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Working memory training: mechanisms, challenges and implications for the classroom

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There is promising empirical evidence regarding the effect of working memory training for students' learning. However, this evidence primarily comes from laboratory contexts, which limits understanding of what this training involves and how such knowledge can have value in education. Further, there is considerable heterogeneity across such studies that make it difficult for researchers to determine optimal conditions for working memory training and for educators to implement working memory training that will achieve their educational goal. Grounded in the context of evidence-based practice, this review focuses on applying working memory training in schools to support students' learning and development, and the need for collaboration between researchers and educators. This review will clarify the theoretical underpinnings of training and transfer and analyse the sources of variation involved in working memory training implementation and outcomes. Building upon this reflection and on existing empirical evidence, this review will consider individual and contextual aspects (e.g., leadership, self-efficacy and school culture) that affect implementation. To support effective implementation within schools, this review discusses the need for a reciprocal researcher-educator partnership to ensure quality implementation of working memory training in the classroom.

KEYWORDS

working memory training, school-based implementation, translational studies, educational practice, challenges, experimental studies, mechanisms, school intervention

1. Introduction

1.1. The theoretical relationship between working memory and academic performance

Working Memory (WM) is a cognitive process responsible for processing and manipulating information while multitasking with other cognitive operations (Baddeley, 1992). WM is essential for directing and sustaining goal-related information despite the appearance of distracting stimuli (Schmeichel et al., 2008; Hofmann et al., 2012). Previous studies have found a positive relationship between WM and self-regulation skills, including attention (Diamond and Ling, 2020), inhibitory ability (Engle, 2002), and emotion regulation (Schmeichel et al., 2008; Xiu et al., 2018). People who score well on WM ability have demonstrated superior performance in focusing on tasks. In contrast, individuals with learning difficulties, self-regulation and attention deficits may have impaired WM and find it hard to inhibit inappropriate behaviour and effectively manipulate and combine goal-relevant information leading to variability in learning (Westerberg et al., 2004; Martinussen et al., 2005; Grégoire et al., 2012;

Van Snellenberg et al., 2016; Xiu et al., 2018). Therefore, there is a robust theoretical and empirical connection between WM and academic performance.

1.2. Theoretical mechanism of the effect of working memory training on academic performance

WM training has been implemented to enhance academic performance, given its strong association with cognitive functioning (Unsworth and Engle, 2007). Research has demonstrated significant improvements in both trained and untrained tasks after WM training, a phenomenon known as "transfer." Near transfer refers to gains in untrained but similar tasks, such as WM updating tasks (Borella et al., 2013), while far transfer refers to gains in untrained tasks that share similar cognitive processes with the training tasks, such as intelligence and verbal ability (Karbach and Verhaeghen, 2014; von Bastian and Oberauer, 2014).

Furthermore, WM training has been shown to improve functional connectivity between the prefrontal cortex and posterior parietal cortex, as well as boost dopamine levels, suggesting that it refines the functional WM network and could lead to wider cognitive gains (McNab et al., 2009; Jones et al., 2022). However, the retention of such gains and the duration of data collection are often under-specified in the literature. More consistent reporting is needed to gain a better understanding of the effect.

Several theoretical mechanisms have been proposed to explain the benefits of WM training, such as neuroplasticity and process-specific theory (Klingberg, 2009; Gathercole et al., 2016). However, these mechanisms do not fully account for the transferable effects of WM training. Söderqvist and Bergman Nutley (2015) proposed a theoretical framework comprising learning and performance routes that considers how WM training improves the ability to grasp information and engage in academic tasks, leading to the establishment of routines that can be transferred to other cognitive tasks.

Moreover, WM training can benefit brain networks that support not only cognitive but also emotional functioning (Pessoa, 2013). Emotion regulation affects learning experiences and academic success, is intertwined with many cognitive processes and provides motivation and engagement with the environment (Sutton and Wheatley, 2003; Graziano et al., 2007; Fried, 2011). WM training can strengthen and extend cognitive routines, enhance inhibitory and regulatory abilities, and improves coping with daily cognitive tasks and negative emotional experiences in the frontoparietal network (Schweizer et al., 2013).

