29 Working Memory Training

From the Laboratory to Schools

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29.1 Working Memory

29.1.1 The Many Concepts of Working Memory

As commonly defined in psychology, working memory (WM) is the ability to maintain and manipulate information in active attention. It includes narrow abilities such as auditory short-term storage, visual-spatial short-term storage, and attentional control. Despite a common definition, working memory is still quite a heterogeneous concept, and it can be measured in many distinct ways. WM was first proposed to be the memory for plans of future action (Miller et al., 1960). Later, the dual-store concept of WM by Alan Baddeley came to dominate cognitive psychology for a long time (Baddeley & Hitch, 1974). In that model, there are two separate domain-specific storage systems: the phonological loop (which stores verbal content) and the visuospatial sketchpad (which stores visuospatial content). And, as in many other models of WM since then, Baddeley's model proposes a central executive system (or attentional/processing component) that controls the flow of information from and to the two storage systems.

Based on empirical findings, there have been multiple revisions and new proposals for WM since Baddeley's model. In non-human animals, lesion studies and electrophysiological recordings from tasks described as "short term memory" or "delayed response" tasks revealed neural correlates of these types of memory to the prefrontal cortex (Fuster & Alexander, 1971; Kubota & Niki, 1971; Pribram et al., 1964). Afterwards, Patricia Goldman-Rakic made the link between this type of memory and WM (Goldman-Rakic, 1987). The sustained firing of prefrontal neurons found in electrophysiological recordings has been modeled with biologically realistic neural networks (Compte, 2000), and corresponding sustained activity has also been found using functional magnetic resonance imaging in humans (Postle et al., 2000). Together, these findings describe a standard model for visuospatial WM (Constantinidis & Klingberg, 2016). However, this model has been challenged by findings suggesting that memory during short intervals can occur without brain activity detected by fMRI (D'Esposito & Postle, 2015). More recently, hybrid models in which memory is retained both by sustained electrical activity and synaptic plasticity have also been suggested (Miller et al., 2018).

There are so many types of memories called WM that no definition fits perfectly. In its most wide concept, WM can be considered any type of on-line memory; not very distinct from other memories with a short delay such as short-term memory and sensory memory. The neural basis of WM might be multiple (Miller et al., 2018), and differ depending on stimulus modality, type of stimuli, and task requirements.

29.1.2 Working Memory Is Highly Relevant to Learning and Intelligence

Regardless of the specific concept used to define and measure it, WM is central to a wide range of cognitive tasks: from daily activities such as remembering instructions to sophisticated ones such as discussing politics. Research findings from the last two decades show that performance in working memory tasks is strongly correlated to learning and the general factor of intelligence – including fluid (abstract, reasoning-based) and crystallized (knowledge-based) measures (Conway et al., 2003). Individuals with higher scores on intelligence standardized tests also have a greater capacity for preserving reliable mental representations of relevant information in the short-term (Colom et al., 2016). Furthermore, statistical modeling of inter-individual differences has shown that updating/monitoring of WM is highly correlated with intelligence (Friedman et al., 2006). Surprisingly, other executive processes were not related to intelligence, such as shifting of mental sets and inhibition of prepotent responses (Friedman et al., 2006).

Why are WM and intelligence so tightly correlated? A possible cognitive explanation is that temporary storage is required for online processing in both reasoning and working memory. Reasoning and WM are clearly distinguishable mental operations, but limitations for short-term maintenance hinder the ability for problem-solving. WM might limit, for example, the number of relationships between elements that can be built and kept active during the reasoning process necessary for solving problems included in standard intelligence tests (Halford et al., 2007). Therefore, individual differences in intelligence can be accounted for by basic mental processes underlying memory span, namely, encoding, maintenance, updating, and retrieval (Jonides et al., 2008).

As reported by Martínez et al. (2011), online memory span factors such as WM are hardly distinguishable from fluid intelligence at the latent variable level. At that level of analysis, the difference between WM and intelligence as constructs might be very subtle. Engle (2018) has recently argued based on past research that the part of executive attention most relevant to WM tasks performance is the part that "maintains information in the maelstrom of divergent thought." And the part most relevant to intelligence tasks is the part that "disengages or unbind [relevant information] and functionally forgets it" (Engle, 2018). In other words, even though storage components might always play a critical role to both, the processing components important to WM might not be the ones important for intelligence.

As we present next, the heterogeneity in WM concepts/measures and the (subtle) differences between WM and learning/intelligence processes are likely relevant to the field of WM training – especially when related to educational outcomes.

