Applied & Educational Psychology (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/appep.2025.060308
ISSN 2523-5842 Vol. 6 Num. 3

The Cognitive Effects of Working Memory Training

Wang Yifan

School of Humanities, Southeast University, Jiangsu, Nanjing, 210000, China

Keywords: Working Memory; WM; WM Training; Transfer Effects

Abstract: Working memory (WM) is a limited-capacity system responsible for the temporary storage and manipulation of information, and it is intricately linked to a broad range of higher-order cognitive functions. Given its central role in cognition, researchers have sought to enhance WM performance through training programs. While several studies report near and far-transfer effects to untrained cognitive domains such as fluid intelligence, attention, and inhibition, others raise doubts about the generalizability and longevity of such benefits. This paper critically examines empirical findings on the cognitive effects of WM training, evaluates methodological limitations in existing research, and discusses theoretical frameworks such as process-overlap theory. By reviewing controversies surrounding transfer effects, sample sizes, and experimental control, we argue that although current evidence remains inconclusive, WM training holds potential as a tool to enhance cognitive efficiency. Future research should prioritize rigorous experimental design, long-term follow-ups, and replication studies with larger samples to clarify the real-world impact of WM training.

1. Introduction

Working memory is defined as a cognitive system with limited capacity that temporarily stores and processes information. As a core component of human cognition, it enables individuals to hold, manipulate, and update relevant information in the face of interference or distraction. This functionality is essential for executing complex cognitive tasks such as reasoning, problem-solving, decision-making, and language comprehension. Given its foundational role, working memory is not only considered a pillar of cognitive architecture but also features prominently in theories of intelligence and models of executive function. Recent decades have witnessed an explosion of interest in cognitive training interventions designed to enhance working memory capacity or efficiency. The rationale for such interventions stems from evidence that WM capacity is significantly correlated with broader cognitive abilities, including fluid intelligence (Gf), selective attention, and inhibitory control. Consequently, researchers have explored whether WM training can lead to improvements not only in WM itself (i.e., near-transfer effects) but also in other untrained domains (i.e., far-transfer effects).Grounded in frameworks such as the process-overlap theory proposed by Kovacs and Conway [1], it is hypothesized that WM training may yield domain-general cognitive benefits by enhancing underlying processes—such as attentional control, interference resolution, and updating—that are shared across multiple cognitive systems. According to this view, WM is not an isolated cognitive function but one that overlaps with many other abilities due to shared executive processes. Therefore, strengthening WM through training could plausibly result in broad cognitive gains. Indeed, numerous studies have reported performance enhancements following WM training interventions, citing both near-transfer improvements in WM tasks and far-transfer effects on standardized intelligence measures such as Raven's Progressive Matrices. For example, Jaeggi et al. found that training on the dual n-back task led to significant gains in fluid intelligence, suggesting a transfer beyond the specific skills trained [2]. Similarly, Klingberg and colleagues documented improvements not only in WM tasks but also in attention regulation, particularly in populations with attentional deficits such as ADHD [3][4].

However, the evidence for these transfer effects is far from unanimous. A number of rigorous meta-analyses [5] have challenged the robustness and generalizability of WM training outcomes. Critics argue that observed improvements may reflect task-specific practice effects, placebo effects, or methodological shortcomings rather than true cognitive enhancement. Moreover, even when gains are observed, questions remain about their durability over time and applicability to real-world contexts. Thus, the current landscape of WM training research is marked by both optimism and skepticism. While some researchers advocate for the promise of cognitive training to elevate cognitive functioning across the lifespan, others caution against premature conclusions given the mixed and sometimes contradictory empirical findings. In light of these tensions, the present paper aims to provide a balanced and critical examination of how working memory training influences human cognition. Specifically, we will: (1) review evidence supporting and challenging WM training effects; (2) highlight methodological limitations and theoretical controversies; and (3) propose directions for future research that may clarify unresolved issues.

