1

Cognitive Perspectives of Working Memory Training

Current Challenges in Working Memory Training

Kenny Hicks and Randall W. Engle

Introduction

Working memory training is an emergent field aimed at improving general cognitive abilities through targeted brain exercises. The prospect of improving cognitive abilities like attention control, comprehension, and reasoning has piqued the interest of the scientific community and the general public alike. If cognitive abilities like working memory capacity can be improved, it is assumed that this improvement will result in benefits to a broad range of real-world abilities associated with working memory capacity, including reading comprehension, math performance, and attention control (Holmes et al., 2010; Jaeggi, Buschkeuhl, Jonides, & Perrig, 2008; Klingberg, 2005; Klingberg, Forssberg, & Westerberg, 2002). However, to date, there is no clear answer to the question of whether cognition will improve through interventions designed to enhance working memory capacity. One reason is an absence of discussion among researchers of various training paradigms, which has resulted in a lack of consensus on the basic underlying principles of the research, including differences in the operational definition of working memory training, inconsistent ways to measure increases in working memory, and little integration of findings into a larger literature on cognitive training or, more broadly, working memory capacity.

This line of research is theoretically important, but it is also unique because of its potential for real-world impact. Working memory training has far-reaching implications for many diverse stakeholders, including not only academics but also any group interested in cognitive improvements. Those concerned with such diverse topics as improving selection, job training, and cognitive remediation are interested in the efficacy of working memory training and its potential for future applications. Products that extoll the benefits of "brain training" and other targeted exercises aimed at increasing cognitive abilities have permeated the public sphere. Such widespread attention has led to an influx of working memory training literature in psychology and other disciplines, but our enthusiasm must be tempered by the evidence.

Preliminary studies on working memory training are not often referred to as pilot studies in media headlines or by the commercial programs that use them for advertisement (Holmes, Gathercole, & Dunning, 2009; Holmes et al., 2010). Simply put, although coverage of preliminary studies may be well intentioned, the results can be easily oversold. It is our hope that the reader will gain perspective on the outcomes of training, evaluate the strength of the current evidence, develop an understanding of the current debate on the most controversial findings, and understand how these findings might transfer to the real world.

Researchers of working memory training claim that cognitive training interventions result in transfer to a domain-general ability (Klingberg, 2005) above and beyond task-specific abilities, such as strategy use (e.g., chunking items into groups). Although perspectives on what constitutes successful transfer are varied, it is generally conceptualized as near and far transfer.

Near transfer refers to gains in tasks that tap the same construct that the intervention seeks to improve. In terms of working memory training, near transfer would be achieved by demonstrating improved performance on novel working memory tasks. Evidence of far transfer occurs when subjects demonstrate superior performance on tasks that require working memory but reflect a fundamentally different construct (e.g., fluid intelligence). The logic here is that working memory is a key component of other higher-order cognitive abilities, such as fluid intelligence, and that improving working memory should lead to an increase in any ability dependent on the working memory construct. Ideally, after working memory training, improvements would be observed in tasks designed to assess both near and far transfer. However, to claim that working memory training increases fluid intelligence, the results should also provide evidence that working memory was improved. That is to say, at a minimum, researchers should demonstrate near transfer before claiming to show evidence of far transfer.

To better understand the complexity of transfer, we can look to the 1992 case study of Rajan Mahadevan. Mahadevan had an exceptional memory for numbers: he could recall a record of more than 30,000 digits of pi. Investigators found that, rather than possessing an innate ability for memorization, he used a mnemonic strategy, namely grouping numbers into blocks of ten. Further evidence that Mahadevan used a memory strategy for numbers came when scientists found that his memory for spatial objects was merely average (Biederman, Cooper, Fox, & Mahadevan, 1992). What is important is that Mahadevan's superior memory performance for digits did not transfer to other domains of memory (Ericsson, Delaney, Weaver, & Mahadevan, 2004).

The goal of working memory training is to demonstrate broad transfer to tasks that involve the same components of working memory that were targeted during

training. Therefore, improvements should be observed on a broad range of tasks that tap the ability being trained. This is measured by observing the difference between pre- and posttest performance on cognitive tasks that subjects have not practiced.

