to further increased benefits.



Improvement in mathematics predicted by baseline working memory capacity and training volume (N=17,000)

Compare this to the group on the left, with a baseline working memory capacity in the seventh percentile (1.5 s.d. below the median). In this group, there is also a positive effect from working memory training, and the effect increases with the training load, but not as steeply.

Next, look at the rightmost group, representing the top 7:th percentile. This group also sees a positive effect in mathematical ability, and here, too, the improvements increase as the training volume grows. However, in this group the difference between low volume and high volume of training is *four times as large* as in the low baseline group.

This is analogous with the finding of how genetic factors determine the interindividual differences in response to working memory training[45], and shows that the higher working memory capacity is at baseline, the greater the improvements can be expected to be from the same amount of training. Thus, in practice, individuals with a lower working memory capacity will need a larger training volume to achieve the same results as those who start at a higher level.

This is probably one of the reasons that Roberts and his team in Melbourne saw smaller effects than many other studies (see section 1.3 above). Recall that in their trial, the selection criteria was children whose working memory capacity was in the bottom 15th percentile. At the same time, the intervention they provided included *less* training than usual, with only 25 out of 200 trainees completing the standard length of the training program. Under those circumstances, a smaller than usual effect size is exactly what should be expected.

In summary, the study of 17,000 normally developing children showed that:

- Cognitive training can increase the effect of math learning in children.
- The more someone is training, the better they perform in math. This is true up to at least 16 minutes per day (the maximum amount tried), at which point there was still no indication of a tapering effect.
- Training visuospatial working memory in a dynamic setting (tasks get harder as the person training gets better) is among the most effective forms of cognitive training tested, and it outperforms tangrams and visual puzzles by a wide margin.

- Children with a low working memory at the baseline require more training to get the same effect as children who start off with a higher working memory capacity.

The authors concluded that "cognitive training results in transfer to academic abilities, adding evidence in favor of the view that cognitive abilities are malleable."

2.3. A study following 600 neurotypical students for 4 years[46]

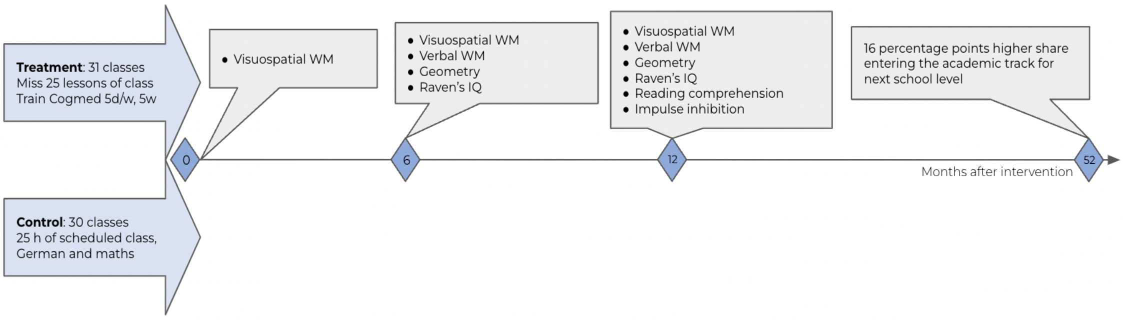
The third of the recently published original contributions to the field is based on a trial carried out in Mainz, Germany, over a span of four years, by a team of researchers led by Eva M. Berger and Ernst Fehr. A total of 572 students (6-7 YOA) were tested at baseline, and then divided by school class, with 16 classes going through the standard Cogmed working memory program (25 sessions, 5 days per week), and 15 classes followed in parallel as control.

All working memory training took place during the morning hour of scheduled class, meaning that the treatment group missed out on a total of 25 lessons in either math or German. Hence, a zero effect of the treatment ought to appear as a negative effect in learning, since that group had missed out on a substantial amount of teaching time. As the working memory training was introduced just like any other school activity, the attendance and compliance rate was high, and only four students missed more than five training sessions.