2. Evidence from Previous Studies

Before delving into the empirical findings, it is essential to revisit the foundational hypothesis underlying working memory (WM) training research: cognitive improvements in WM performance are expected to emerge following structured training interventions. This assumption is grounded in the idea that targeted cognitive exercises can stimulate neuroplastic changes or strategic adaptations that enhance the brain's capacity to temporarily store and manipulate information. Early studies provided optimistic results. For example, von Bastian and Oberauer reported in 2013 that young adults approximately can recall eight items after 20 WM training sessions, which is double the average level of normal adults [6]. This finding demonstrates that training may have the potential to elevate WM capacity beyond normative levels, at least within controlled experimental conditions. Similarly, a visual working memory training found that working memory training can enhance visual working memory capacity [4], suggesting a promising trajectory for domain-specific interventions. However, these positive findings have not remained uncontested. Moriya rejected this result in the recent research, but he found that the adjusted adaptive visual working memory training can improve the ability to allocate limited resources of visual working memory [7]. These contradictory results indicate that while improvements in WM performance may be attainable, their form—whether in capacity, allocation efficiency, or strategic deployment—varies depending on the training protocol and measurement criteria. Notably, one key implication of Moriya's findings is the distinction between increasing raw capacity and improving processing efficiency. That is, although the number of items retained may not significantly increase post-training, the precision and flexibility with which individuals utilize their WM resources can be substantially enhanced. This nuance has important consequences for how training outcomes are interpreted: performance gains may reflect qualitative shifts in strategy rather than quantitative increases in storage. Moreover, through training sessions, participants can learn some memory strategies to increase their efficiency to process more items correctly. Such strategies—like chunking, rehearsal, or attentional allocation—might not only improve WM task performance but could potentially generalize to novel tasks, depending on the overlap in cognitive demands.

Despite these positive indicators, skepticism persists. Many reviews have questioned whether training has brought improvements. In a meta-analysis study reported by Melby-Lervåg and Hulme, the performance of working memory was significantly improved after training in adults and children, but improvements did not maintain for a long time [8]. The temporality of such effects calls into question their practical utility: short-term gains with no enduring impact may offer limited value outside of laboratory settings. These conflicting conclusions reflect broader debates within cognitive psychology regarding the transferability of WM training outcomes. Some researchers argue that improved performance on post-training tasks may be attributable to increased familiarity or test-retest effects rather than genuine cognitive change. Others maintain that WM training facilitates deep learning of generalizable executive control processes, which can subsequently influence other cognitive domains. Moreover, some researches reported that we can found some close links between working memory capacity (WMC) and other cognitive skills, including fluid intelligence [2] , selective attention [3] , inhibition [9] , updating [10]. Besides, working memory capacity and intelligence share approximately 50% common variance (measured with latent variables) [11]. This body of work strengthens the rationale for exploring transfer effects: if WM and other cognitive skills are indeed statistically and mechanistically related, training interventions designed to improve WM may also affect broader cognitive outcomes. In addition, De Simoni and von Bastian [12] mentioned in their study that working memory has three mechanisms, including focus switching, removal of working memory contents, and interference resolution. These component processes have strong theoretical relevance for executive functioning. Obviously, we can found that focus switching and removal of working memory contents are closely related to attention, processing speed, and task switching, and inhibition is linked with interference resolution. Theoretically, training these core operations may generalize to cognitive control domains, which underpin many real-world tasks such as problem-solving, multitasking, and reasoning. Building upon this foundation, a large number of empirical studies have been conducted to examine potential transfer effects to untrained but cognitively adjacent skills. A study in 2002 reported that compared with the control group, the training group not only improved the performance of visual working memory but also improved the performance in similar tasks and the score in standardized intelligence test (Raven's Progressive Matrix) [4]. One of the earliest working memory training studies reported that there are transfer effects to fluid intelligence after training sessions [2]. Two recent meta-analyses claim that working memory training can effectively enhance adult cognitive skills and prevent cognitive abilities decline in older adults [13].