Investigating Transfer

Given our lab's substantial contributions to the theoretical aspects of working memory capacity and its relationship to fluid intelligence (Engle & Kane, 2004; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Shipstead, Redick, & Engle, 2012b), we were intrigued by the prospect of improving cognition and the potential theoretical and real-world implications. In particular, we were motivated to further our understanding of the mechanisms that drive the cognitive improvements.

The task of selecting which training regimen to investigate was difficult because no unified approach to the study of working memory training exists. Due to the highly influential claim that training on the dual N-back task led to improvements on matrix reasoning, one of the best indicators of fluid intelligence (Jaeggi et al., 2008), our first study implemented the dual N-back paradigm. While offering an exciting prospect for the field, Jaeggi and colleagues' article included methodological shortcomings, such as measuring fluid intelligence with a single test instead of multiple indicators. Further, the 2008 article actually represents the combination of four studies that differed significantly, including different measures of fluid intelligence across studies, differing deadlines for completing the test of fluid intelligence, and the use of no-contact control groups (see Redick et al., 2012, for a more in-depth discussion of the studies). In an attempt to replicate Jaeggi and colleagues' 2008 findings, we conducted a follow-up study that addressed the previous study's shortcomings by including a dual N-back training group, an active control group that performed an adaptive visual search task, as well as a no-contact control group. Practice on a visual search task was chosen as the active control condition because previous research found no relationship between working memory capacity and visual search performance across a number of studies that varied the difficulty of the search task (Kane, Poole, Tuholski, & Engle, 2006). The training study also included measures designed to simulate real-world performance (e.g., the ability to manage air traffic and perform complex multitasks). Despite adequate statistical power and the inclusion of multiple indicators of both fluid intelligence and multitasking, the results of the training study failed to demonstrate any behavioral improvements after dual N-back training (Redick et al., 2012).

After our failure to replicate far transfer to fluid intelligence after dual N-back training, our research became focused on investigating near transfer. Therefore, our next study explored the effects of training on measures of short-term memory and the complex span (Chein & Morrison, 2010; Unsworth, Heitz, Schrock, & Engle, 2005; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). Subjects were randomly assigned to a short-term memory training condition, a complex span training condition, or an active control group that practiced a visual search task. All three were adaptive tasks (i.e., increased in difficulty with success). To investigate far transfer, we administered multiple measures of fluid intelligence at pre- and posttest, including Raven's Progressive Matrices, the Letter Sets task, and the Number Series task. We also included other measures related to working memory capacity, such as free recall. None of our training groups showed improvements in fluid reasoning (e.g., far transfer). We found partial evidence for moderate transfer (tasks representing moderate transfer that were different from the training paradigm but still relied heavily on many of the same memory processes involved in the training tasks). For instance, improvements in the secondary memory portion of immediate free recall were observed, while evidence for the Keep Track Task was less interpretable (Harrison et al., 2013). Overall, this study represented our second failure to demonstrate domain-general improvements to cognitive abilities after extensive working memory training.

Criticisms of Working Memory Training

Shipstead and colleagues (2010) published the first systematic review analyzing the methods and results used in the working memory training literature. Prior to 2010, the claims that working memory training led to vast improvements in intelligence and attention control had gone largely unchallenged. The Shipstead article was fittingly titled "Does Working Memory Training Generalize?" If working memory capacity can predict performance across a range of important cognitive outcomes, does working memory training lead to improvements across a wide range of cognitive tasks? Although the question posed is simple, it has received surprisingly little attention. The conclusion of Shipstead and colleagues was that most working memory training studies failed to control for threats to internal validity, failed to include adequate control groups for comparison, and consistently relied on a single test to represent constructs of interest—practices that continue in the working memory training literature today.

In the publication, "Cogmed Training: Let's Be Realistic About Intervention Research" by Gathercole and colleagues (2012), the researchers argued that many of the criticisms raised about working memory training are impractical. They justified their perspective with two arguments. First, the authors maintained that