A vast battery of test data was collected at three points: immediately after the intervention, 6 months after, and 12 months after. The measures taken represent near transfer (working memory performance on untrained tasks), far transfer to academic ability (mathematical skills and reading comprehension), and far transfer to general cognitive capacity and executive functions (fluid intelligence and the ability to inhibit impulses).

Immediately after the intervention, only the near transfer to non-trained working memory tasks had improved significantly more in the treatment group. But as the students had more time to put their improved working memory capacity to use, other effects began to appear. One year after the intervention, there was a statistically significant transfer effect in each of the categories, including fluid intelligence and impulse control.

Nearly four years after the intervention, the researchers returned to the classes to follow up how they had fared. In the German school system, children at age 10 are sorted into one of three tracks, with different levels of academic ambition. The most advanced level, *Gymnasium*, typically requires either that the student has a grade point average above a defined threshold, or that the student passes an entry exam. For each 100 students who had trained with Cogmed, 16 more students were accepted into the Gymnasium, compared to the control group.



Near transfer effects were immediately visible, while the effects in academic performance, general cognitive ability, and executive functioning took longer to appear.

In summary, the German study of school-wide implementation showed that:

- A large-scale implementation of Cogmed during scheduled classes is logistically feasible and produces no adverse effects on learning, even if it requires a short term loss of 25 regular lessons.
- Working memory training of normally developing children leads to an immediate increase in working memory capacity.
- The increase in working memory capacity has the potential to transfer to a wide range of academic subjects and cognitive functions.
- It can take up to a year to see some of the benefits from working memory training.
- Training working memory at a young age can have a substantial positive effect on grades and examination scores several years later.

The authors concluded:

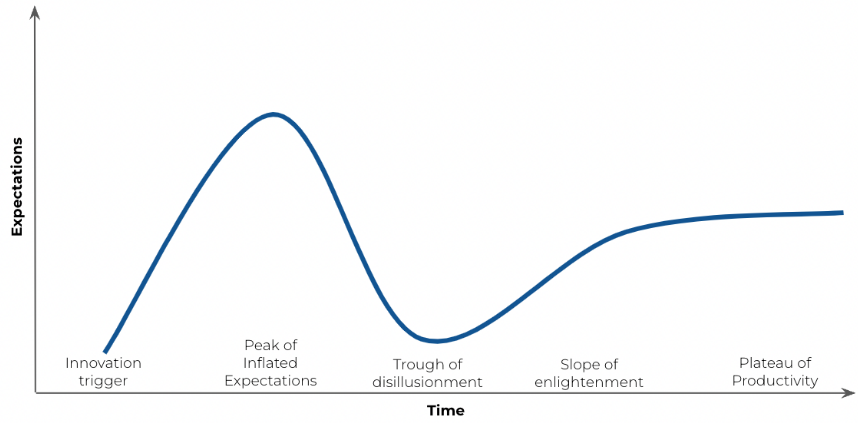
> *We find substantial immediate and lasting gains in working memory capacity. In addition, we document relatively large positive effects on geometry skills, reading skills, Raven's fluid IQ measure, the ability to inhibit pre-potent impulses and self-regulation abilities. Moreover, these far-transfer effects emerge over time and only become fully visible after 12-13 months. Finally, we document that 3–4 years after the intervention, the children who received training have a roughly 16 percentage points higher probability of entering the academic track in secondary school.*

2.4. The Hype Cycle

Gartner Group, the consultancy and research firm, has a model to describe the maturity, trust, and expectations of a technical innovation, which they call the *Hype Cycle.* Novel things with a technical component, they claim, often follow a similar pattern, with four distinct phases.

At first, the innovation sparks enthusiasm and hope, which with time grows to become excessive, and the innovation reaches the *Peak of inflated expectations.*

As experiments and implementations based on these excessive assumptions fail to deliver, interest and belief in the innovation wanes, until it bottoms out in a *Trough of Disillusionment*. Many firms invested in the technology fail and previous supporters become opponents.



