Development of Working Memory: implications for Attention Deficit

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Executive Summary

Working memory capacity is an important factor in a child's development, largely defining the child's ability for controlled attention, and influencing outcomes in other areas such as academic performance.

One in six children lags three or more years behind in working memory development, and the chances of ever catching up entirely are small. Children with ADHD/ADD are especially likely to belong to this group.

Working memory deficit is caused by a combination of genetic factors and differences in the amount of cognitive challenges the child experiences on a regular basis. Due to unfortunate but natural interactions between the genetic and environmental factors, children with an innate tendency to working memory deficit are especially vulnerable to behaviors, habits, and environments that further reinforces their lower-than-necessary development path.

These children can be identified early, both through classroom behavior and psychological tests. A range of practical support systems and interventions are available to help them, with the potential to improve school results as well as functionality in everyday life.

Among the most effective interventions are working memory training, which can be especially potent when applied early in life.

Working memory

What is working memory?

Working memory is a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning[1].

Have you ever tried to follow a recipe for an unfamiliar dish, and been frustrated at how often you have to go back and reread the next step, as it seemed to slip out of your mind as soon as your attention to the current step? Or have you perhaps got up from your desk to fetch a snack, only to find yourself moments later, standing in front of the fridge wondering what you came to get. Or when you pick up your phone to carry out a task, only to be distracted by a notification and forgetting about the task that brought you there in the first place. Then you have a sense of how limited the capacity of your working memory is.

The usefulness of working memory

The immediate usefulness of working memory might be limited to simple tasks, such as reading a recipe or successfully fetching a snack, but a high capacity working memory is useful in many other ways too, the most immediate of them being *increased attention*. When observing a human brain in an fMRI scanner, it is all but impossible to tell if the subject is doing a task aimed at pushing their working memory or one that is aiming at controlling their attention[2,3,4].

Alan Baddeley, one of the psychologists coining the term working memory, said that if he had the chance to go back and redo it, he would have called it "working attention" instead, as it gives more relevant associations to what cognitive processes are affected.

In one study, researchers tested the working memory capacity of more than 120 students. The following week, each of the students were prompted at random intervals, eight times per day, to answer questions about what they were doing and to what extent they were focused on the task at hand.

When analyzing the results, the researchers found that students with average or high working memory were more likely to stay focused on tasks that were more cognitively demanding, while those with lower working memory capacity instead wandered off in

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[2] Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. Nature Neuroscience, 7(1), 75–79. https://doi.org/10.1038/nn1165

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[4] Cubillo, A., Hermes, H., Berger, E., Winkel, K., Schunk, D., Fehr, E., & Hare, T. A. (n.d.). Intra-individual variability in task performance after cognitive training is associated with long-term outcomes in children. *Developmental Science*, *n/a*(n/a), e13252. https://doi.org/10.1111/desc.13252

their mind, daydreaming[5]. Daydreaming may indeed be both pleasant and a helpful method for creative problem solving, but sometimes it is necessary to hunker down and force through a difficult or boring task, and students with low working memory are generally less capable to do that, even when they know that is what is needed.

This is just one of many examples where working memory turns out to be a source of something useful in life. Other studies have shown working memory capacity to be associated with many other abilities[6,7], including verbal fluency[8], reading comprehension[9], mathematical skills[10,11,6], executive functioning[12], reasoning[13], learning of new languages[14], general academic performance[15], and even entrepreneurship[16].

How can such a general ability serve so many different functions? Well, if you were to study muscle strength in a population, you would find that it was positively correlated with many different characteristics, including being a better basketball player, a faster springer, and being able to bring more groceries home. It seems that working memory has a similar role in the brain, being a *muscle of your mind*, doing some of the heavy lifting in many different tasks, even ones that you might not immediately associate with memory or even attention.

With this wide range of positive association, it is hardly surprising that scholars, clinicians, and educators alike want to know how working memory develops in the young mind and to what extent it can be influenced.

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[6] Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. Educational Psychology Review, 26(2), 197–223. https://doi.org/10.1007/s10648-013-9246-y

[7] Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. Educational Psychology Review, 26(2), 197–223. https://doi.org/10.1007/s10648-013-9246-y

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[10] Noël, M.-P., Seron, X., & Trovarelli, F. (2004). Working memory as a predictor of addition skills and addition strategies in children. Cahiers de Psychologie Cognitive/Current Psychology of Cognition, 22, 3–25.