1.3. Aims and method

Despite a considerable amount of evidence supporting the efficacy of working memory (WM) training for learning, there is still a gap in our understanding of its long-term impact in educational settings, as well as how it can be effectively delivered in the classroom and what factors influence its effectiveness in practice. The purpose of this mini review is two-fold: first, to clarify the theoretical foundations of WM training and transfer, and second, to investigate the conditions and variations in the implementation of WM training in educational contexts, including how educators perceive and deliver this training, and ultimately, how it affects student learning outcomes. Additionally, this review highlights the need for a collaborative partnership between researchers and educators to support the effective implementation of WM training in schools.

This mini narrative review therefore aimed to synthesise and summarise the key findings and challenges in the literature related to WM training in the classroom context. The search was conducted in online databases, including Web of Science, PsycINFO, PubMed, Education Resources Information Center (ERIC), and Google Scholar. The author also used snowballing methods, which included backward and ancestry techniques, to identify relevant articles by searching through their bibliographies and reference sections. Additionally, citation-tracking methods (e.g., bibliographic coupling) were utilised to identify forward-looking research.

The search strategy included a combination of relevant keywords, such as "working memory training," "implementation," "intervention," "educational practice," "classroom," "school context," "challenges," "dilemmas," "applicability," and "transferability." Boolean operators were used to refine the search, including AND, OR, and NOT.

Inclusion criteria for studies were: (1) both secondary research and empirical research studies on implementing WM training in educational settings (e.g., schools, colleges, universities) or discussing the implementation of WM training for educational practice, (2) published in peer-reviewed journals across native English-speaking countries, (3) focused on children in compulsory education from ages 5–16 years, post-16 education or students in higher education institutions, and (4) available in full-text format.

To ensure the quality and relevance of the studies included in this review, the author followed a rigorous screening process. The author conducted a preliminary search and screened articles based on their relevance to the topic and that they address the review research questions and met the inclusion criteria. The author excluded studies that did not meet the inclusion criteria. After the initial screening process, the author reviewed the full-text versions of the remaining articles to ensure they met the inclusion criteria. The author also searched the reference lists of these articles for additional relevant studies that were missed in the initial search. Finally, the author extracted relevant findings from the included articles to synthesise and summarise the key findings and challenges in the literature.

2. Exploring the limitations and debates for the transfer effect of working memory training in the classroom

While multiple benefits may be possible from WM training, implementing WM training in classroom environments is challenging.

2.1. Can transfer effects be detected after the training?

WM training has the potential to produce near transfer effects, but far transfer effects are less common. WM training has been found to be beneficial for students in areas related to language, such as reading comprehension and listening comprehension (Artuso et al., 2019), as

well as in mathematical abilities such as numerical capacities, reasoning, and arithmetic skills (Holmes et al., 2009; Kuhn and Holling, 2014; Söderqvist and Bergman Nutley, 2015), emotion regulation (Xu et al., 2021), attention level (Volckaert and Noël, 2015), and intelligence (Jaeggi et al., 2008). However, a similar volume of research evidence has shown limited or no improvement after training. For example, Dunning et al. (2013) found that while training improved spatial short-term memory, verbal WM, and visuo-spatial WM, it had no effect on verbal short-term memory (Verhagen and Leseman, 2016). Thorell et al. (2009) similarly noted that training failed to enhance attention and general fluid intelligence, with the transfer of training effects to WM capacity being limited to visuo-spatial tasks. This variability in findings is also reflected in several published reviews. Sala and Gobet's (2017) meta-analyses of experimental studies showed a robust near-transfer effect on relevant memory tasks, but only a small to moderate far transfer effect on fluid intelligence, cognitive control, mathematics, and literacy. Melby-Lervåg and Hulme (2013) and Melby-Lervåg et al. (2016) conducted meta-analyses on computerised WM training in typically developing individuals, and their findings suggest that the evidence for near transfer is mixed and the claims for far transfer effects are poorly supported. They found that short-term training effects only supported near transfer effects when they were specific to the trained task and did not generalize to other areas, such as word decoding, verbal ability, and arithmetic outcomes. As Dahlin et al. (2008) suggested, post-test gains would only be observed when the measurement tasks share the same cognitive function as the training tasks.