Gartner's Hype Cycle

However, when the underlying innovation does bring a real benefit, there is a remaining pool of users who stick with the innovation, and spread the word. Gradually, the innovation regains some of its support through a *Slope of enlightenment*, where people are ready to reassess the novelty and give it a fair chance, without the inflated expectations. Eventually, expectations level out to a realistic level, and the innovation becomes a staple of everyday life as it reaches the *Plateau of productivity.*

This model offers a fitting explanation of how working memory training in general, and Cogmed in particular, has developed. After an initial period of high expectations it reached the peak of inflated expectations around 2012, followed by a period of disappointment and criticism, hitting the trough of disillusionment in about 2017.

The last few years have seen a steady stream of robust trials and experiments, and a gradual increase in the number of clinics and schools taking the program onboard. Each of the new studies contributes one facet of the emerging consensus leading up along the slope of enlightenment, toward the plateau of productivity. It is now increasingly accepted that the potential is indeed there, but also that substantial effort is required to achieve the desired results and that Cogmed is by no means a panacea, solving every problem for every person.

3. State of the art: eight things we now know about working memory training

Let us now return to the question raised in the introduction, “does cognitive training work?”, and consider what the developing body of evidence and 20 years of real world experience can contribute to its answer. First of all, it is not a very good question. In an article published in the *Proceedings of the National Academy of Sciences,* summarizing the last 100 years of research into “brain training,”[47] one group of researchers compared it to asking “does medicine work?” without specifying which medicine and for what condition.

So what, then, would be a better question? Well, a set of questions that ought to be more helpful includes at least the following:

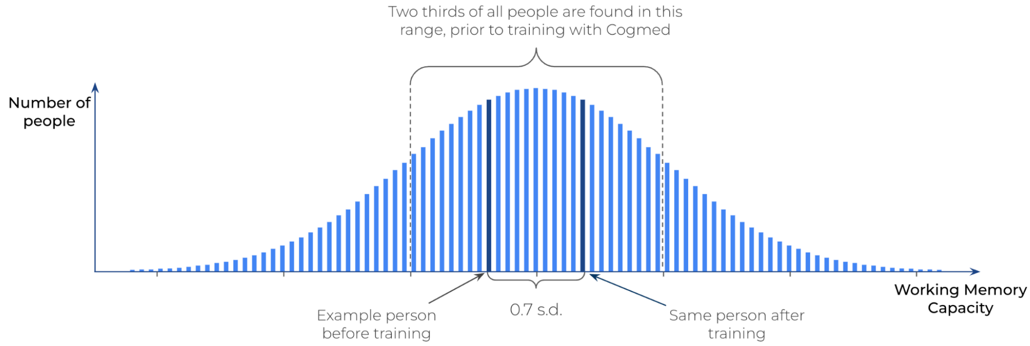
- Which particular types of cognitive training have a positive effect?
- Which clinical conditions, cognitive skills, and other functions are affected by it?
- Under what circumstances does the training have the desired effect?
- How large is the effect? (This is a methodologically important question, as many studies fail to take account of how effect size d relates to sample size N and statistical significance p.)

With the evidence and experience that is now available, we can finally attempt to answer some of these questions, present a new state of the art, and suggest a new integrated framework for how working memory training fits into the larger psychological and sociological context that clinical and pedagogical practices operate in.

In this section the current state of evidence regarding working memory training and its effects are summarized in the form of eight statements, striving both to stay true to the scientific evidence and, at the same time, be concrete enough to be useful for practitioners.

3.1. If you train your working memory, it will increase in capacity

Asking whether or not working memory capacity was at all malleable is where it all began, and, even the researchers who have been the most critical of the efficacy of working memory training agree on this much: a completed program of frequent, intensive, dynamically adjusted working memory training does lead to a meaningful increase in working memory capacity, as measured by non-trained tasks.



On average, one completed Cogmed training program leads to an increase in working memory capacity of 0.7-0.8 standard deviations

Not all people who go through the 20 hours of intensive training that makes up a Cogmed program get the same increase in working memory capacity, but nearly everyone gets at least some. Averaged across a large number of studies, the increase in working memory capacity of non-trained tasks (near transfer) is between 0.7 and 0.8 standard deviations. Near the center of a normal distribution, this is equivalent to going from recalling seven digits in a series to recalling eight, or, in other words: "overtaking" about one quarter of the population.