29.2 Working Memory Training

29.2.1 Working Memory Development, Training, and Plasticity

WM has been traditionally regarded as a fixed trait, and one of the natural limitations on the information processing abilities of the human brain (Miller, 1956). Note, however, that throughout development, the WM of most children improves dramatically, and there are considerable inter-individual differences. At any given age, children differ in WM's capacity and rate of change, with some children developing their WM earlier and at a faster rate, while some others struggle far behind (Ullman et al., 2014). Why is that the case? The factors underlying the development of WM and the related inter-individual differences are still poorly understood. Even so, many researchers in the field default to a maturation/fixed interpretation – stating that the changes in WM over the years are under strict and inflexible genetic programing. Based on recent evidence, this maturation/fixed view of WM is likely to be incomplete.

In the first modern studies on WM training, one of the authors of this chapter, Klingberg gave children intensive and extensive training on visuospatial WM tasks for about forty-five minutes per day, five days per week for five weeks (Klingberg et al., 2002, 2005). These studies used mainly visuospatial tasks similar to the span-board task. The difficulty of the tasks was adapted close to the capacity limit of the children and the active control group received the same tasks, but the difficulty was not adapted. In those original studies, children did not only improve on the trained tasks but also in non-trained tasks (Klingberg et al., 2002, 2005). Since then, the method of WM training has been used as a tool to explore basic scientific questions: such as the question on the neural plasticity underlying WM (Constantinidis & Klingberg, 2016), and whether the neural basis of changes occurring during training corresponds to the changes underlying cognitive development during childhood.

Combined evidence from electrophysiology, neuroimaging, molecular genetics, and behavior genetics show some genes and associated brain activities in common between the WM gains during childhood development and the WM gains during WM training (for a review, see Klingberg, 2014). For example, our research group has previously found that WM development is predicted by both striatal volume and a polymorphism of the dopamine transporter gene – both factors are known to influence learning and brain plasticity (Nemmi et al., 2018). Furthermore, we found that a polymorphism in a dopamine receptor gene is associated with increased gains during WM training (Söderqvist et al., 2014). Recent studies with non-human animals reveal detailed evidence on the plasticity of WM. For example, particular factors underlying innately higher general cognitive abilities in mice can be recreated by WM training programs; including neuronal sensitivity in the prefrontal cortex and dopamine receptor turnover rates (Wass et al., 2013, 2018).

Together, these laboratory findings indicate that WM changes during childhood years and during weeks of training are both influenced by genetic factors on brain plasticity potential, which, in turn, modulate the effect of environmental factors. In contrast to the traditional view of a fixed WM, the new evidence suggest that WM is, to some extent, plastic, and show that WM training programs can have beneficial effects on an individual's WM.

29.2.2 Working Memory Training – Differences in Methods, Aims, and Populations

The rationale for the initial studies on WM training was not only to test if WM could be improved but also to test if this was beneficial for children with ADHD. That idea was based on the theory that deficits in WM are linked to inattention – a central aspect of the symptomatology of ADHD (Barkley, 1997). Neuroimaging shows that visuospatial WM and spatial attention are closely related concepts, both dependent on the prefrontal and intraparietal cortex (Jerde et al., 2012). Consistent with this, when children with attention deficits, either associated with ADHD or trauma, improved their WM, there was also a decrease in inattentive symptoms (Bigorra et al., 2016; Conklin et al., 2015; Green et al., 2012; Klingberg et al., 2005).

In 2008, Susanne Jaeggi and collaborators conducted the first WM training study using a different method: the dual n-back task (Jaeggi et al., 2008). The research also differed in two important aspects: the aim was not improving attention, but improving intelligence, and the participants were not children with ADHD, but healthy university students. The publication by Jaeggi et al. received major media attention and was a milestone in what came to be known as the brain training hype. The hype and the connection to commercial companies with claims that were not always based on solid research resulted in many academics reacting negatively, and a polarized discussion ensued.

There are now around 500 publications on WM training. However, the heterogeneity of WM's concepts is also reflected in the many different methods for improving WM. In addition to the Cogmed training and n-back training, other training approaches include using lists (Dahlin et al., 2008) or complex WM tasks (Chein & Morrison, 2010). Furthermore, WM training studies also differ in the schedules and support the training, the activities of control groups, the types of participants, and the outcome measures. Given the wide range of tasks to which WM capacity has been associated, studies testing the transfers of gains from WM to other abilities also differ: from "pure" measures, such as for intelligence and long-term memory, to more "ecological" measures directly relevant to education, such as reading and mathematics.