2.2. Can training effects be sustained?

One important factor to consider is the duration for which the effects of WM training persist. Although there is no clear consensus on what constitutes short-term or long-term retention, this literature review will provide a brief classification based on evidence from empirical studies.

2.2.1. Short-term sustainability

Holmes et al. (2009) report typically developing children with initial low WM ability showed improvements in mathematical ability and WM ability following training, and this was sustained for 6 months. Holmes et al. (2009) also identified that these improvements generalised to untrained and validated WM assessments. A further meta-analysis reported the training effect on visuospatial WM was sustained for 5 months (Melby-Lervåg and Hulme, 2013). These studies suggest that post-test and follow-up testing at 5–6 months after training may reveal a positive training effect on WM training programs.

2.2.2. Long term sustainability

Berger et al. (2020) conducted a four-year longitudinal study that found WM training to be associated with improved reading, geometry, and self-regulation skills. Dahlin et al. (2008) reported stable near transfer effects from WM training for 18 months in both young and older adults. In a double-blinded randomized controlled trial by Holmes et al. (2009), the impact of WM training on children's verbal WM ability was maintained for 12 months, along with improved visuospatial short-term memory and visuospatial WM. However, far transfer effects, such as verbal, word reading, and arithmetic, were not maintained at follow-up tests conducted 9 months after training. This variability is also reflected in meta-analyses by Melby-Lervåg and Hulme (2013) and Melby-Lervåg et al. (2016), which suggest that measures of verbal WM and far transfer effects were not maintained at follow-up tests conducted 5 and 9 months after training. In summary, while the longer-term retention of WM training effects remains mixed, it appears that the effects sustained within a short to medium period after WM training are less contested.

3. Current challenges in implementing working memory training for educational practice

3.1. A disconnection between theoretical mechanisms and practice

Although theories have attempted to explain the effects of WM training, the inconsistency in achieving transfer effects remains unclear (Jaeggi et al., 2012). A lack of investigation into how experimental and individual characteristics moderate training outcomes makes it difficult to determine whether different components of WM training follow the same mechanism and require further investigation. According to the Context Mechanism Outcome Configuration (CMOc) framework, the mechanism cannot be separated from the context and the individual's reasoning in response to the program (Dalkin et al., 2015). As per Pawson and Tilley's (1997) realist evaluation, a mechanism is not merely a theory that refers to program activities, but an interplay process that explains how a specific outcome was achieved. Therefore, given the diverse individual- and implementation-related characteristics across WM training studies, the current mechanisms are less informative for real-world application.

To better understand the underlying mechanisms that drive effective training, researchers and practitioners need to refine theoretical frameworks and create more robust experimental approaches. Factors such as different training methods, experimental settings, and individual differences of both trainees and program implementers should be considered as they contribute to the theoretical mechanisms that underlie effective training programs, which may or may not have practical value for educators.

3.2. Recognising the role of education practitioners in implementing working memory training

WM studies often overlook the roles of researchers and educators, as well as their interaction and collaboration, and the external support and resources obtained (MacMahon et al., 2022). The traditional school-based implementation follows a unidirectional partnership, where researchers disseminate and interpret findings, and educators adapt the designs to fit their educational purposes. However, this approach fails to address the research-practice gap and ecological validity of research evidence (Daniel and Pollmann, 2012; Palinkas and Soydan, 2012; Joram et al., 2020; MacMahon et al., 2022). Van Atteveldt et al. (2018) proposed a bidirectional collaborative approach that involves educators in the design and implementation of research

to facilitate research translation. However, educators and researchers have different epistemological and philosophical beliefs, and it is unclear how their perspectives may influence the decision-making process and implementation outcomes. Future research must explore how to incorporate diverse perspectives into all stages of the implementation process.

In terms of implementer-related variables, the impact of teachers' motivation and self-efficacy on implementation outcomes has been considered (Durlak and DuPre, 2008). Knowledge brokers have been proposed to help translate research into other contexts in an accessible way (Malin and Brown, 2019; Cooper et al., 2020). However, concerns exist about the necessary financial or time expenses and coordination for such support. Therefore, those involved in implementation should work collaboratively to establish contextually compatible and robust translation, taking into account various factors.