3.2. Effort and persistence is required to successfully train your working memory

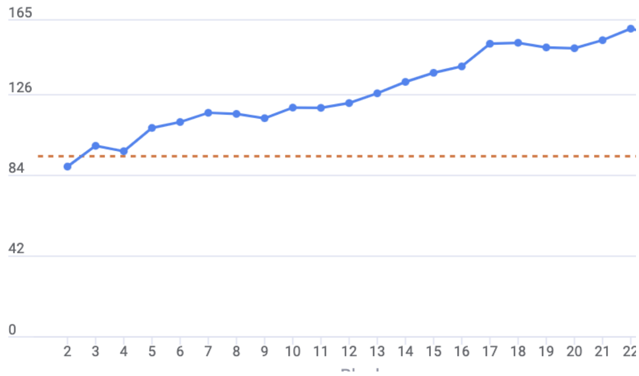
Many of the experimental studies of working memory training have failed entirely, or produced non-robust results, because they have not succeeded in getting their test subjects to complete the intervention.

This is also reflected in the clinical application of Cogmed: most people are not able to complete the training program without some level of active coaching, which typically includes reminders, encouragement, and in the case of children and teenagers, some kind of reward at defined milestones along the way.

In this way, Cogmed is similar to any other rehabilitation program–it only works if you put in the effort, and keep at it for a sustained period of time.

3.3. The more you train it, the more your working memory increases

There is a clear and consistent link between the amount of training and the resulting increase in working memory capacity. Even by the end of the standard 20 hour Cogmed protocol, working memory increases almost linearly at about 0.04 s.d. per hour of training.



As a person trains their working memory with Cogmed, they typically increase in performance throughout the entire training period, indicating that further training likely would lead to further benefits

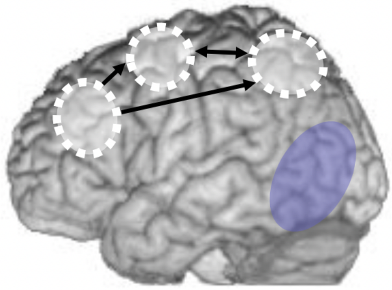
Presumably, there is a limit at some point where the effect levels out, and additional training is of little or no use. But, a single 50 minutes-per-day, 5 days-per-week, five-week long program is still within the scope where more training leads to more benefits.

So, some training is better than no training at all, and if you are not satisfied with the results of five weeks of training, there is a good chance that you will see better results if you keep at it for another few weeks.

3.4. Increased working memory leads to improved attention

Attention is a skill that is closely related to working memory, perhaps best defined as the ability to focus selectively on a chosen stimulus, sustaining that focus and shifting it at will. In everyday parlance, attention is synonymous with the ability to concentrate. While working memory and attention are not the same thing, they share a substantial overlap which can be seen directly in the neurological activity in the brain, as well as in the resulting behavior and skills.

By placing people in brain scanners such as fMRI, and having them carry out tasks requiring attention or working memory, the activated brain areas can be seen to be largely identical between the two.



Working memory and attention are closely linked,
and relies on largely the same cortical regions in the brain, indicated by dashed circles

By stimulating activity in these regions through training one's working memory, the capacity to hold information in mind increases. And, as a direct result, so does the attentional capacity. As an average across multiple clinical trials, when working memory increases by 0.7 s.d., attention increases by 0.4 s.d.[48].

Hence, any person who struggles to direct and sustain their attention is likely to get some benefit from working memory training. However, performance on attention demanding tasks can be improved in other ways too, and the simplest way is almost always to remove distractions. A mind that is occupied with other thoughts, or one that is disturbed by a noisy environment, is unlikely to be able to pay attention. For working memory training to have full effect, it is always advisable to look out for distractions and disturbances, and remove as many of those as possible, before any meaningful results can be expected.

3.5. Training-induced increase in working memory can reduce symptoms of several medical and neurological conditions

Deficit in working memory is a central cognitive symptom in several clinical diagnoses and neurological conditions, including ADHD, stroke, traumatic brain injury, preterm birth, and side effects of cancer treatment. In all of these cases, it has been shown that training working memory has the potential to relieve some of the symptoms, and improve the outcome for the person affected (see section 1.2).