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[13] Simms, N. K., Frausel, R. R., & Richland, L. E. (2018). Working memory predicts children's analogical reasoning. Journal of Experimental Child Psychology, 166, 160–177. https://doi.org/10.1016/j.jecp.2017.08.005

[14] Sanz, C., & Leow, R. P. (2011). Implicit and Explicit Language Learning: Conditions, Processes, and Knowledge in SLA and Bilingualism. Georgetown University Press.

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[16] de Mel, S., McKenzie, D., & Woodruff, C. (n.d.). Returns to Capital in Microenterprises: Evidence from a Field Experiment.

Development of Working Memory

Rapid growth and large variance

Working memory increases with age, and quite rapidly so during the early childhood years. Between the age of six to seven, a typical child sees a 20 percent increase, after which the development is slower, before it flattens out a few years into the twenties.

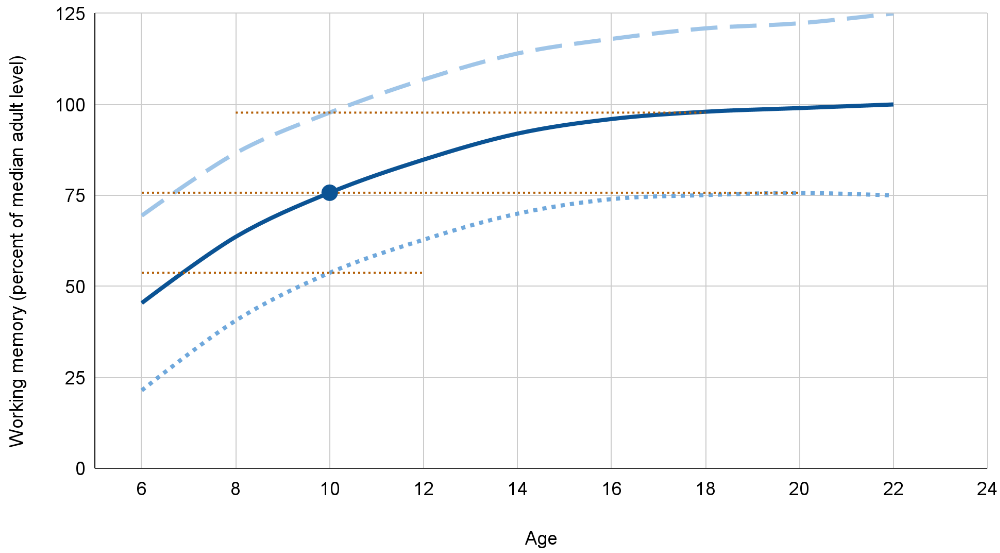

Fig. 1. Stylized working memory development path. Solid blue line marks path for median individual, dashed and dotted blue lines mark +/- one standard deviation respectively.

Figure 1 above is consolidated from several studies measuring working memory capacity (for details, see Appendix). The dark solid line shows the development path for a median child as they grow into adulthood. Below it runs a lighter blue dotted line, showing the development path of a child who is one standard deviation below the median. This latter person has a working memory capacity that is lower than 84 percent of their peers.

Similarly, the dotted line that runs above and almost parallel to the solid line represents a person whose working memory is one standard deviation above the median, and thus *larger* than 84 percent of their peers.

Take the case of a typical ten-year-old (dark blue dot). Their working memory capacity is at about 55 percent of the level they will reach as an adult. Compare this to the child who is one standard deviation below the median; they are at a working memory capacity that the median child was when they were seven years old (indicated by the lower of the horizontal dotted lines).

Similarly, the child who is one standard deviation above the median is far ahead of their peers, already close to the highest level that the median child is expected to reach as an adult (as the upper horizontal dotted line shows).

The relationship between the slope of the curve (the pace at which working memory develops) and the substantial variance in working memory capacity (the distance between the solid and dashed lines), illustrates something that most people who work in education have an intuitive understanding of: the difference between the cognitively most mature and most immature child in the same class is equivalent to many years of natural development.

A neurophysiological view of working memory development

From a functional perspective, working memory has been described with reasonable precision for at least 60 years. Up until recently it was however mostly unclear to what extent the functional components constituted neurological processes of their own, or if they were the result of some other underlying processes, which would then be what determines the maturation and developmental path of what we observe as working memory.

Today a lot is known about how working memory manifests in the brain and which groups of genes that are mostly responsible for its development. One of the most revealing studies that has shed light on this comes from a 2014 research study at the Karolinska Institute in Stockholm, lead by Henrik Ullman[17]. In it, the researchers gathered observations of children's brains using magnetic resonance imaging. Based on this information they could predict the level of working memory capacity, not only at the time of the observation, but also two years later. In other words, by objective observation of a child's neurophysiology it was possible to estimate their working memory capacity (shown by the *vertical position* on the chart in figure 2) as well as the speed at which the capacity was increasing (shown by the *slope* of the path in the same chart).