training studies are costly and time consuming. Second, they argued that too much rigor in the early stages of investigation could be wasteful because the outcome of a training study is uncertain. They advised initial studies on working memory training to focus on ways to minimize costs in order to maximize the chance for a successful outcome (e.g., no-contact and active control groups are expensive, so they shouldn't be required during early stages of research). The authors made their case by describing the results of two pilot studies they were able to complete successfully while reducing the cost of training. The first study (Holmes et al., 2009) did not include a control group, while the second study (Holmes et al., 2010) included a no-contact control group. For Gathercole and colleagues' logic to hold true, they must assume that the results of working memory training studies are not dependent on whether the study includes a passive or active control group. However, meta-analytic work investigating this issue has found the opposite. Researchers have found substantial differences in training outcomes that depend on the type of control group included in the study. Specifically, training studies including no-contact control groups have much higher rates of finding positive training effects, whereas studies including active control groups have found little to no reliable effects of training (for a more in-depth review, see Melby-Lervåg & Hulme, 2013; Melby-Lervåg, Redick, & Hulme, 2016). This result is further supported by Dougherty and colleagues (2016), who conducted a re-analysis of N-back training studies. In line with the broader literature on working memory training, the authors found significant evidence in support of working memory training when studies included a no-contact control group, but no evidence for training-related benefits for studies that included an active control group. In light of these findings, we agree with Shipstead and colleagues (2012b) that researchers should pursue more robust experimental designs. In addition to the inclusion of active control groups, researchers should also be cautious when interpreting their findings. An in-depth analysis of five studies by Redick (2016) showed that several studies supporting working memory training are the result of a general decline in the performance of the control group from pre- to posttest, which render the results uninterpretable from any theoretical perspective.

In consideration of this work, the aim of the current chapter is to pose a series of questions to researchers investigating the efficacy of working memory training. By adopting a common-question approach, we are following the example set by *Variation in Working Memory* (Conway, Jarrold, Kane, Miyake, & Towse, 2007), where each contributing research group is asked to address questions that motivate discussion about the commonalities and distinctions in the field of working memory training. Through answering these directed questions, each research group will discuss what motivates their work, cover the research results of their particular paradigm, and express their views on the current state of working memory training as it relates to various training interventions. The questions raised here touch on fundamental issues integral to working memory training research and will open a dialogue among researchers with various perspectives and methodologies.

Four Directed Questions

Question 1: Theory of Working Memory Training

What is your theory of working memory capacity? What theoretical framework guides your perspective on working memory capacity? How has this perspective influenced the way you design interventions aimed at improving it?

One of the first things proponents of working memory training need to present before claiming to improve cognitive abilities is a theory of working memory capacity that outlines the mechanisms responsible for its relationship to higher-order cognition. Before claims of cognitive improvements can be taken seriously by academic researchers and the general public, proponents of working memory training first need to describe a theory of working memory that outlines the mechanisms responsible for its relationship to higher-order cognition (see von Bastian & Oberauer, 2014, for a more in-depth discussion of this issue).

Although a number of studies have reported increases in reasoning (Jaeggi et al., 2008; Klingberg, 2005; Klingberg et al., 2002), attention control (Klingberg et al., 2005), and memory performance (Holmes et al., 2009), the question is: Why? So far, the literature lacks a concrete theoretical framework that can shed light on this question.

While we acknowledge that the assumptions regarding the underlying structure of working memory capacity may differ greatly between research groups, we encourage each contributor to provide evidence for the malleability of working memory capacity and other aspects of higher-order cognition. Since differences in perspectives influence how researchers investigate the effects of working memory training (e.g., guiding selection and creation of training paradigms), it is important for each research group to outline their concept of working memory capacity and the underlying mechanisms that govern it. Future work in this area will need to more clearly explain specific mechanisms responsible for individual differences in working memory capacity and the way in which working memory training paradigms target and improve the mechanisms.

Question 2: Major Claims of Working Memory Training

What specific claims do you make concerning the efficacy of your training program? What are the specific claims your research group makes about the improvements that should result from your training regimen? How do your claims differ from those of other research groups? Have your initial claims changed in response to newer evidence?

The research groups selected for this volume implement a diverse range of training interventions, which has resulted in substantial differences in the claims researchers have made regarding their findings. For example, the claims made by Eichenbaum, Bavelier, and Green (see Chapter 9) are specific to improvements in visual attention, while the claims about improving attention made by Jha, Krompinger, and Baime (2007) are much more general.

The questions in this section seek to clarify the discrepancies between the past and present claims of researchers of working memory training. Before we can fully consider the efficacy and utility of training, it is important to understand the current positions of each group and how their understanding has evolved based on developments in the field.