3.3. Dilemmas of translating experimental studies into classroom environments

Randomized controlled trials (RCTs) are highly valued for evaluating interventions that can inform educational decision-making (Burnett and Coldwell, 2021). However, implementing RCTs in schools can be challenging due to high attrition rates, cost-effectiveness, and potential overestimation of effect sizes due to insufficient sample sizes (Cheung and Slavin, 2016; Dawson et al., 2018). Researchers have suggested recording participant information in detail to address low response rates or high dropout rates, but such solutions may not always be contextually appropriate and require further empirical studies. Alternative methods, such as quasi-experimental designs, have been proposed but have been criticized for failing to clarify the mechanisms underlying treatment effects (Gopalan et al., 2020).

Another consideration regarding WM training within education is the issue of measurement tasks. The training effect is often calculated by by comparing performance at pre-test and post-test, but this may not sufficiently demonstrate the extent to which experimental manipulation modifies performance compared to a baseline level (Goodhew et al., 2020). Moreover, the measurement tasks adopted across studies are diverse. For example, Sánchez-Pérez et al. (2018) used the Spanish version of the Woodcock-Johnson III (WJ-III) Achievement battery to measure mathematical skills, while Oka et al.'s (2021) study used mental arithmetic, and Studer-Luethi et al. (2016) used a battery of phonological encoding, recoding, and reading comprehension to evaluate reading ability. Such varied assessments may account for inconsistencies in findings regarding the nature and timing of WM transfer effects. Furthermore, the relationship between the measurement tasks used in WM studies and academic tests in schools is not yet clear. Although the purpose of WM training is to generalize transfer from a training program to academic performance in school, experimental studies often overlook this connection.

Implementation frameworks may serve as a bridge for successful WM training implementation in school contexts. For instance, Meyers et al. (2012) Quality Implementation Framework outlines critical steps and phases throughout the implementation process, including decisions on preparations, structuring support and resources, and reflection or evaluation. Durlak and Dupre's (2008) ecological framework, which looks at factors at the community, provider, innovation, and delivery system levels and provides a clear vision for both researchers and implementers to consider relevant elements involved in the process. However, empirical research is needed to examine how these implementation frameworks are integrated, how the factors in these frameworks contribute to implementation outcomes in educational contexts and how frameworks can be adapted to examine different schools and relate to a range of practitioner-level characteristics and knowledge.

For successful implementation of WM training in education, prospective studies should incorporate an evaluation of process and a framework for assessing the quality of study design to achieve educational purposes.

4. Suggestions tied to working memory training in the classroom

Discrepancies and challenges across WM training research evidence have added to the difficulty of validating experimental results. This section presents ideas at the level of the implementation context and the implementer, respectively, and further explores the possibilities for implementation effectiveness.

4.1. Examining the reconstruction of theoretical mechanisms through the lens of realist social theory

Realist social theory underlying the CMOc framework highlights the interconnections between individuals and society. By adopting realist social theory, researchers can critique "evidence-based" claims in a more nuanced manner (Archer, 1995; Clegg, 2005). Realist social theory acknowledges that the relationship between mechanisms and outcomes is not always straightforward, and that each project implementation may activate or reconfigure pre-existing environmental mechanisms in unique ways, resulting in a variety of potential outcomes. By evaluating these outcomes, researchers can identify when and for whom the project is effective (Pawson and Manzano-Santaella, 2012). This approach has proven valuable in studying school intervention programs (Warren et al., 2020).

4.2. Exploring available approaches to support ecological validity of rigorous experimental study

The implementation of research evidence is influenced by contextual attributes (Tabak et al., 2018), such as ecological validity, which refers to the extent to which findings from a study can be applied to real-life settings (Andrade, 2018). However, the transfer of psychological research from controlled laboratory environments to educational settings can present challenges. Schmuckler (2001) proposed that ecological validity can be assessed based on three dimensions: (1) the nature of stimuli,

(2) the nature of task, behaviour, or response, and (3) the nature of the research context. Each dimension could be evaluated based on the degree of artificiality–naturality (Hoc, 2001; Schmuckler, 2001) and simplicity–complexity (Peelen and Kastner, 2014; Lappi, 2015). To improve the generalizability of research evidence, researchers can explore factors and strategies that promote ecological validity and facilitate transfer to real-world settings.