These biological observations even turned out to give stronger predictions of future capacity than what could be had from many of the standard cognitive tests, including *n-back*, *digit-span*, and *Raven's standardized progressive matrices.* This is a powerful testimony of working memory as not only a functional faculty of mind, but an objectively observable neurological construct.

Genes and the environment

Understanding *how* the development of working memory influences learning and executive functioning is important when planning an intervention, but it can also be helpful to have an idea of *why* working memory develops the way it does.

[17] Ullman, H., Almeida, R., & Klingberg, T. (2014). Structural Maturation and Brain Activity Predict Future Working Memory Capacity during Childhood Development. *Journal of Neuroscience*, *34*(5), 1592–1598. https://doi.org/10.1523/JNEUROSCI.0842-13.2014

An important clue to this is given in a 2021 study by Bruno Sauce and colleagues, which tracks the causes of how working memory develops, and starts to disentangle the influence of heritability and environment[18]. As it turns out, there is a highly significant genetic component that influences which of the developmental paths an individual is most likely to follow, but this observation should not be taken as an indication of a fatalistic view that “some have it and some don’t, and there is nothing you can do about it”.

On the contrary, the genetic influence at play does *not* inscribe a predetermined developmental path, along which the individual moves as they mature. Instead, it defines *how sensitive the individual is* to activities that are sufficiently cognitively challenging for the brain to trigger growth. Thus, to phrase it in a non-deterministic way; a child that is observed to develop near the lower path in fig. 1 is likely to be genetically predisposed to require *more exposure to cognitive stimulation* in order to reach the same level of cognitive capacity as their peers.

A second and important observation made in the same study is that the brain reacts the same way to the “natural” cognitive stimulation that comes from attending school and other activities, as it does to an “artificial” cognitive stimulation, in the form of a digital training program aimed at pushing the children’s working memory near its maximum capacity.

These two findings are consistent with previous research which found that the number of years of schooling a person has gone through is a better predictor of working memory capacity than chronological age[19]. It tells us that working memory is not a faculty whose principle development is to “mature with time”, but rather to “develop with exposure and practice. A similar causality is likely behind the observation that increased education seems to improve not just knowledge, but also fluid intelligence[20].

In addition to this gene-environment distinction, there is an important second order effect that increases the genetically predisposed tendency. A child that has higher than average working memory is more likely to be high performing in school and other cognitively challenging activities, which typically makes it more likely that they also enjoy those activities. Likewise, a child who struggles with attention demanding tasks, is more likely to shun away from them when they have that option. Through this natural but unfortunate logic, the children who have the least need for cognitive training are often those who get most of it, and those who are in dire need of more, are those who end up with the least amount of it.

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[18] Sauce, B., Wiedenhoeft, J., Judd, N., & Klingberg, T. (2021). Change by challenge: A common genetic basis behind childhood cognitive development and cognitive training. *Npj Science of Learning*, *6*(1), Article 1. https://doi.org/10.1038/s41539-021-00096-6

[19] Roberts, G. et al. Schooling duration rather than chronological age predicts working memory between 6 and 7 years. J. Dev. Behav. Pediatr. 36,68–74 (2015).

[20] Ritchie, S. J. & Tucker-Drob, E. M. How much does education improve intelligence? A meta-analysis. Psychol. Sci. 29, 1358–1369 (2018)

Prevalence and consequences of low working memory

Why should we care about working memory? Does it even matter how many digits a child can repeat backwards and forwards? Well, recall that working memory is closely related to how a student fares in school. Differences in measurement of visuospatial working memory explains as much as 40 percent of the difference in mathematical performance among primary school students. Other academic skills that are associated with working memory include problem solving, reading comprehension, and language acquisition.

Let us return to the large variance seen in working memory capacity in each cohort of students. In figure 1, we looked at how working memory developed over time. Figure 2, below, illustrates one cross-section of that path. The vertical line at the center marks the median working memory capacity, around which most students are found. To the left, the same dotted line as in fig. 1 is seen, marking one standard deviation lower than the median. This leaves 16 percent of the students with a working memory that is at the level of someone *at least* three years younger. In this group, the prevalence of ADHD is naturally higher (since a relatively low working memory is a typical manifestation of that condition).