Separate forthcoming whitepapers will look in detail at each of these cases.

3.6. Increased working memory can lead to measurable and meaningful improvements in other areas of cognition and learning

One of the main critical points raised against working memory training is that it would not lead to any meaningful improvement in other areas of cognitive functioning. While a short term increase in working memory capacity is evident in nearly every study ever run with Cogmed, the results with far transfer effects are more mixed.

This, however, is not surprising, since any outcome identified as far transfer is dependent on a complex interaction of many factors. The more additional factors involved in determining an outcome, the more sensitive the cause-effect-relationship is to a deficit in any of the other factors involved.

If, for example, you were to study the effect of working memory training on mathematical learning, and you failed to provide adequate instruction or opportunity to practice, then the test subjects would likely not learn very much at all, and you would come to the conclusion that working memory training has no discernible effect.

To complicate the issue further: if you then extend the scope of study to cover "far transfer in general", and bundle together a wide range of different outcome measures (some of them more distantly associated with working memory than others) then you are likely to see even smaller effect sizes. Research studies with small numbers of participants, or meta-analyses with a heterogeneous set of outcome variables, are especially vulnerable to false negative conclusions.

In order to get closer to a true picture of the potential of far transfer effects of working memory training, a research study would thus need to meet at least these criteria:

1) A large enough sample size to get significant results for complex interaction effects.
2) A well defined outcome, such as mathematical learning, reading comprehension, or self regulation, with a corresponding valid and reliable method for measurement, over short and long term.
3) A treatment that ensures that the most important *other* factors needed for the desired outcome are adequately provided, both in the treatment and control groups.

Over the last few years, we have seen a number of large-scale trials with well defined outcome variables and sufficiently controlled surrounding circumstances to meet these criteria. Those studies show that people can indeed benefit from working memory training in a range of ways, beyond a simple increase in recalling digits forward and backwards. Meaningful and long lasting effects have been shown in attentional capacity, ability to initiate activities, self monitoring and regulation, learning behavior, mathematical ability, reading comprehension, ability to inhibit impulses, fluid intelligence, and general academic performance (see sections 2.1-2.3 for details and references).

Thus, one of the main points of criticism of working memory training is now effectively repudiated and proven incorrect.

3.7. Those who have, shall be given; everyone else should train more

Among those who go through a complete Cogmed training program, almost all show an increased working memory capacity by the end of the program. However, the increase in working memory capacity differs between individuals, and more importantly, the degree to which this increase transfers to improvements of other areas is not the same for everyone.

To some extent this has been explained by genetic factors, but the largest explanatory factor determining who will receive the greatest benefit from working memory training is the baseline working memory capacity. People who have a very low working memory at the start typically require a larger amount of training to see substantial increase and transfer of benefits (see sections 2.2-2.3 for discussion and references).

It is not yet exactly understood which mechanisms are at play, nor how a working memory program can be tailored to the individual in order to maximize the results. But, as a rule of thumb: the lower the baseline working memory a person has, the more likely they will benefit from a larger training dose, possibly boosted by going through the program more than once.

3.8. The benefits from working memory training can be long lasting, and even increase with time

The second of the two main points of criticism against working memory training has been the notion that any positive effects wane with time, and are thus not worth pursuing. However, not only has this point been thoroughly disproven by the latest research, it is also accompanied by a curious observation: the positive effects do not just remain, but in many cases even *increase* in magnitude with time. This effect is more pronounced for benefits that are categorized as *far transfer*, compared to those that are tested with tasks closer to those being trained.

The most detailed view of this mechanism that has been documented is with mathematical skills. Being "good at math" requires a combination of things, including at least:

1. Having sufficient working memory to store and manipulate information in mind, in order to analyze a problem and solve calculations.
2. Having sufficient attentional capacity to stay on task for long enough to reach the solution of a complex problem.
3. Having learned and automated the factual knowledge, methods, and algorithms required for the problem at hand.