29.3 Overview of Working Memory Training in Education

Since the start of WM training programs twenty years ago, there has been an interest in testing whether a potentially increased WM after training can transfer (or generalize) to increased school performance. There have been attempts to summarize the literature from WM training, and there are mixed results. For example, a meta-analysis by Schwaighofer et al. (2015) concluded that WM training does not improve academic outcomes, while another study by Bergman Nutley and Söderqvist (2017) concluded that transfer occurs in some studies but with no significant effect in the majority of studies, though limited and dependent on other factors. Although qualitative and quantitative meta-analyses are certainly valuable to the field, their conclusions will reflect the specific designs of each study analyzed. As noted, WM training programs can be extremely heterogeneous, and this diversity and complexity are rarely taken into account by meta-analyses.

To give a glimpse of the field WM training in education, here we will overview a few studies that used the same WM training program, the Cogmed Working Memory Training, or "Cogmed Training" (Klingberg et al., 2005). Cogmed is the most widely used training program to date, and so represents a great platform for future refinements in going from the laboratory to schools. The Cogmed Training is a computerized training program with twelve different visuospatial and verbal WM span tasks that adapt to the capacity level of the trainee. Training is typically implemented during a period of five-to-seven weeks, thirty-to-forty minutes per day, five days a week, with weekly support from a certified coach that ensures compliance with the program.

Perhaps the most comprehensive study to date on Cogmed Training effects in education was recently performed by Berger et al. (2020). The study was a randomized control trial involving 572 children (six-to-seven-year-old first graders) that embedded Cogmed Training in regular teaching across thirty-one school classes. They found that training led to immediate and lasting gains in working memory capacity as well as relatively large gains in geometry skills, reading skills, and fluid IQ. Interestingly, the transfer effects emerged over time and only became fully visible after twelve months (at the end of this section, we discuss the relevance of this lagged, long-term effect in relation to the two main transfer routes for WM training). Finally, this study by Berger et al. (2020) also showed a direct effect on future school attainment: four years after the intervention, the children who received training had a 16 per cent higher probability of entering the academic track in secondary school.

Next, we discuss some Cogmed Training studies in more detail on the skills of reading and mathematics. The brief overview here is only supposed to illustrate a few examples and shed light on important points regarding transfer effects in schoolchildren. For a structured and extensive review of transfer from Cogmed Training, we recommend the study by Bergman-Nutley & Söderqvist (2017).

29.3.1 Transfer of Cogmed Training to Reading

Studies with Cogmed Training that assess reading gains by measuring passage comprehension frequently show positive results in both clinical and non-clinical samples (Dahlin, 2011; Egeland, Aarlien, & Saunes, 2013; Phillips et al., 2016). However, a study on reading after Cogmed Training in a sample of six- and seven-year-olds did not find reading gains (Roberts et al., 2016). The measures that the authors used to assess reading in a twelve-month follow-up were word reading, sentence comprehension, and spelling, and in a twenty-four-month follow-up, they used word reading and spelling. Note that these are all measures of simple word recognition and comprehension.

WM is only one of several processes that are necessary for reading. Previous research has shown WM to be predictive of certain aspects of reading at certain ages only. For example, WM does not predict simple word recognition (Kibby et al., 2014) and reading comprehension when using simple sentences (compared to longer texts; Seigneuric & Ehrlich, 2005). This pattern might be behind the negative findings of the study by Roberts et al. (2016). Considering this point, it is not surprising that improvements were not observed in their measures. WM training studies should be careful at selecting appropriate outcome measures of transfer to school performance for each age bracket.

There is a clear difference in the processes supporting reading acquisition and reading comprehension (Chall, 1983). The role of the level of a child’s WM gradually transitions from being just one of several processes underlying reading acquisition (“learning to read”) to later becoming a crucial process in reading comprehension of content (“reading to learn”). This matters because studies including students on both ends of reading proficiency are likely to see differential effects on the same outcome after WM training – such as in a study by Phillips et al. (2016) that included children ranging from age eight to sixteen years.