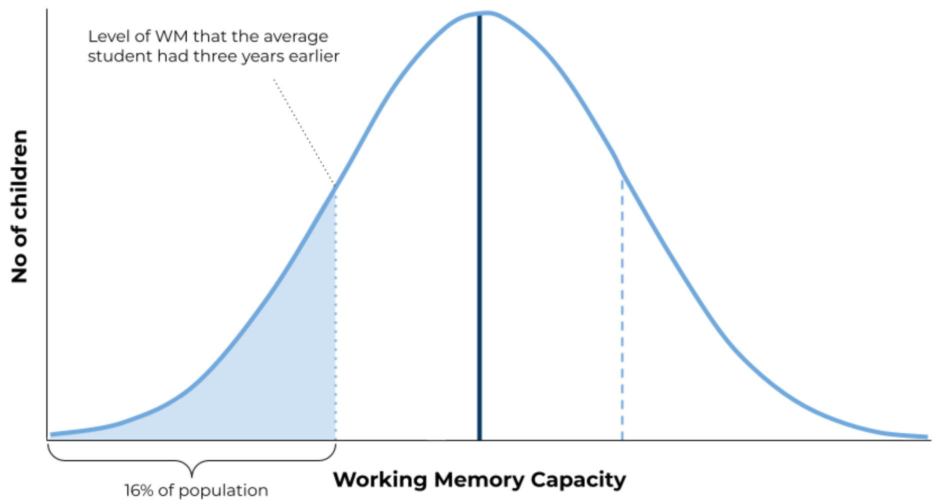

Fig. 2 Roughly one sixth, or 16 percent, of a typical cohort of children lag three years or more behind the average child's working memory capacity

In addition to the naturally occurring working memory deficits, events in a person's life can shift working memory downward. A child that suffers from pediatric cancer is typically treated with radiation and/or chemotherapy, both of which can have dramatic negative effects on cognition, including working memory capacity[21,22,23,24]. Being severely prematurely born is also associated with lower than average working memory[25,26,27], as is traumatic brain injury [28,29,30]. Thus, the share of the population with a naturally occurring low working memory capacity is also accompanied by groups whose working memory is lowered due to non-genetic circumstances, making the true share of a cohort with low working memory likely to be in excess of 16 percent, and increasing with age.

Within the group of children who start off with a lower-than-average working memory, the interaction between genes and environment, discussed above, often makes things worse. Children who are especially gifted in some area–be it playing basketball, solving equations, or writing horror stories–will find that they enjoy that activity more, and therefore spend more time doing it. That gives them more exposure, which again makes them more skilled at it.

The same thing is true for working memory. Children who happen to be good at paying attention and keeping information in mind are likely to spend more time doing activities where these capacities are pushed to their limits, and thereby grow even faster. And those that are not so good at those things, are more likely to avoid activities that expose them to their weaknesses. This is sometimes called the *Mathew effect*, as it dictates that those who have will be given more, and those who do not have will get even less (from the Bible's Gospel of Matthew, Matt. 25:24–30).

[21] Conklin HM, Ashford JM, Clark KN, Martin-Elbahesh K, Hardy KK, Merchant TE, Ogg RJ, Jeha S, Huang L, Zhang H (2017) Long-Term Efficacy of Computerized Cognitive Training Among Survivors of Childhood Cancer: A Single-Blind Randomized Controlled Trial. J Pediatr Psychol 42:220-231.

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[29] Johansson B, Tornmalm M (2012) Working memory training for patients with acquired brain injury: effects in daily life. Scand J Occup Ther 19:176-183.

[30] Lundqvist A, Grundstrom K, Samuelsson K, Ronnberg J (2010) Computerized training of working memory in a group of patients suffering from acquired brain injury. Brain Inj 24:1173-1183.

Deficit in Working Memory and Attention

Behaviors associated with working memory and attention might not be as easily spotted in a classroom as those related to hyperactivity. An experienced teacher however, rarely needs more than a few lessons to identify the children most at risk. The signs include:

- being easily distracted
- making careless mistakes
- appearing forgetful or losing things
- being unable to stick to tasks that are tedious or time-consuming
- appearing to be unable to listen to or carry out instructions
- constantly changing activity or task
- having difficulty organizing tasks

Based on what is now known about the development of working memory and how it underpins academic achievement, it is possible to offer some actionable advice to practitioners and parents who struggle to help children with lower-than-average working memory. To evaluate any such advice, it is helpful to bear in mind the interaction between *genetically defined sensitivity* to exposure, and the *environmentally defined* amount and quantity of such exposure.

There are many methods and interventions that can be helpful when trying to cope with the symptoms of attention deficit, and depending on which health agency or authority you talk to, you will receive somewhat different advice. Two interventions that are almost universally on the list are medication and adaptation.