A person who has just undergone a working memory training program is likely to see an immediate improvement in the first two of these factors. In addition, the increased attentional capacity is *also* likely to help the person keep up with math lessons in school, and thereby *gradually* increase their capacity for the third.

If this hypothesis holds true, one would expect students who train their working memory to show a sudden one-time increase in performance (intercept) followed by an increase in learning pace (slope), and this is exactly what the empirical studies presented above (2.2-2.3) confirm.

Mathematics is both the subject that is most often studied and where results are the strongest, but clear positive results are shown in other subjects too. Reading comprehension and grade point averages across an entire curriculum are both shown to be positively influenced by working memory training (see section 2.3 for detail and references).

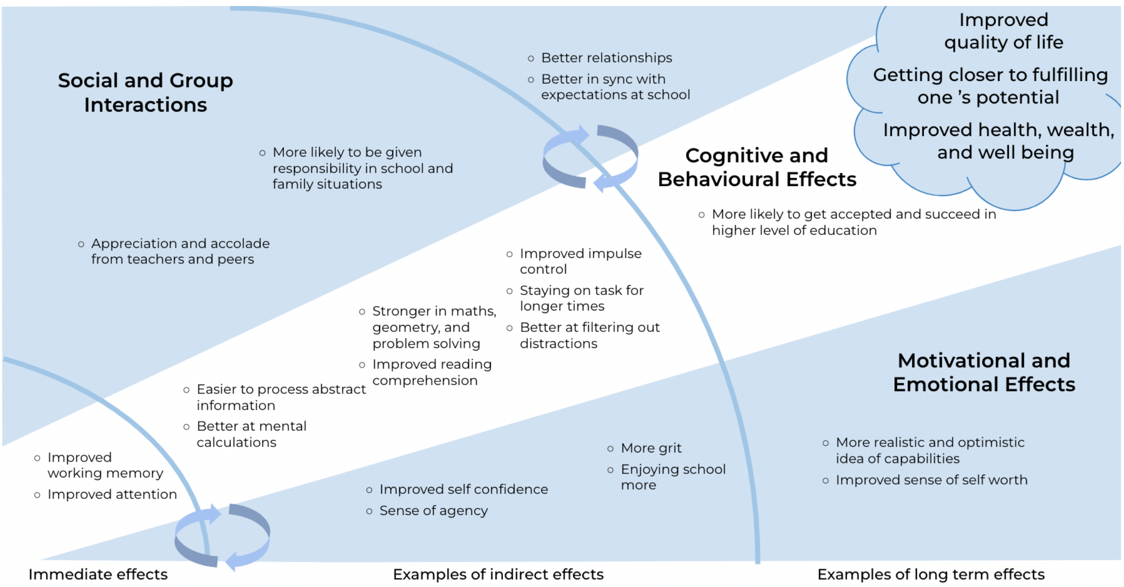
4. A new framework emerges

What is summarized in the previous section shows that training working memory with Cogmed has a vast and persistent potential for rehabilitation and reduction of symptoms related to specific medical and neurological conditions, as well as for academic performance among normally developing children.

The observations made above relating to working memory and learning, describing both an *intercept* and a *slope* style of improvements, establishes the existence of a positive feedback mechanism, whereby the *ability* to learn is increased, which can then lead to more actual learning. This is a candidate for explaining far transfer and long term effects, but it is possibly not the only one.

When asking patients, students, teachers, parents, and clinicians who have either gone through the program themselves, or have observed someone as they have done so, the most frequently used words to describe the effects are *increased* or *regained self-confidence.* Other common themes from Cogmed users recounting their perceived effects include a change in how *other people* have perceived and treated them, when they start exhibiting their new skills and abilities.

This is not something that has been studied scientifically or under controlled circumstances, but the pattern of subjective descriptions do fit the observed effects on group level. It ought to be reasonable to hypothesize that emotional and social positive feedback mechanisms can be triggered by an increase in working memory, as it leads to improved attention and better results in school.