Question 3: Methodological Issues

What are the biggest methodological issues in your area? How do you address these issues presently, and how do you plan to address them in the future?

The purpose of this question is to require each research group to address common methodological pitfalls that inhibit researchers' ability to draw causal inferences about their interventions. Some researchers have tackled this issue head on. For example, Eichenbaum, Bavelier, and Green (see Chapter 9) discuss the importance of adequate sampling and control groups. Specifically, they claim that wait-list or no-contact controls are insufficient and that active control groups are becoming the gold standard in the field (see Green & Bavelier, 2012).

No Single Test Is Process Pure: The Importance of Measuring Constructs With Multiple Indicators

The strength behind a theoretical account of working memory depends on how well researchers can measure the underlying construct. Since all laboratory tasks are imperfect, they include variance related to the ability of interest (e.g., working memory capacity) and variance that is unrelated (error variance). The only way to tease the two apart is to administer several working memory tests to derive the common variance among them and to isolate the task-specific variance of each task. This way, the only commonality among the tasks will be working memory capacity. The point here is that observing performance on a single task does not afford an adequate measure of working memory. Instead, latent abilities like working memory capacity can be measured only by observing performance across multiple indicators and investigating the common variance shared among them.

Multiple indicators are rarely used in the working memory training literature. As noted by Shipstead and colleagues (2012b), near transfer can occur for a variety of reasons other than improvements in working memory capacity. The most parsimonious account of improvements on a single task of working memory capacity is that subjects simply learn a strategy that is specific to performing the training tasks and can, in turn, apply this strategy to other memory tasks (Shipstead et al., 2012b). This result should not necessarily lead to the conclusion that working memory capacity has improved. In fact, it could imply that performance on a particular task is artificially inflated after training due to practice effects and that the measure is no longer a valid estimate of the subject's ability.

Active Control Groups

To infer causality, researchers must ensure internal validity. Internal validity refers to the degree of certainty that an intervention is responsible for causing changes at posttest. Without a robust experimental design, any evidence supporting working memory training could be explained by extraneous factors unrelated to the training program. In order to assume that an intervention is responsible for changes in behavior, the experimenter must eliminate these threats (Campbell & Stanley, 1966).

To claim causation, experimenters must make certain that the treatment is the only viable explanation for their results. Protecting against threats to internal validity requires training studies to include an active control group. Subjects should be randomized into treatment and control conditions to control for sampling bias and the influence of experimenter expectations (Campbell & Stanley, 1966). A good active control group is one that equates to the treatment group in every way except for the critical manipulation thought to be responsible for the treatment effect.

The measurement of latent abilities with a single indicator, inclusion of no-contact control groups, and inadequate subject randomization have not been an exception; these practices have been the rule, and the widespread use of these methods has stymied researchers' ability to provide a convincing answer to the most basic questions related to working memory training.

Question 4: Contributions to the Field

How has your research contributed to understanding of the working memory construct? How do you integrate your findings into the context of a larger literature on working memory training?

A primary concern about the present state of working memory training studies is that there is little standardization and convergence of findings. Research groups have different working memory training approaches and assess varying cognitive skills and transfer measures, and minimal research has been done on the comparative efficacy of the various approaches. This question encourages each contributing research team to discuss the implications of their findings for other researchers of working memory capacity and their perspectives on various interventions designed to improve cognitive abilities.

Conclusion

In summary, the purpose of this chapter is to address the best way to integrate and to synthesize the current findings on working memory training. The strength of this volume is the inclusion of various techniques in, and perspectives on, working memory training. Consideration of different perspectives is critical for advancing understanding of the overall efficacy and effect size of working memory training. Identifying the commonalities in results and focusing on key differences in theoretical perspectives, methodologies, and outcomes will lead to more focused developments in the field.

References

Biederman, I., Cooper, E. E., Fox, P. W., & Mahadevan, R. S. (1992). Unexceptional spatial memory in an exceptional memorist. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(3), 654–657. doi:10.1037//0278-7393.18.3.654

Campbell, D. T., & Stanley. J. C. (1966). *Experimental and quasi-experimental designs for research*. Boston, MA: Houghton Mifflin.

Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: Training and transfer effects with a complex working memory span task. *Psychonomic Bulletin & Review, 17*(2), 193–199. doi:10.3758/PBR.17.2.193

Conway, A. R., Jarrold, C. E., Kane, M. J., Miyake, A., & Towse, J. N. (2007). *Variation in working memory*. Oxford, UK: Oxford University Press.