In the last section of this paper, we shall present those two briefly, and then compare it to a third and less often applied method, which is based on what is now known about how working memory and attention develops in people with ADHD and related conditions.

Before we go on to make this comparison however, note that there is no implied suggestion to select one and discontinue other methods. Instead, all three methods listed all have their advantages and disadvantages, and it is up to the educational or healthcare professional to compose an appropriate combination of these and other methods.

Method 1: Medication with central stimulants

Working memory deficit is common among individuals diagnosed with ADHD, and for them the use of central stimulants is often an option. The most widely prescribed alternative among the central stimulants is methylphenidate, which acts by inhibiting the reuptake of the neurotransmitters norepinephrine and dopamine. (Brand names include Ritalin and Concerta; generic options are available.)

Compared to placebo, methylphenidate has been shown to be effective in reducing symptoms associated primarily with hyperactivity (such as deficit in impulse inhibition) in around 70 percent of clinical trials, while no more than half of the trials show improvements in attention and working memory deficit[31]. The effects on response inhibition have an average effect size of 0.4 standard deviations, while the effect on working memory tasks that include some level of executive control were smaller, with an average effect size of 0.26 standard deviations[32]. Among those children and adolescents with ADHD who do experience a large effect, many attest to the pharmaceutical's important contribution to their ability to cope with school and social situations.

Others are less likely to continue with the medication, often because the effect is too small in relation to the sometime severe side effects, which can include tachycardia, palpitations, headache, insomnia, anxiety, hyperhidrosis, weight loss, decreased appetite, dry mouth, nausea, abdominal pain and more[33]. Quitting medication is especially common during adolescence, which is unfortunate as this is often a period when the child would benefit especially from improved attention and reduced impulsivity.

Central stimulants also have a potential for dependency and addiction, which is one reason that many parents are hesitant to let their children use them.

ADHD medication is not like antibiotics, where you take a dose to get rid of an infection and once it is gone there is no need for additional medicine. Instead, to retain the effect of central stimulants, they must be taken every day that the effect is desired, and if you stop taking them, the effect goes away which leaves many children in a situation where they take a psychotropic pharmaceutical regularly for the better part of their upbringing.

[31] Pietrzak, R. H., Mollica, C. M., Maruff, P., & Snyder, P. J. (2006). Cognitive effects of immediate-release methylphenidate in children with attention-deficit/hyperactivity disorder. *Neuroscience & Biobehavioral Reviews*, *30*(8), 1225–1245. https://doi.org/10.1016/j.neubiorev.2006.10.002

[32] Coghill, D. R., Seth, S., Pedroso, S., Usala, T., Currie, J., & Gagliano, A. (2014). Effects of Methylphenidate on Cognitive Functions in Children and Adolescents with Attention-Deficit/Hyperactivity Disorder: Evidence from a Systematic Review and a Meta-Analysis. *Biological Psychiatry*, *76*(8), 603–615. https://doi.org/10.1016/j.biopsych.2013.10.005

[33] U.S. Department of Health and Human Services: *Methylphenidate: MedlinePlus Drug Information*. Retrieved November 4, 2022, from https://medlineplus.gov/druginfo/meds/a682188.html

Medication with central stimulants	
Benefits	**Drawbacks**
● Easy to administer ● For methylphenidate, generic low cost options are available ● Often covered by public healthcare or private insurance systems	● Only about 50 percent chance of improved working memory, with limited magnitude of effect ● Side effects are common ● Risk of dependency and addiction ● Need to keep taking the medicine for as long as the effect is desired

Method 2: Adaptation by reducing distractions

Rather than changing the chemistry of the brain, it is sometimes preferable to change the environment that surrounds it. Working memory is a limited resource, effectively throttling your capacity to focus, think, learn, and to adequately apply executive functions. If some portion of this scarce capacity is spent filtering out background noise or a busy visual environment, processing worrying thoughts, or trying to keep in mind a list of instructions that could just as easily have been written down, then there is a strong candidate for improvement available.

While an adequately calm and quiet working area is helpful for most people, it can be absolutely essential for a person with reduced working memory[34]. (Note that this does not necessarily mean absolute silence and absence of decorative elements. Many people, especially those with ADHD, find that some level of background noise is preferable to silence[35].)

In school, at home, and at work, it is a good idea to remove unnecessary distractions and sources of unwanted noise and interruptions. Few people can keep their attention on an important but boring task if their telephone lies next to them, with a constant stream of notifications reminding them of more stimulating activities[36].