4.2.1. The nature of the task, behaviour, or response

In order to ensure the rigor of a study, strict procedures are followed in laboratory settings, but this may also introduce biases in participants' performance and undermine the study's external validity. To mitigate this issue, researchers should be attentive to participants' responses during implementation and identify contextual or implementer-related factors that may impact their responses. When measuring the transfer effects of WM training, researchers can adapt measurement scales by incorporating the characteristics of school testing content to ensure measurements are ecologically valid (van Atteveldt et al., 2018).

4.2.2. The nature of the research context

Including a process evaluation is crucial to understanding the context that underpins the findings of a study, including real-world evidence (Styles and Torgerson, 2018). To enhance ecological validity, researchers can combine the analysis of results and implementation processes from diverse contexts, focusing on the environmental stimuli that support the transferability of research findings (Highhouse, 2009). For research to be applicable to school settings, the translation of findings must be specified. This requires more than just using school examination tasks or simulating school environments in experimental settings. To increase external validity and generalisability, researchers should attend to factors such as participants' responses and task performance, specify the experimental context's characteristics, and encourage empirical evidence and enriched theory to build on validity.

4.3. Emphasising a bidirectional relationship between researchers and educators

Developing an effective evidence-based approach requires a collaborative implementation process, where educators' team building, collaboration, and leadership are critical factors (Jones et al., 2022). Ford and Sutton (2009) indicated that effective collaboration between researchers and educators is essential to enhance students' learning experiences. To promote teacher participation and collaboration with researchers, it is important to understand the factors that influence the establishment of a bidirectional partnership from the teachers' perspective (Jones et al., 2022). A key issue is how teachers with varying research skills can assume an equal and proactive collaborator role. Teachers need to understand how the research being conducted can support their teaching and professional development to engage in research (Muhonen, 2014). Therefore, offering professional development opportunities to acquire research knowledge and skills, as well as access to educational resources and tools, is crucial (Kuntz, 2013). School leaders also have an important role in establishing a culture of research and continuous learning to support teachers' research aspirations and long-term engagement with research (Cantalini-Williams et al., 2016; Cramp and Khan, 2019).

Such bidirectional relationships are informed by the interaction between the teaching team and researchers and extends to school administrators, parents, and stakeholders, whose value and investment can strengthen the implementation outcomes. Only when the agenda of teacher participation in research is given attention and prioritised by external parties can teachers' self-efficacy and agency in research be enhanced. As Boyer (1991) notes, research should conceptualise the interaction between research and teaching to promote their integration and achieve a mutually reinforcing and shaping effect.

5. Discussion and conclusion

Given the attention on integrating psychological research into education, it is imperative to identify potential challenges and explore pathways that will facilitate translation and implementation. This review summarises the challenges into three main categories: mechanisms, implementation, and implementation providers and offers prospective recommendations within each of these categories. By emphasising a dynamic, iterative, and systematic implementation process and building a bidirectional partnership, this review provides a valuable contribution to the effective translation of WM training into classrooms.

Author contributions

JS conceptualized and designed the literature review study, identified the themes and literature objectives, and conducted the comprehensive literature searches, and critically evaluated the retrieved articles for inclusion. SM and AH supervised the project, provided guidance, and contributed their sights on the organization and structure of the manuscript, they also revised the manuscript for important intellectual content. All authors read and approved the final version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Andrade, C. (2018). Internal, external, and ecological validity in research design, conduct, and evaluation. *Indian J. Psychol. Med.* 40, 498–499. doi: 10.4103/IJPSYM.IJPSYM_334_18

Archer, M. S. (1995). *Realist Social Theory*. Cambridge University Press, Cambridge

Artuso, C., Carretti, B., and Palladino, P. (2019). Short-term training on working memory updating and metacognition in primary school: the effect on reading comprehension. *Sch. Psychol. Int.* 40, 641–657. doi: 10.1177/0143034319881671

Baddeley, A. (1992). Working memory. *Science* 255, 556–559. doi: 10.1126/science.1736359

Berger, E. M., Fehr, E., Hermes, H., Schunk, D., and Winkel, K. (2020). The impact of working memory training on children's cognitive and noncognitive skills. NHH Deptartment of Economics Discussion Paper. (9).