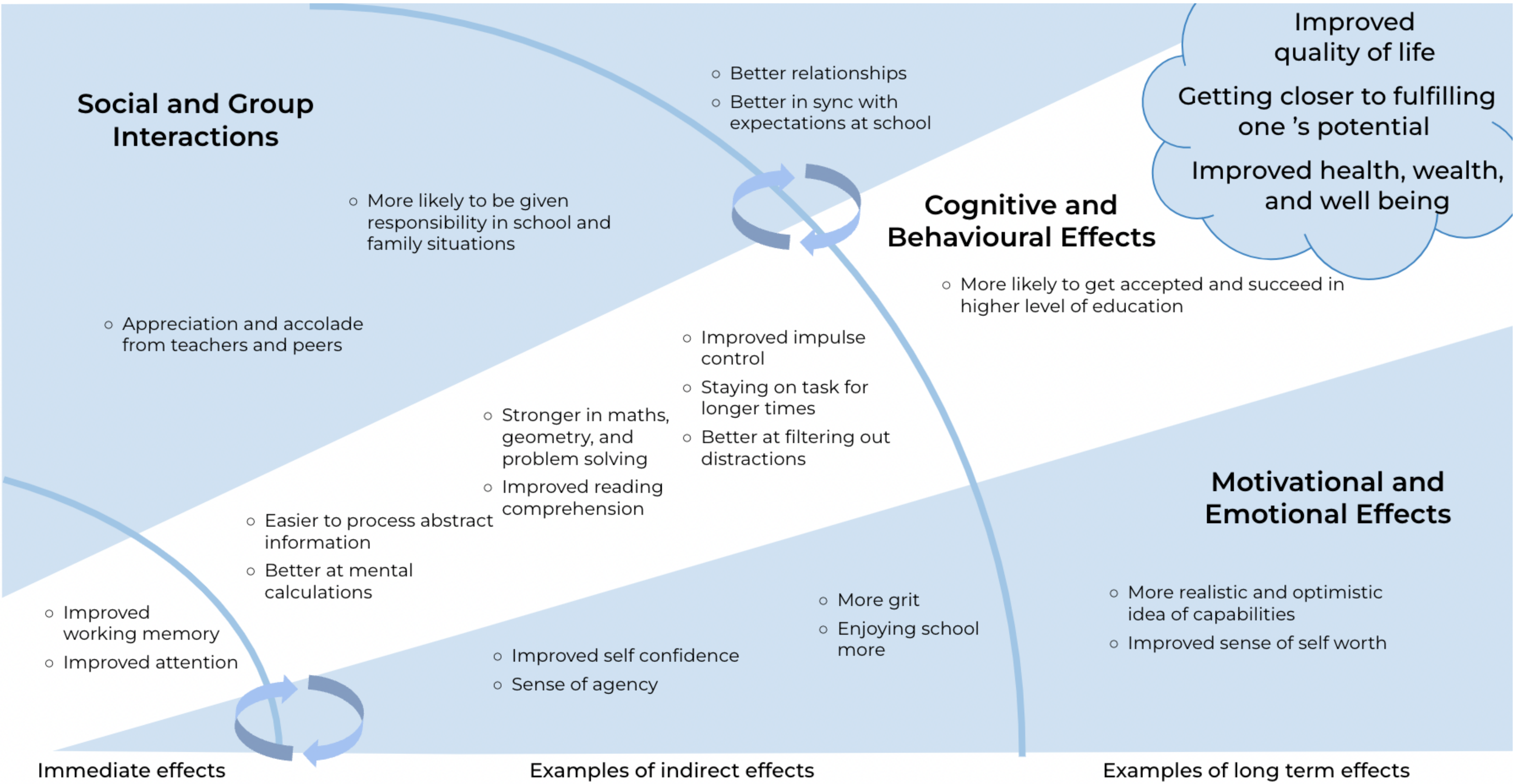
An integrated framework proposed for understanding the complex dynamics of how the neurological adaptation triggered by working memory training can have vast and long lived implications in areas not immediately associated with working memory. (See below for a full page version)

However, as plausible as these interaction and feedback effects are, they are not to be taken for granted. An increase in working memory capacity does not necessarily lead to a boost in self confidence. For that to happen, the increase in working memory and attention must first be made useful, e.g. in a learning situation. If the circumstances in school are such that one cannot make use of an increased ability to pay attention, then no increase in academic performance is likely to appear. Likewise, if the social situation is such that an increase in academic performance does not lead to any appreciation either at home nor in school, then it is unlikely to trigger any material increase in self confidence.