However, as beneficial as it is to remove *unnecessary* distractions, this strategy is restricted to making changes to the environment only and does not affect the actual working memory capacity itself, which leads to some of its limitations:

[34] Forster, S., Robertson, D. J., Jennings, A., Asherson, P., & Lavie, N. (2014). Plugging the attention deficit: Perceptual load counters increased distraction in ADHD. *Neuropsychology*, *28*, 91–97. https://doi.org/10.1037/neu0000020

[35] Baijot, S., Slama, H., Söderlund, G., Dan, B., Deltenre, P., Colin, C., & Deconinck, N. (2016). Neuropsychological and neurophysiological benefits from white noise in children with and without ADHD. Behavioral and Brain Functions, 12(1), 11. https://doi.org/10.1186/s12993-016-0095-y

[36] Kushlev, K., Proulx, J., & Dunn, E. W. (2016). "Silence Your Phones": Smartphone Notifications Increase Inattention and Hyperactivity Symptoms. Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, 1011–1020. https://doi.org/10.1145/2858036.2858359

Firstly, some tasks are themselves inherently demanding on working memory, and no amount of white noise or calm work spaces can make them less so.

Secondly, recall that working memory develops in response to exposure to cognitive challenges. An overzealous adaptation, in which the resulting environment is not providing sufficient challenges will further reduce the pace of development, precisely for the individuals that would need it the most.

Finally, as much as we want to help our students, patients, and children, it is also our responsibility to prepare them for a future in which we are not there protecting them. Adaptation of the controlled environment in school is often beneficial, but it does not necessarily help the child prepare for the next phase in life, in which no such adaptations may be available.

Adaptation by reducing distractions	
Benefits	**Drawbacks**
• No risk of dependency or addiction • Many adjustments can be initiated immediately by anyone near the child, without need for a formal decision or a doctor's prescription • No adverse clinical effects • Can be tailored to the specific needs of each child • The same adaptations that help children with low working memory are often beneficial to typically developing children too	• Requires willingness and capacity from school and other places where the child spends their time • Some tasks inherently require a lot of working memory, even without distractions and in a controlled environment • Risks removing exposure to cognitive challenge, which is necessary for growth in this area • Eventually, the child will be facing situations outside of home or school, where adaptations can not be ensured.

Before going into the third category of methods, let us recall five key points of working memory and its development:

1. Working memory capacity has a powerful influence over academic achievement and executive function.
2. A substantial share of all children have a working memory that makes them lag several years behind their peers in cognitive capacity, most prominently displayed in those with ADHD.
3. Working memory develops in response to exposure to challenge (as opposed to maturing in response to time passing).

4. Children with a low working memory are not genetically prevented from development–they just have to practice more to get the same results.
5. Those who need to practice their working memory the most are also those who are least likely to seek out and stick to activities that provide the required exposure.

An effective intervention would thus be one that identifies children who follow a lower-than-average developmental path, and then provides them with additional exposure to activities that stimulate and challenge their working memory. Catching up with their peers will require quite a lot of training, since they need to compensate both for being less responsive to training, and for the fact that they are likely to get less of it spontaneously.

Method 3: Working memory training

A large scale longitudinal study published in 2021 shown that a five week working memory program, in which school children spend 40-50 minutes per day doing focused working memory tasks, provided long lasting positive effects: effects that can be seen in grade point averages and admission to more academically advanced school-tracks several years later[37]. Another study from the same year showed that each additional minute of daily working memory training readily translates into faster mathematical learning, but also that those who start off with a lower working memory capacity need to spend at least twice as much time training to get the same results as the median child[38].

As promising as working memory training sounds, it does require a substantial effort on behalf of the child. This means that teachers, clinicians, and parents often need to team up to support and coach the child through the training process. It is always easier to swallow a pill than to carry out rehabilitation exercises, regardless of whether they are prescribed by a physiotherapist or a neurologist. Therefore, a working memory training program needs to be well planned and integrated in the daily schedule, with consistent support and encouragement from the surrounding, both at school and at home.

Working memory training has been known to be an effective method to improve several symptoms of attention deficit disorder since at least 2005[39], but it is still much less known compared to pharmacological interventions. Since it does require a substantial amount of effort and support during the training period, it may also be resisted for the short term challenges it may impose on scheduling and logistics.

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Working memory training	
Benefits	**Drawbacks**
• 3 in 4 of all participants show a clinically relevant increase in working memory after completed intervention • Largest effect size of all studied WM interventions, with an average of 0.7 s.d. • Effects remain after completed intervention, and often even increase in magnitude with time • Easy to adjust training dosage, to serve more to those who need it the most • No risk of dependency or addiction • No adverse clinical effects	• Completing an intervention requires substantial effort over the course of several weeks • Educational, healthcare, and insurance systems may be unfamiliar with this type of intervention, leading to decision making and funding being more difficult than for alternatives

Comparison of methods

In the above, we have briefly summarized three fundamentally different methods of coping with working memory deficit. The effect that each of them offer can be illustrated in a stylized way on the development path introduced in figure 1.