Dougherty, M. R., Hamovitz, T., & Tidwell, J. W. (2016). Reevaluating the effectiveness of N-back training on transfer through the Bayesian lens: Support for the null. *Psychonomic Bulletin and Review, 23*(1), 306–316. doi:10.3758/s13423-015-0865-9

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 44, pp. 145–199). New York, NY: Elsevier Science. doi:10.1016/S0079-7421(03)44005-X

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128*(3), 309–331. doi:10.1037//0096-3445.128.3.309

Ericsson, K. A., Delaney, P. F., Weaver, G., & Mahadevan, R. (2004). Uncovering the structure of a memorist's superior "basic" memory capacity. *Cognitive Psychology, 49*(3), 191–237. doi:10.1016/j.cogpsych.2004.02.001

Gathercole, S. E., Dunning, D. L., & Holmes, J. (2012). Cogmed training: Let's be realistic about intervention research. *Journal of Applied Research in Memory and Cognition, 1*(3), 201–203. doi:10.1016/j.jarmac.2012.07.007

Green, C. S., & Bavelier, D. (2012). Learning, attentional control and action video games. *Current Biology, 22*(6), 197–206. doi:10.1016/j.cub.2012.02.012

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science, 24*(12), 2409–2419. doi:10.1177/0956797613492984

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*(4), F9–F15. doi:10.1111/j.1467-7687.2009.00848.x

Holmes, J., Gathercole, S. E., Place, M., Dunning, D. L., Hilton, K. A., & Elliott, J. G. (2010). Working memory deficits can be overcome: Impacts of training and medication on working memory in children with ADHD. *Applied Cognitive Psychology, 24*(6), 827–836. doi:10.1002/acp.1589

Jaeggi, S. M., Buschkeuhl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America, 105*(19), 6829–6833. doi:10.1073/pnas.0801268105

Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive Affective and Behavioral Neuroscience, 7*(2), 109–119. doi:10.3758/cabn.7.2.109

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*(2), 189–217. doi:10.1037/0096-3445.133.2.189

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention." *Journal of Experimental Psychology: Learning Memory and Cognition, 32*(4), 749–777. doi:10.1037/0278-7393.32.4.749

Klingberg, T. (2005). Training and plasticity of working memory. *Trends in Cognitive Sciences, 14*(7), 317–324. doi:10.1016/j.tics.2010.05.002

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., . . . Westerberg, H. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177–186. doi:10.1097/00004583-200502000-00010

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781–791. doi:10.1076/jcen.24.6.781.8395

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270–291. doi:10.1037/a0028228

Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer": Evidence from a meta-analytic review. *Perspectives on Psychological Science, 11*(4), 512–534. doi:10.1177/1745691616635612

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., . . . Engle, R. W. (2012). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General, 142*(2), 359–379. doi:10.1037/a0029082

Redick, T. S., Shipstead, Z., Wiemers, E. A., Melby-Lervåg, M., & Hulme, C. (2016). What's working in working memory training? An educational perspective. *Educational Psychology Review, 27*(4), 617–633. https://doi.org/10.1007/s10648-015-9314-6.

Shipstead, Z., Hicks, K. L., & Engle, R. W. (2012a). Cogmed working memory training: Does the evidence support the claims? *Journal of Applied Research in Memory and Cognition, 1*(3), 185–193. doi:10.1016/j.jarmac.2012.06.003

Shipstead, Z., Redick, T. S., & Engle, R. W. (2010). Does working memory training generalize? *Psychologica Belgica, 50*(3–4), 245–276. doi:10.5334/pb-50-3-4-245

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012b). Is working memory training effective? *Psychological Bulletin, 138*(4), 628–654. doi:10.1037/a0027473

Shipstead, Z., Redick, T. S., Hicks, K. L., & Engle, R. W. (2012). The scope and control of attention as separate aspects of working memory. *Memory, 20*(6), 608–628. doi:10.1080/09658211.2012.691519

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*(3), 498–505. doi:10.3758/BF03192720

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635–654. doi:10.1080/09658210902998047

von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: A review. *Psychological Research, 78*(6), 803–820. doi:10.1007/s00426-013-0524-6