Even when WM is an important process for the educational outcome, if another process/ability is acting as a bottleneck for the outcome, then WM training alone is not likely to result in a noticeable transfer. Reading acquisition, for example, is more impacted by phonological awareness than by WM (Leather & Henry, 1994). However, if WM is impaired, then this is likely to disturb the decoding progress, which would make WM a bottleneck in those samples. In harmony with that idea, studies with Cogmed Training assessing reading proficiency in young children tend to show positive transfer on phonological awareness (Fälth et al., 2015; Foy, 2014), whereas studies assessing older children on this measure tend to find effects primarily in impaired samples (Dahlin, 2011; Egeland et al., 2013). Thus, WM training seems to transfer to reading only when it is a bottleneck for reading acquisition (i.e., the samples have lower WM than needed for the relevant learning process). The lesson here is that we should not expect WM training to have a homogeneous effect on reading proficiency. Instead, researchers in the field should explore the different levels of restriction that WM causes on the outcome and find in which situations WM training can make the most impact.

29.3.2 Transfer of Cogmed Training to Mathematics

Bergman-Nutley and Söderqvist (2017) summarized the thirteen studies using Cogmed WM training with mathematics as an outcome. Three of the studies showed significant improvement (Bergman-Nutley & Klingberg, 2014; Dahlin, 2013; Holmes & Gathercole, 2014). There were also positive effect sizes (Cohen's $d > 0.25$) in seven of the measures from the thirteen studies, but negative effect sizes in four measures.

At this point, it is unclear what explains the differences in results between studies, but it could include differences in outcome measures, population characteristics, sample sizes, and quality of training.

The importance of large sample sizes is discussed in Section 29.4.2. The question of population characteristics, such as diagnoses and baseline WM capacity, is discussed in Section 29.5.1. At this point, there is too little data to draw firm conclusions about the importance of baseline measures for Cogmed training. In particular, there is a lack of studies of typically-developing children.

For example, recent research examined the transfer to mathematics after increasing the amount of coaching during Cogmed training in nine-to-twelve year-olds (Nelwan et al., 2018). The authors found that the highly coached group performed better in visual WM after training (though, surprisingly there were no differences for verbal WM) compared to a group who received a lesser amount of coaching and a non-trained group. More interestingly, the gains in mathematical ability were higher in the highly coached group right after the end of Cogmed training, and these children also retained their advantage in mathematics four months later compared to the other groups. This suggests that transfer effects from WM training might depend on the quality of the training and the engagement of the children.

The outcome measures used in training studies are important. Like with reading, WM is consistently found to relate to mathematical performance, and the specific patterns of this relation are complex. The relationship of mathematics and WM seems to change at different stages of development (De Smedt et al., 2009) and WM can be more or less important to different aspects of mathematics within the same age group (Wiklund-Hörnqvist et al., 2016). The attention/processing component of WM and visuospatial storage appear to be mostly recruited for learning and application of new mathematical skills

It's also worth noting the ways in which WM training can potentially impact education in general. Bergman-Nutley and Söderqvist (2017) defined two main routes for WM training to transfer to school performance: the learning route and the performance route. In the learning route, WM training will influence academic performance by improving learning capacity. This could be, for example, due to increased attention in class and from an increased capacity to process new information taught. In this route, effects from WM training would be more evident in the long-term, and outcome measures would match specific curricular content. In the performance route, WM will influence academic performance through

WM's direct involvement in academic tasks. So, effects from increased WM capacity from training would show on outcome measures of already learned skills that are tapping WM (and only if, before training, WM was a bottleneck for performing the learned skill, as opposed to other factors not affected by WM training such as speed of processing or knowledge of arithmetic).

29.4 Methodological Challenges

29.4.1 Methodological Aspects of Cognitive Interventions

A paper authored by forty-eight researchers (including one of the authors of this chapter, Klingberg) attempted to make headway in the often polarized discussion about cognitive training, in particular, to suggest guidelines for methodological practices (Shawn Green et al., 2019).

A first suggestion in the article was that "Behavioral interventions for cognitive enhancement can differ substantially in content and target(s) and thus a common moniker like 'brain training' can be misleading" (p. 3). We briefly discussed this problem in Section 29.3, and the situation becomes even worse in the broader literature where approaches used for enhancing cognitive ability by training include standard neuropsychological tasks, commercial computer games, and meditational practices. Some studies use a single task for the entire training while others use a wide range of tasks. Some studies use rigorous monitoring of subjects, while others just give access to a range of tasks to be "played" at home at leisure. Despite this, the term "brain training" is used as if it is a concept specific enough to answer the question of "does brain training work?" (Owen et al., 2010; Simons et al., 2016). Such a question is as scientifically meaningless as the question of whether "do drugs work"! Instead, conclusions should be more specific, regarding method, subjects, and outcome.