In figure 3, below, the principle difference between the three methods described is shown as it relates to the development of working memory in a person who is one standard deviation below the median:

Chart A illustrates the effect of a 0.25 standard deviation increase in working memory, which is a typical effect from pharmacological treatment with methylphenidate. In this illustration, the child is eight when they start to try out which kind of medication to use and titrate the dose, and then take the medication regularly into their late teens. Discontinuing medication in this age is a common behavior as the adolescent wishes to rid themselves of the side effects while the parents have less influence over the medication.

Chart B illustrates the effect of adapting the environment, to effectively create a situation in which a lower level of working memory is sufficient to meet the demands. As long as the adaptations are in place, the effect *appears as if* working memory capacity were higher, but as adjustments are removed, the child is still following their lower than average, and no longer sufficient, development path. Note that this is not to say that adaptations should be avoided–on the contrary, everything that is learned in school during the low-demand period remains with the child, and for many children these adaptations may be what is required to keep them in school at all.

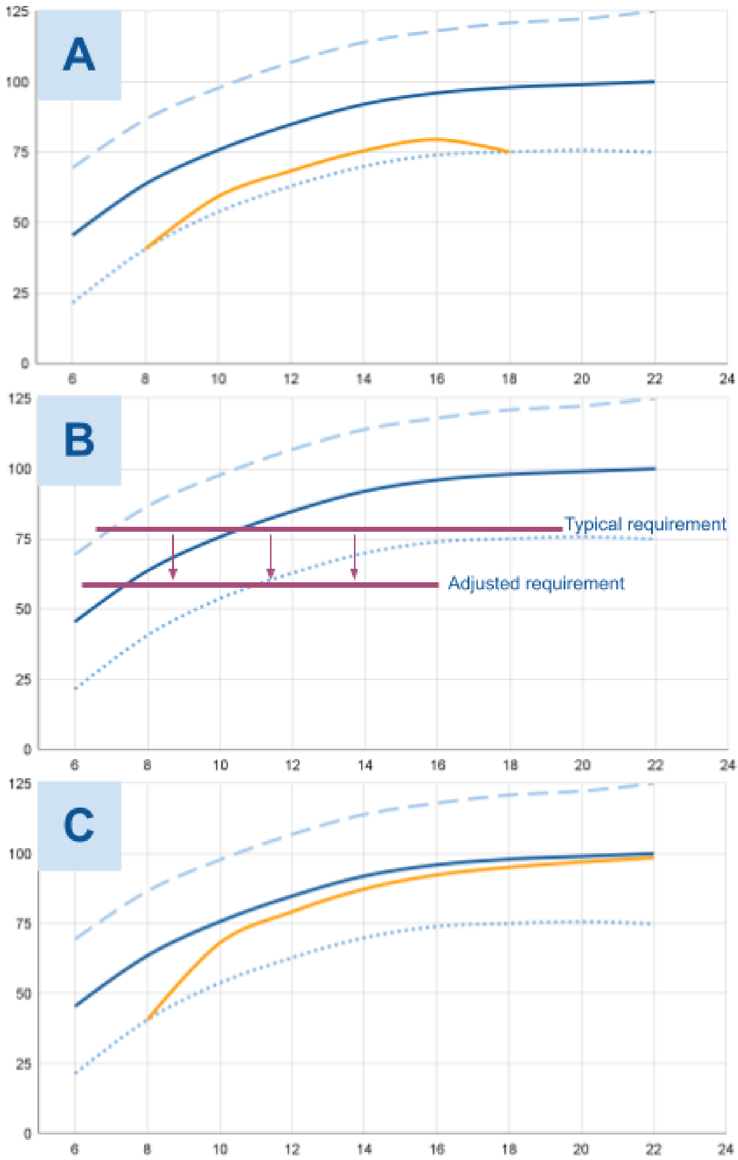

Fig 3: stylized influence on development and requirements from three different categories of intervention

Chart C illustrates the potential of an intensive working memory training intervention. It leads to an immediate increase in the working memory capacity (a parallel upward shift of the path), which is then followed by another effect that takes longer to see, but which has even greater potential. As soon as the child has increased their working memory and attentional capacity, they are able to cope with additional exposure to cognitive challenges, which in turn leads to further development. Hence, increasing working memory capacity at an age where it is still under development leads both to an immediate upward shift of path, and to a faster developmental pace (a steeper upward slope of the path).