These findings are encouraging, particularly in the context of aging populations where maintaining cognitive functioning is a growing public health priority. Nonetheless, other scholars remain unconvinced. Some studies have also questioned those transfer effects of working memory training, arguing that there is no evidence that working memory training can improve intelligence [14][15]. In two recent studies, it has also been reported there is the lack of Bayesian evidence of transfer effects after training, both in older adults and younger adults with updating and binding Training approaches [12][16]. There is also a mate-analysis shown that working memory training does not improve the performance of intelligence and other cognitive skills [17]. And Rapport and his colleagues questioned the impact of working memory training on the real world in a mate-analysis [18]. They reported that there is no evidence that working memory training can reduce the symptoms of ADHD. These negative results have provoked critical reassessments of the field’s foundational assumptions. In a study about WM training and fluid intelligence (GF), the authors reported that although computer-based WM training usually has a significant improvement of in-lab WM training tasks, this effect can only be transferred to similar tasks, but have a weak transfer to GF [19]. According to these findings, the so-called transfer may be limited to task-specific learning and may not represent broader cognitive gains. The authors summarize the possible reasons for this result that the initial strong correlation (WM sometimes is prior information access to advanced cognitive abilities and those abilities also share cognitive resources with WM, as mentioned in the first paragraph) between GF and WM training tasks gradually decreasing in the training process. For complete tasks, participants tend to use more WM relevant strategies that result in more task-related skills and strategies are acquired by participants or the needs of WM relevant resources are gradually reduced during the task. This insight introduces a critical nuance into the discussion: as participants develop task-specific strategies, they may offload demands from WM, thereby weakening the relationship between WM training and transfer.

However, based on this assumption, researchers viewed that future research may find a way to maintain a high GF-related training process, to improve the transferability of training [19]. In addition, there is no evidence of such transfer effects may indirectly reflect that the relationship between WMC and GF is just patily-related, but not causal [20]. The extant literature on WM training paints a picture that is both promising and problematic. While certain studies suggest potential cognitive benefits, others underscore limitations in durability, generalizability, and causality. A clearer understanding of these mixed findings requires not only more rigorous methodologies but also a deeper theoretical synthesis of how and why WM training may (or may not) work.

3. Problems of previous studies

In the review of Claudia, some factors that may affect the working memory training effect were proposed, one is the difference of the training design, including intensity, duration, and method. The other is individual differences of participants, for example, biological factors and the baseline of cognitive abilities. Those two factors are also the main points of this part. Firstly, this paper wants to discuss the difference in the nature of the training regime. In recent years, there are different interventions have raised, for instance meditation [21] , video games [22] and computerized working memory training, which is the most popular and widely used [13]. Shipstead et al. pointed out two design problems in the common working memory training literature. One is that the control group did not receive similar interventions, while the training group does training sessions. The second is to assess cognitive improvements through single task (may exist Practice effect). Initially, working memory training used repetitively executed N-back tasks [2], and the improvement in task performance might be caused by practice effect. Adaptively adjusted task has been proposed that can avoid the practice effect and gradually change the task difficulty according to personal performance during training sessions. Adaptively adjusted task require participants to rely on and improve their working memory during intervention duration [23]. We can find that researchers are constantly optimizing the training sessions. In addition, the control groups receive similar tasks in recent studies, to avoid the improvements of working memory training occurring naturally rather than through training itself. Moreover, intensity and duration also cannot be ignored. One study reported that the transfer effect of working memory training to fluid intelligence depends on the number of training sessions that have been completed [2]. During the training sessions, participants may learn some memory strategies, such as chunking strategies, which require participants to be proficient before using those in daily life. Besides, experimental control is also an important problem in previous studies. For instance, researchers require participants to do each training module in a quiet environment. However, we cannot guarantee whether participants followed the experimental requirements to complete [12]. Furthermore, the different effects also depend on individual learning habits. Some participants may tend to apply their learning to daily life, but some participants are just completing the training. For individual differences, there is a common view that different populations and the cognitive baseline will affect the training effect. However, Guye et al. used three different interventions to explore individual differences [24]. In younger and older adults, they found that there was a correlation between the original cognitive ability and the training effect, but they claimed that participants with better basic cognitive ability benefit more from training, especially younger adults. Therefore, future researches need to explore a better training design, including the optimization of training intensity, duration, intervention methods, and experimental control. Whether individual differences can significantly affect the training effect need more evidence, because various psychological experiments always involve individual differences, and this problem can be improved by the increase of sample size. The large sample has better predictability. However, the sample size of cognitive training including working memory training is always small, which can affect the statistics power and research result.