Secondly, the paper by Shawn Green et al. (2019) suggests that it is important to make distinctions between different types of studies: (a) feasibility studies; (b) mechanistic studies; (c) efficacy studies; and (d) effectiveness studies, as described next.

Feasibility studies test the practical aspects of study design. In a drug trial, such a study might investigate possible side-effects of a drug. In an intervention study, a researcher might test whether the tasks are too difficult for the target population, but also evaluate economic, technical, and compliance problems. Feasibility studies can also give an indication of the expected effect size, and thus inform subsequent studies.

Mechanistic studies try to answer basic scientific questions about the neural or cognitive mechanisms by which an intervention works. They might involve neuroimaging, genetics, or try to use a wide range of cognitive tasks in order to pinpoint a cognitive effect.

Efficacy studies aim to test if an intervention causes cognitive or behavioral improvements above and beyond any placebo effects. The question can be framed as "Does the paradigm produce the anticipated outcome in the exact and carefully controlled population of interest when the paradigm is used precisely as intended by the researchers?" This type of study should ideally be done as a randomized, placebo-controlled, blinded trial, comparing the test–retest effect of the treatment group to the test–retest effect of a control group involved in some kind of meaningful alternative activity.

Finally, effectiveness studies try to answer the question of whether an efficient intervention is also effective in a real-world setting. This setting often includes non-compliant subjects who do not perform the training as intended or a wider range of included subjects who have not gone through a careful screening as in an efficiency study. This type of study might be especially relevant when an intervention is to be implemented in a school setting. The sample size of an effectiveness study should be based not only on effect sizes, as in an efficiency study, but also allow for drop-out and non-compliance, and could use an intent-to-treat analysis.

Another methodological problem that is especially relevant to WM training on school performance: studies typically have a wide age range of participants. As we discussed in the topics of reading and mathematics gains, a wide age range will induce large variance due to childhood development and how much WM is required by distinct processes. Furthermore, in the case of a study using standardized assessments (such the Wechsler Individual Achievement Test), the actual tasks performed by children within the same study will differ due to the assessment's wide inclusion of different mathematical domains (Raghubar et al., 2010), and the start and stop rules typically used within these assessments. All those problems make it difficult to interpret and generalize results. Therefore, the field of WM training needs more studies with a small range of age.

29.4.2 Statistical Power, Sample Size, and Latent Measures

Genetic research was for a long time troubled with a lack of replications and inconsistent findings. As technology made genotyping faster and less expensive, researchers realized that the effects of single nucleotide variability were very low, and that larger samples were required. The field of cognitive training is still young but will probably go in a similar direction. Effect size (ES) can be measured as Cohen's delta, which quantifies the change in the treatment group in terms of standard deviations, minus the effect of the change in the control group. Most interventions or drugs intended to improve cognitive function have a low-to-medium effect size. Antidepressants, such as SSRI, have an effect size of at best 0.3, but often around 0.2 (Kirsch, 2008). The effects of anticholinergic drugs on dementia is around 0.15. A meta-analysis of the effect of physical fitness on working memory showed a short-term effect of 0.15 and a long-term effect of 0.05 (Álvarez-Bueno et al., 2017). The effect of methylphenidate on WM is around 0.25 (Coghill et al., 2014). A meta-analysis on the effect of stimulating a "growth mindset" found an effect of less than 0.1 (Sisk et al., 2018). In the "What works clearinghouse," a cut-off of 0.25 is used to classify an intervention as effective.

We should not expect effects from WM training to be much higher than the typical effect size from other interventions in psychology. Any study aiming to evaluate the efficiency or effectiveness of WM training should thus have enough power to detect a 0.3 effect size. Power-calculations will depend on the data and statistical model, but, typically, in order to have a statistical power of 0.8, i.e., an 80 percent chance of finding a true effect is also statistically significant, we will require around 350 participants, 175 in each group. Most WM training studies to date have around fifty-to-sixty participants in total and are thus underpowered. This increases the risk of both false negative and false positive findings and contributes to the inconsistencies between studies.

When it comes to the effect of WM training on academic abilities, it is especially important to take long-term effects into account. A cognitive intervention might improve the ability of a child to pay attention, or keep information in WM, but does not install any new long-term memories or skills. It is not that you suddenly know Pythagoras theorem because you have a better working memory. A pre–post-test that mainly assesses knowledge would thus theoretically have no effect. As mentioned in Section 29.3.2, however, cognitive training might affect learning ability itself (via the learning route) rather than performance (via the performance route). If this is the case, studies need to allow for sufficient time between training and assessment for learning to take place. Therefore, long-term follow-ups are critical to the field, especially to test transfer from WM training via the learning route.