Borella, E., Carretti, B., Zanoni, G., Zavagnin, M., and De Beni, R. (2013). Working memory training in old age: an examination of transfer and maintenance effects. *Arch. Clin. Neuropsychol.* 28, 331–347. doi: 10.1093/arclin/act020

Boyer, E. L. (1991). The scholarship of teaching from: scholarship reconsidered: priorities of the professoriate. *Coll. Teach.* 39, 11–13. doi: 10.1080/87567555.1991.10532213

Burnett, C., and Coldwell, M. (2021). Randomised controlled trials and the interventionisation of education. *Oxf. Rev. Educ.* 47, 423–438. doi: 10.1080/03054985.2020.1856060

Cantalini-Williams, M., Curtis, D., Eden-DeGasperis, K., Esposto, L., Guibert, J., Papp, H., et al. (2016). Exploring the benefits of a collaborative inquiry team in education (CITE) initiative to develop a research community and enhance student engagement. *Brock Educ. J.* 25, 56–72. doi: 10.26522/brocked.v25i1.439

Cheung, A. C. K., and Slavin, R. E. (2016). How methodological features affect effect sizes in education. *Educ. Res.* 45, 283–292. doi: 10.3102/0013189X16656615

Clegg, S. (2005). Evidence-based practice in educational research: a critical realist critique of systematic review. *Br. J. Sociol. Educ.* 26, 415–428. doi: 10.1080/01425690500128932

Cooper, A., Rodway, J., MacGregor, S., Shewchuk, S., and Searle, M. (2020). "Knowledge brokering: 'not a place for novices or new conscripts'" in *The role of knowledge brokers in education: Connecting the dots between research and practice*. eds. J. L. Malin and C. Brown (England: Routledge), 90–107.

Cramp, A., and Khan, S. (2019). The convivial space – exploring teacher learning through practitioner research. *Prof. Dev. Educ.* 45, 344–355. doi: 10.1080/19415257.2018.1431957

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., and Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science* 320, 1510–1512. doi: 10.1126/science.1155466

Dalkin, S. M., Greenhalgh, J., Jones, D., Cunningham, B., and Lhussier, M. (2015). What's in a mechanism? Development of a key concept in realist evaluation. *Implement. Sci.* 10:49. doi: 10.1186/s13012-015-0237-x

Daniel, R., and Pollmann, S. (2012). Striatal activations signal prediction errors on confidence in the absence of external feedback. *NeuroImage* 59, 3457–3467. doi: 10.1016/j.neuroimage.2011.11.058

Dawson, A., Yeomans, E., and Brown, E. R. (2018). Methodological challenges in education RCTs: reflections from England's education endowment foundation. *Educ. Res.* 60, 292–310. doi: 10.1080/00131881.2018.1500079

Diamond, A., and Ling, D. S. (2020). "Review of the evidence on, and fundamental questions about, efforts to improve executive functions, including working memory" in *Cognitive and working memory training: Perspectives from psychology, neuroscience, and human development*. eds. J. M. Novick, M. F. Bunting, M. R. Dougherty and R. W. Engle (Oxford: Oxford University Press), 143–431.

Dunning, D. L., Holmes, J., and Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? A randomized controlled trial. *Dev. Sci.* 16, 915–925. doi: 10.1111/desc.12068

Durlak, J. A., and DuPre, E. P. (2008). Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. *Am. J. Community Psychol.* 41, 327–350. doi: 10.1007/s10464-008-9165-0

Engle, R. W. (2002). Working memory capacity as executive attention. *Curr. Dir. Psychol. Sci.* 11, 19–23. doi: 10.1111/1467-8721.00160

Ford, M., and Sutton, I. (2009). Researcher/teacher collaboration: a symbiotic relationship. *Soc. Educ.* 27, 7–15. doi: 10.3316/aeipt.178219

Fried, L. (2011). Teaching teachers about emotion regulation in the classroom. Australian. *J. Teach. Educ.* 36. doi: 10.14221/ajte.2011v36n3.1

Gathercole, S. E., Dunning, D. L., Holmes, J., and Norris, D. (2016). Working memory training involves learning new skills. *J. Mem. Lang.* 105, 19–42. doi: 10.1016/j.jml.2018.10.003