Over the last 20 years, the amount of information gathered from research and real world experience in more than 30 countries is vast and crosses many academic disciplines. Observations are made on many different scales, from the tiniest level of interactions between neurons, via objective measurements of cognitive performance, teachers' and parents' assessments of executive functions using standardized rating scales, performance in academic disciplines, to the subjective descriptions of emotional, motivational, and social effects as experienced by the people who have gone through the program.

While there is no single study or experimental design that can bring all this information together, there is a broad pattern in the data from which a new framework is emerging. It suggests an integrated model for how the long-term improvements from training with Cogmed must take feedback effects into account, including direct, indirect, and long term interactions on each of the scales where observations are made.

We suggest using this framework as a backdrop for research as well as practical implementation of working memory training, as it offers a reminder both of the direct cause-and-effect relationships, and the more complex and non-deterministic interactions, that require a deep understanding of the specific situation in which the training is applied, with special attention not just to the training program itself, but also to which other important factors are involved in enabling the sought after effects.



Cogmed working memory training has direct, immediate, and almost universal effect on working memory capacity and attention. Depending on the baseline working memory capacity, the surrounding environment, support structure, school or work environment, the presence of positive or negative social reinforcement, these direct effects can then, to a varying degree, transfer to other areas of cognitive capacity, performance, and quality of life in general.

5. Suggested direction for further research

As much as is now known about the Cogmed program and its potential effects, there is still a lot that is unknown about working memory training. Some of the questions that the clinical and educational practitioners run into include:

- How are children with very low baseline working memory best treated, other than offering more training? Are there any particular training tasks that are more helpful? How should the increased training volume be scheduled?
- Why is it that results in mathematics appear to improve more than other subjects from working memory training? Can the training be adjusted to fit other subjects better?
- Virtually all research on working memory training has been based on a one-off five-week training intervention. What would be the results if it was instead implemented as a constant but low frequency activity, e.g. one session per week all year around?
- Working memory is an important dimension of general intelligence, but not the only one. To what extent can the other dimensions be trained?
- Cognitive decline appears to be an unavoidable part of aging. To what extent can working memory training relieve some of that?
- Brain fog is a term often used to describe a general reduced level of cognitive performance, that is both uncomfortable and leads to lowered functioning. It is cited as a symptom of post-Covid, stress induced exhaustion, and burn-out. To what extent can working memory training relieve some of that?
- Completing a full Cogmed working memory training program is taxing. Without the support of a coach or sessions scheduled as part of a mandatory classroom activity, the majority of those who try it will not manage to complete the program. What can be learned from rehabilitation programs, workout regimens, and other effortful but healthy programs, in order to improve adherence?
- What is the role of self confidence and other subject-internal mental intrinsic factors, when it comes to long-term far transfer effects?
- What is the role of changed expectations, mirroring, peer influence, and other social interactions and feedback loops when it comes to long term far transfer effects?

These lines of inquiry and others are ones that we are interested in, and it is our hope that researchers around the world will keep these in mind as they develop future research into the mechanisms and effects of working memory and other cognitive training.

6. About this whitepaper

This whitepaper is written and verified with scientific sources by a team of professionals at Neural Assembly Int AB (NAIAB).

This is edition 1.0 of the paper, published on October 10, 2022.

NAIAB is the company behind the Cogmed working memory training program. We employ neuroscientists, statisticians, software engineers, and other professionals with the skills and experience to maintain and improve on one of the most promising innovations in digital health.

Torkel Klingberg is a full-time professor at the Karolinska Institute in Solna, Sweden, and one of the founders and owners of NAIAB, where he is also part-time active as Chief Scientific Officer.

Cogmed can be licensed by hospital clinics, private practicing therapists, and educational institutions with a proven capability to deliver the program responsibly and professionally to their clients and students. Go to cogmed.com to learn more or to get in touch with a local distributor.

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