Although long-term follow-ups increase the risk of introducing confounding factors, this can be avoided with well-controlled designs. In these studies, a researcher should ensure that the education given to both groups is comparable for reliable conclusions. Some studies in the past (such as by Roberts et al., 2016) had selected children to take part in a WM training intervention, who are taken out of class to perform the intervention, thus missing out on some regular school lessons. In the long-term, having improved the WM of these students is unlikely to replace the education they have missed. If anything, that specific intervention design could even result in negative effects in school performance.

One last point on methods: Tests of WM transfer to school performance (such as for reading and mathematics) should, ideally, match the curriculum in each particular school. An outcome measure one or two years after WM training will be better if it reflects what the students have been learning in school. One method likely to be fruitful is the use of metrics that schools already use, such as exams and national achievement measures, since these are already designed to capture learning progress. Another possibility is to exploit the explosion of new forms of wearable technology. These could provide a host of reliable, valid, and scalable dependent variables of improvements in education in scenarios outside of school, and that can also be tracked over long time periods (Shiffman et al., 2008). Of course, researchers need to keep in mind that the designs and protocols ought to respect the privacy and rights of participants, with special caution given the relative novelty of wearable technologies in research.

29.5 Visions for the Future of Working Memory Training in Education

29.5.1 Personalized Training

Most cognitive training interventions to date have used a one-size-fits-all approach, and not considered individual differences in either content or extent of training. The question of personal training, or personal learning, has some bad associations to a field of education promoted as "brain-based learning" – aimed to classify children according to their "learning style" as either auditory, visual, or tactile learners. This is one of the most prevalent brain myths among teachers but has no ground in science (Howard-Jones, 2014). The fact that the "astrological" explanation of inter-individual personality differences is nonsense does not mean that research about personality differences (nor astronomy) should be banned due to guilt-by-association. Serious research about inter-individual differences in learning might be very fruitful.

The clearest example of inter-individual differences might be that subjects differ in the rate of learning. One of the earliest examples of this is Thorndike's study from 1908: "The effect of practice in the case of a purely intellectual function" (Thorndike, 1908). When healthy volunteers were given practice in multiplying large numbers, all of them improved, but the difference in the amount of improvement was three-fold. Interestingly, he found that subjects with higher baseline abilities improved more, an effect later to be known as called the *Matthews effect*, or the *rich-get-richer* effect.

Similarly, the effect of WM training has been shown to be larger for subjects already at a relatively high level at baseline (Au et al., 2015; Jaeggi et al., 2008), and children with higher intelligence have larger transfer to non-trained WM tasks (Gathercole et al., 2019). Thus, the effect of WM training on academic abilities could be dependent on baseline characteristics. Evaluating differences in the impact of an intervention can ideally be done as showing an interaction between group (treatment or control) and baseline measures. For example, Nemmi et al. (2016) showed that the effect of WM training, when mathematical performance was the outcome measure, depended on baseline performance in a WM task. The interaction was positive, that is, in line with the *Matthews effect*. If this turns out to be a replicable finding, it is somewhat ironic that most studies of WM training to date have been including subjects with lower than average WM, which might have been preventing detection of any effect on WM gains.

Finally, the field of WM training in education may very well be one in which a big part of the impact from interventions reflects multiple interacting factors in addition to the intervention itself: such as diet, sleep, exercise, baseline levels of WM, baseline levels of skills, specific mindsets, specific motivational techniques, etc. Thus, WM training in the future ought to test these effects and take relevant individual differences into consideration.

29.5.2 Videogames and ESports

Videogames have been used for educational purposes since the early days of computers. Here, it's important to distinguish between educational videogames and cognitive training videogames.

Educational videogames are the oldest and most widespread in schools. They are software designed to help the teaching of curricular content (e.g., number division or multiplication tables) by gamifying typical exercises/homework and keeping students motivated and more in control of their learning. In an extensive meta-analysis, Clark et al. (2016) analyzed twelve years of research on educational videogames in postsecondary schools in areas such as Engineering, Natural Sciences, and Social Sciences. The meta-analysis found that digital games significantly enhanced student learning relative to non-game conditions, and that "augmented games," that is, games based on research and theories of learning, have a larger effect than plain educational games. Interestingly, he found that factors such as game mechanics characteristics, videogame genre, and narrative mattered to the effects (Clark et al., 2016). At least to some extent, it seems that educational games are becoming another useful pedagogical tool to educators – similar to video animations of a lesson (e.g., the mechanism of digesting food), field trips, and group activities.