In contrast to medication and adaptation, the effects of working memory training remain with the child, even when the intervention is no longer present. This makes it an ideal component of a long term plan to deal with attention deficit, that has a potential not only to relieve the pressures of the current situation, but also to make the child more ready for a situation outside of school, where there will be less support and adaptation available.

Cogmed working memory training

Cogmed is the world's most well researched training program for enhancing working memory and attention. It has been used by more than 200,000 people worldwide, to lessen the effects of ADHD, stroke, cancer treatment, traumatic brain injury, and other impairments that reduce working memory and concentration.

Cogmed was originally developed by researchers at the Karolinska Institute and is today maintained by the company Neural Assembly Int AB, and distributed globally by Pearson Assessment.

To learn more about Cogmed and receive a free trial, please visit **cogmed.com/provider**

Appendix

The development path of working memory through life has been measured and estimated a number of times, with slightly different definitions of the median path. Fig A1 shows five influential sources, published over the past 25 years (references for each charts: A[40], B[41], C[42], D[43], E[44]). For clarity, the distinguishing characteristics of these paths are recreated as a smoothed average in figure 1 in the main text, where curves are added for one standard deviation above and below the mean, taken from the studies that include this data.

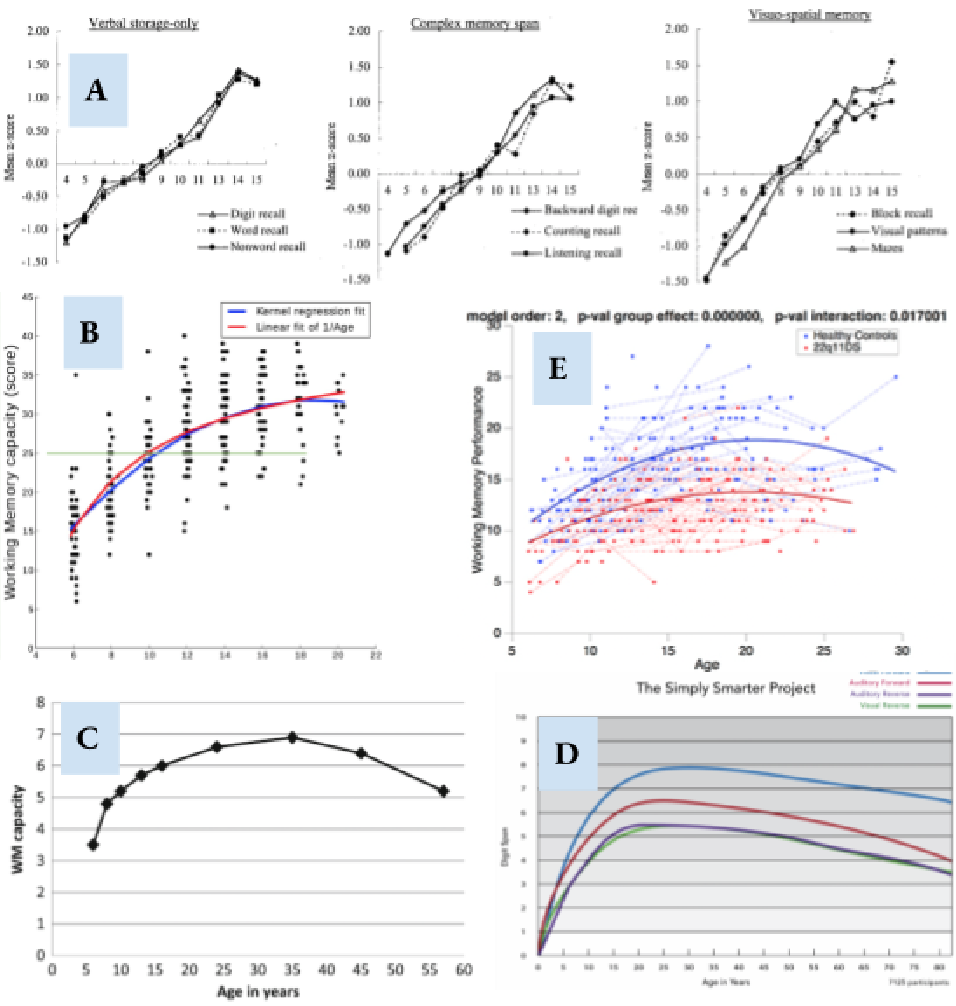

Fig. A1. Typical development paths for working memory from five studies 1999-2018

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About this whitepaper

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

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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.

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