Goodhew, S. C., Dawel, A., and Edwards, M. (2020). Standardizing measurement in psychological studies: on why one second has different value in a sprint versus a marathon. *Behav. Res. Methods* 52, 2338–2348. doi: 10.3758/s13428-020-01383-7

Gopalan, M., Rosinger, K., and Ahn, J. B. (2020). Use of quasi-experimental research designs in education research: growth, promise, and challenges. *Rev. Res. Educ.* 44, 218–243. doi: 10.3102/0091732X20903302

Graziano, P. A., Reavis, R. D., Keane, S. P., and Calkins, S. D. (2007). The role of emotion regulation and Children's early academic success. *J. Sch. Psychol.* 45, 3–19. doi: 10.1016/j.jsp.2006.09.002

Grégoire, S., Rivalan, M., Le Moine, C., and Dellu-Hagedorn, F. (2012). The synergy of working memory and inhibitory control: behavioral, pharmacological and neural functional evidences. *Neurobiol. Learn. Mem.* 97, 202–212. doi: 10.1016/j.nlm.2011.12.003

Highhouse, S. (2009). Designing experiments that generalize. *Organ. Res. Methods* 12, 554–566. doi: 10.1177/1094428107300396

Hoc, J. (2001). Towards ecological validity of research in cognitive ergonomics. *Theor. Issues Ergon. Sci.* 2, 278–288. doi: 10.1080/14639220110104970

Hofmann, W., Schmeichel, B. J., and Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends Cogn. Sci.* 16, 174–180. doi: 10.1016/j.tics.2012.01.006

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

Jaeggi, S. M., Buschkuehl, M., Jonides, J., and Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proc. Natl. Acad. Sci. U. S. A.* 105, 6829–6833. doi: 10.1073/pnas.0801268105

Jaeggi, S. M., Buschkuehl, M., Jonides, J., and Shah, P. (2012). Cogmed and working memory training—current challenges and the search for underlying mechanisms. *J. Appl. Res. Mem. Cogn.* 1, 211–213. doi: 10.1016/j.jarmac.2012.07.002

Jones, J. S., Adlam, A. R., Benattayallah, A., and Milton, F. N. (2022). The neural correlates of working memory training in typically developing children. *Child Dev.* 93, 815–830. doi: 10.1111/cdev.13721

Joram, E., Gabriele, A. J., and Walton, K. (2020). What influences teachers' "buy-in" of research? Teachers' beliefs about the applicability of educational research to their practice. *Teach. Teach. Educ.* 88:102980. doi: 10.1016/j.tate.2019.102980

Karbach, J., and Verhaeghen, P. (2014). Making working memory work: a meta-analysis of executive-control and working memory training in older adults. *Psychol. Sci.* 25, 2027–2037. doi: 10.1177/0956797614548725

Klingberg, T. (2009). *The overflowing brain: information overload and the limits of working memory*. Oxford University Press.

Kuhn, J. T., and Holling, H. (2014). Number sense or working memory? The effect of two computer-based trainings on mathematical skills in elementary school. *Adv. Cogn. Psychol.* 10, 59–67. doi: 10.5709/acp-0157-2

Kuntz, J. (2013). Keep calm and carry on? An investigation of teacher burnout in a post-disaster context. *N. Z. J. Psychol.* 42:57. Available at: http://www.psyc.canterbury.ac.nz/research/earthquake%20research/NZJP%2013%20Vol2%20Kuntz.pdf

Lappi, O. (2015). Eye tracking in the wild: the good, the bad and the ugly. *J. Eye Mov. Res.* 8. doi: 10.16910/jemr.8.5.1

MacMahon, S., Leggett, J., and Carroll, A. (2022). Partnering to learn: a collaborative approach to research translation for educators and researchers. *Mind Brain Educ.* 16, 79–88. doi: 10.1111/mbe.12317

Malin, J., and Brown, C. (Eds.). (2019). *The Role of Knowledge Brokers in Education: Connecting the Dots Between Research and Practice* (*1st*). England Routledge.

Martínez-Otero, V. (2007). *La buena educación: reflexiones y propuestas de psicopedagogía humanística*. La Buena Educación, Spain, 1–174.