A common problem in most working memory training studies is that the small sample size, approximately the average group size is n = 20 , even many studies smaller than average [17]. This makes most WM training studies lack statistical power, and the repeatability of results will be reduced. Those studies with a small sample size are largely affected by the individual differences, and the low statistical power also increases the possibility of false-negative and false-positive results [25] . Moreover, the results obtained through small samples are not convincing. Because in the study of working memory training, we can not get a causal relationship, we can only assume that the improvement of working memory and other transfer effects are related to working memory training. If the sample is too small, we cannot use the results to predict the common population.

4. Future studies

The mixed results and methodological concerns outlined in previous sections highlight the pressing need for more rigorous and theoretically grounded research on working memory (WM) training. To advance the field and resolve ongoing debates, future studies must not only refine their experimental methods but also expand the scope of inquiry. This section identifies several key areas where future research efforts should concentrate, including theory development, experimental design, sample diversity, longitudinal evaluation, real-world relevance, neural correlates, and ethical considerations.

One of the major limitations in current WM training research is the lack of strong theoretical models guiding the design of interventions and interpretation of results. Many studies operate under vague assumptions that increasing WM capacity will lead to improvements in other cognitive domains. While intuitively appealing, this hypothesis remains insufficiently specified. Future studies should anchor their work in detailed models such as the process-overlap theory [1], which posits that shared executive processes underlie the observed correlations between WM and higher-order cognition. In addition to refining existing frameworks, researchers should articulate mechanistic models that explain how training leads to change. For instance, is cognitive enhancement the result of neuroplasticity, improved strategy use, changes in attentional control, or increased motivation? By specifying mechanisms of change, researchers can design more targeted and falsifiable interventions and distinguish between structural and strategic improvements.

Future WM training studies could adopt stricter methodological standards. This includes using adequately powered sample sizes, active control groups matched for cognitive engagement, and standardized training protocols. Pre-registration of study hypotheses and procedures, along with open data sharing, will also help address the reproducibility crisis that affects many areas of psychology and cognitive science. The field would benefit greatly from agreed-upon guidelines regarding task types, training durations, and outcome measures. This would enable researchers to make meaningful comparisons across studies and conduct more informative meta-analyses. Without such standardization, the field risks continued fragmentation and interpretive ambiguity. Moreover, outcome measures should include both near and far-transfer tasks, with clearly defined operationalizations. Researchers must ensure that improvements on post-tests are not simply due to practice effects or task familiarity. The inclusion of novel transfer tasks that differ in modality and structure from the training task would provide stronger evidence for generalization.

Many current WM training studies rely heavily on university students or small, homogenous convenience samples. To ensure findings are generalizable, future research must incorporate more diverse participant populations, including children, older adults, clinical groups (e.g., individuals with ADHD, traumatic brain injury), and people from varying cultural and socioeconomic backgrounds. In addition, researchers should systematically explore how individual differences—such as baseline cognitive ability, age, motivation, sleep quality, and personality traits—moderate training outcomes. Guye et al. found that those with higher baseline WM capacity derived more benefit from training [24]. Understanding for whom and under what conditions training is most effective would enable the development of personalized or adaptive training interventions. It is also important to examine how different cognitive styles and prior experiences interact with training content. Some participants may respond more positively to visuospatial tasks, while others may excel in verbal domains. Tailoring interventions based on cognitive profiles could enhance efficacy and adherence.

Many studies assess WM gains immediately following the conclusion of training, but few track participants over time. Without follow-up testing, it is unclear whether training effects are durable or simply transient. Future studies should implement multiple follow-up assessments (e.g., 1 month, 3 months, 6 months) to evaluate the longevity of training effects. Moreover, longitudinal designs could help determine whether WM training contributes to developmental changes or prevents age-related cognitive decline. Repeated assessments over longer timeframes can also reveal whether cognitive gains translate into improvements in real-world outcomes, such as academic performance, occupational efficiency, or independent living. Longitudinal work could also explore whether booster sessions or ongoing cognitive engagement are necessary to maintain gains. Such work would have important implications for the cost-effectiveness and practical implementation of WM training programs in educational and clinical settings.