In this chapter, however, we are primarily interested in the second, and newest type of videogames for educational purposes: cognitive training videogames. These games can be either designed based on cognitive tasks from research or originally designed for entertainment (such as popular commercial videogames) that happen to train cognition as a side-effect. Overall, these are all software that can potentially be used to motivate and automate the training of general abilities such as WM. Typical laboratory WM training tasks, such as the dual n-back, can be quite arduous and become tedious after a few weeks of daily training. Cognitive training videogames could solve that engagement problem and expand the audience for WM training.

The literature so far on the efficacy of cognitive training videogames is mixed. Many of these studies have focused on possible transfer effects on general abilities other than WM, such as visual tasks, reaction time, visuospatial rotation, and visual search (for a review, see Latham et al., 2013). Regarding WM, cross-sectional studies comparing expert video gamers with novices have commonly found superior performance of gamers on such tasks (e.g., Boot et al., 2008; Greenfield et al., 1994; West et al., 2008), and expert players have higher functional connectivity between attentional and sensorimotor networks (as expected from higher WM capacity) (Gong et al., 2015).

Of course, the results of these studies could merely mean that people with higher WM are more driven toward videogames (and are the people who keep playing them). As stronger evidence, two meta-analyses looked at the efficacy of cognitive training games in increasing WM and other related abilities (Powers et al., 2013). The first meta-analysis computed correlational and quasi-experimental studies comparing players with non-players and found that video game players were superior to non-players in measures of cognitive control/executive functioning (also considered the processing component of WM). The second meta-analysis was on randomized, controlled interventions, and they also found positive, yet smaller, effects of video game training in cognitive control/executive functioning (among other measures less related to WM that also showed positive results). Furthermore, Palaus et al. (2017) concluded that distinct neural correlates of attention, cognitive control, and verbal and spatial working memory seem improved from different types of video games.

There are also negative results in the literature, however. Sala et al. (2017) conducted a meta-analysis and found small-to-null cognitive effects from playing video games, and null effects in cognitive abilities such as attention, spatial ability, cognitive control, and intelligence. And Gobet et al. (2014) found no effects of video game expertise on attention (flanker task and change detection). The mixed literature on cognitive training videogames somewhat mirrors the mess in the larger literature on cognitive training. Studies on videogames probably suffer from similar theoretical and methodological problems, as we discussed in the previous paragraphs. There are poorly designed studies, lack of agreement on parameters, small power, and meta-analyses ignoring differences between videogame genres (i.e., mixing apples and oranges, as a genre might not tap into WM at all, while another might require a lot of it).

Despite the mixed literature, the positive results so far and the increasing popularity of videogames represent a great potential for WM training in education. Videogames are a huge industry, and children of the current generation have videogames as an integral part of their day-to-day lives. A 2008 report in the US (Pew Research Center, 2008), for example, found that nearly all American teenagers aged twelve-to-seventeen play videogames (computer, web, console, or mobile games), totaling 99 percent of boys and 94 percent of girls. Regarding frequent gaming, there are significant gender differences, but the gap is not as large as people imagine – with 39 percent of boys and 22 percent of girls reporting daily gaming. And 34 percent of boys and 18 percent of girls in the US play video games for two hours or more daily. Furthermore, a 2017 report in the UK showed that children aged five-to-seven years spend an average of 7.3 hours per week playing videogames, while children aged twelve-to-fifteen spend a remarkable 12.2 hours per week playing them (Statista, 2017). These statistics, of course, mean that videogames for WM training are becoming easier to be adopted and implemented by schools, since both educators and students are now more familiar with the language of games, and can derive more motivation/pleasure from using them. If we can reliably increase WM via videogames, that would represent an immense help to WM training programs in education: in going from the laboratory to schools.

As a vision for the future of WM training videogames in schools, we see two potential and critical roles for researchers (these, of course, are not mutually exclusive).

Vision for role #1: Researches will directly help in the development of new cognitive training videogames. These laboratory-produced videogames would potentially borrow much from already existing WM training programs in psychology and combine them with principles in game design. Such as the way it was done, for example, with the app Vektor. There are a few guides and suggestions in the literature on how to build better memory training games. For example, Deveau et al. (2015) propose specific ways to augment the efficacy of WM training by borrowing from the fields of Perceptual Learning (research on reinforcement, multisensory facilitation and multi-stimulus training) and Computer Science (research on engaging environments from game design). This area, however, is still immature, and much work still needs to be done.