A key criticism of existing WM training research is its limited ecological validity. Many outcome measures are highly artificial and may not reflect meaningful improvements in real-life functioning. Future studies should incorporate assessments that capture everyday cognitive challenges, such as task switching at work, managing distractions in a classroom, or organizing activities in daily life. In particular, intervention studies in naturalistic environments—such as schools, homes, or workplaces—can provide more accurate estimates of training effectiveness. Researchers might also consider integrating WM training into broader educational curricula or rehabilitation programs to evaluate its additive effects. Furthermore, collecting subjective feedback from participants regarding perceived changes in cognition, emotional regulation, or daily functioning can complement objective performance data. Mixed-methods approaches combining quantitative and qualitative data can offer a more holistic understanding of WM training effects.

To move beyond behavioral data, future research should incorporate neuroscientific methods to examine the neural correlates of WM training. Structural and functional imaging (e.g., fMRI, EEG, DTI) can reveal whether training leads to changes in brain volume, connectivity, or activation patterns. For instance, changes in the dorsolateral prefrontal cortex or parietal regions could indicate neural adaptation resulting from cognitive training. Identifying neurobiological markers associated with training responsiveness could help explain individual differences and inform the design of personalized interventions. For example, baseline activity in WM-related brain regions might predict who benefits most from training. In clinical populations, changes in neural connectivity could serve as proxies for treatment effectiveness. Additionally, studies using neurofeedback or transcranial stimulation in conjunction with WM training could help isolate causal mechanisms and amplify training gains. The integration of cognitive neuroscience with intervention research holds great promise for enhancing both theoretical understanding and practical outcomes.

Cognitive training research has been disproportionately conducted in Western, educated, industrialized, rich, and democratic (WEIRD) societies. This raises concerns about the cultural generalizability of findings. Cognitive processes—including WM—are influenced by language, education systems, and socio-cultural norms. Future research should investigate whether WM training produces similar effects across cultures and languages, and whether interventions require adaptation to local contexts. For example, verbal WM tasks may be more challenging in agglutinative languages with longer syllables, which may influence training efficacy. Understanding these differences is essential for developing inclusive and globally applicable training programs.

Finally, future research must address the ethical and practical implications of WM training. If certain individuals consistently benefit more than others, what are the equity considerations for educational or clinical applications? Should WM training be offered as part of public programs, or reserved for high-performing individuals? What are the risks of overpromising cognitive enhancement in commercial platforms? Moreover, the commercialization of WM training tools (e.g., "brain games") has outpaced the scientific evidence supporting their use. Researchers must communicate findings accurately to the public and policymakers, avoiding exaggerated claims while highlighting genuine potential. Transparent reporting and consumer protection standards should be developed alongside scientific advancements.

5. Benefits of WM training studies

Working memory training research is needed and can benefit a lot. If there is some strong evidence that working memory training can improve working memory performance and have transfer effects to other untrained cognitive skills. It means that human cognition can be trained and can be improved through acquired efforts. It can also provide new insight to brain scientists, for example, whether training can change some brain structures to improve cognitive abilities or just gain more strategies. Moreover, because working memory is an important part of human cognition. If the effectiveness of working memory can be verified, even if the working memory training effect is limited to working memory itself, it also can bring many benefits to human cognition. Because working memory is closely related to many prior and advanced cognitive abilities. Even if there is a very weak and difficult to find transfer effect, working memory as a temporary information processor, its capacity and working efficiency can be trained to improve, which is undoubtedly good to the entire human cognition. Melby-Lervåg, Redick, and Hulme mentioned in the review that if it could be confirmed that working memory training have improvements in intelligence test performance, it means that working memory training would have potential implications for education and economic, as well as for theories about the nature and limitations of human cognitive abilities [17].

6. Conclusion

In conclusion, working memory, as important temporary information storage and processor, is closely related to other cognitive skills. Therefore, many studies hypothesize that working memory training can not only improve working memory itself , but also have transfer effects to other untrained cognitive skills. However, we still need more empirical research, systematic theory, and methodology support, which requires the joint efforts of psychologists and brain scientists. The current effect on working memory training is still controversial, and this type of controversy is also common in various cognitive training studies. Once the performance of working memory can be improved by training is proven, the contribution of working memory training to human cognition will be meaningful, including not only primary cognitive functions, such as attention but even higher-level cognition ability, such as reasoning and inhibition. Overall, working memory training is beneficial and meaningful to human cognition.

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