The advantage of laboratory-produced videogames is that they could be extremely effective at increasing WM per hour played compared to popular, standard videogames. Laboratory training programs are typically based on tests developed from decades of research in cognitive psychology and psychometrics, so there is high confidence that these tasks reliably and strongly tap the relevant construct (such as WM). The disadvantage of laboratory-produced videogames is that the vast majority of these games will not be as engaging and motivating as big-budget videogames. It is unlikely that children will play these laboratory-produced games by themselves as pure entertainment. So, even though they are more effective at increasing WM per hour played, we cannot expect children to play for too many hours a week. In order to counter this problem, researchers and companies should be in closer contact with schools to implement these videogames as part of homework or during a set time in school. It is still unclear, however, if this approach could achieve voluntary playing in all children with the amount of playing needed to have cognitive effects.

Vision for role #2: Researches will help to provide evaluations and guides of already existing popular, commercial videogames. Some studies and laboratories will focus on testing which are the best videogames at improving cognitive abilities (e.g., WM, reasoning, intelligence) and school performance. As a proof of concept, a study by Baniqued et al. (2013) attempted to evaluate the cognitive abilities tapped by a variety of commercial videogames. They used twenty web-based commercial games and tested their relationship with a battery of cognitive tasks by using factor analyses. The authors found five interpretable cognitive groups with close correspondence to pre-defined game categorizations: working memory and reasoning games, spatial integration games, attention/multiple object tracking games, and perceptual speed games. For example, games categorized to tap working memory and reasoning were robustly related to performance on working memory and fluid intelligence tasks. The methods used in Baniqued et al. (2013) could be used in the future to assess the best games to be used for WM training, and show that videogames can be heterogenous on the cognitive abilities they tap on. Furthermore, the diversity in cognitive requirements that Baniqued et al. (2013) found among games could also explain, in part, the mixed results in the videogame training literature.

In role #2, researchers would act the same way as nutritionists: suggesting which types of food are healthy, and how much of each should be consumed. Or, closer in analogy, the researcher's role would be of physical education experts in schools: suggesting the correct schedules of sports and exercising programs of already well-established activities, such as running, football, swimming, and basketball.

In fact, some videogames are gradually resembling traditional sports in many ways. ESports (electronic sports) is a form of organized, videogame competition between players or teams of players. ESports can be quite diverse (and, consequently, could be diverse in their requirements of distinct cognitive abilities), including the genre/modality of real-time strategy (e.g., StarCraft), fighting (e.g., Street Fighter), first-person shooter (e.g., Counter-Strike), multiplayer online battle arena (e.g., League of Legends), and digital card game (e.g., Hearthstone). Since the 2000s, eSports have become a significant factor in the entertainment industry, with audiences in numbers equal to leagues of traditional sports such as the NBA. Moreover, the competitive aspect of eSports is attracting the attention of the International Olympic Committee: some eSports are confirmed to be medal events in the 2022 Asian Games and are being considered for the 2024 Olympic Games. In this context, schools might in the future add eSports as part of recreational/break time and/or add eSports to the sports training curriculum. Further, it is likely that eSports will get amateur leagues within and between schools – similar to what already exists nowadays with football, swimming, volleyball, etc. (And similar to eSports college leagues that already exist in a few universities in the United States, for example.) If these visions come true, the school environment will soon need studies on the effects of eSports on education and on cognitive training.

Extending the analogy of fitness/sports in our speculations of what could happen in the field's future: regarding role#1, small companies and gyms can create new and very effective exercising programs and group activities, and experts (such as personal trainers) can fine-tune these to smaller groups of individuals. This would be the role of researchers for WM training videogames. In role #2, well-established sports such as football, tennis, and swimming might not be the most effective at improving one's fitness, and cannot be changed, but their reach, engagement, and user numbers are much higher. The role of researchers would be choosing the best big-budget videogames and eSports at improving WM, as well as establishing the best schedules.

As far as we know, there is still no controlled research on the effect of eSports on WM. However, given some of the positives results with other popular videogames, the strategic and reasoning requirements of these games, and the number of hours played by children, it is likely that at least some of these games might be efficacious to WM. This, of course, is just informed speculation. However, the potential is there! Both roles of researchers in this vision could potentially bring enormous future gains to education using the method of WM training.

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