Martinussen, R., Hayden, J., Hogg-Johnson, S., and Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *J. Am. Acad. Child Adolesc. Psychiatry* 44, 377–384. doi: 10.1097/01.chi.0000153228.72591.73

McNab, F., Varrone, A., Farde, L., Jucaite, A., Bystritsky, P., Forssberg, H., et al. (2009). Changes in cortical dopamine D1 receptor binding associated with cognitive training. *Science* 323, 800–802. doi: 10.1126/science.1166102

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

Melby-Lervåg, M., Redick, T. S., and 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. *Perspect. Psychol. Sci.* 11, 512–534. doi: 10.1177/1745691616635612

Meyers, D. C., Durlak, J. A., and Wandersman, A. (2012). The quality implementation framework: a synthesis of critical steps in the implementation process. *Am. J. Community Psychol.* 50, 462–480. doi: 10.1007/s10464-012-9522-x

Muhonen, S. (2014). Songcrafting: a teacher's perspective of collaborative inquiry and creation of classroom practice. *Int. J. Music. Educ.* 32, 185–202. doi: 10.1177/0255761413506657

Oka, M., Muta, J., Sato, K., Ikuta, E., and Iramina, K. (2021). Effect of working memory training on learning ability of high school students. In 2021 13th biomedical engineering international conference (BMEiCON) (pp. 1–4). IEEE.

Palinkas, L. A., and Soydan, H. (2012). *Translation and Implementation of Evidence-Based Practice*, Oxford. Oxford University Press.

Pawson, R., and Manzano-Santaella, A. (2012). A realist diagnostic workshop. *Evaluation* 18, 176–191. doi: 10.1177/1356389012440912

Pawson, R., and Tilley, N. (1997). "An introduction to scientific realist evaluation" in *Evaluation for the 21st Century: A Handbook*. eds. E. Chelimsky and W. R. Shadish (Thousand Oaks, CA: Sage Publications, Inc.), 405–418.

Peelen, M. V., and Kastner, S. (2014). Attention in the real world: toward understanding its neural basis. *Trends Cogn. Sci.* 18, 242–250. doi: 10.1016/j.tics.2014.02.004

Pessoa, L. (2013). *The Cognitive-Emotional Brain: From Interactions to Integration*. MIT Press, Cambridge.

Sala, G., and Gobet, F. (2017). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Curr. Dir. Psychol. Sci.* 26, 515–520. doi: 10.1177/0963721417712760

Sánchez-Pérez, N., Castillo, A., López-López, J. A., Pina, V., Puga, J. L., Campoy, G., et al. (2018). Computer-based training in math and working memory improves cognitive skills and academic achievement in primary school children: behavioral results. *Front. Psychol.* 8:2327. doi: 10.3389/fpsyg.2017.02327

Schmeichel, B. J., Volokhov, R. N., and Demaree, H. A. (2008). Working memory capacity and the self-regulation of emotional expression and experience. *J. Pers. Soc. Psychol.* 95, 1526–1540. doi: 10.1037/a0013345

Schmuckler, M. A. (2001). What is ecological validity? A Dimensional Analysis. *Infancy* 2, 419–436. doi: 10.1207/s15327078in0204_02

Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., and Dalgleish, T. (2013). Training the emotional brain: improving affective control through emotional working memory training. *J. Neurosci.* 33, 5301–5311. doi: 10.1523/JNEUROSCI.2593-12.2013

Söderqvist, S., and Bergman Nutley, S. (2015). Working memory training is associated with long term attainments in math and reading. *Front. Psychol.* 6:1711. doi: 10.3389/fpsyg.2015.01711

Studer-Luethi, B., Bauer, C., and Perrig, W. J. (2016). Working memory training in children: effectiveness depends on temperament. *Mem. Cogn.* 44, 171–186. doi: 10.3758/s13421-015-0548-9

Styles, B., and Torgerson, C. (2018). Randomised controlled trials (RCTs) in education research –methodological debates, questions, challenges. *Educ. Res.* 60, 255–264. doi: 10.1080/00131881.2018.1500194

Sutton, R. E., and Wheatley, K. F. (2003). Teachers' emotions and teaching: a review of the literature and directions for future research. *Educ. Psychol. Rev.* 15, 327–358. doi: 10.1023/A:1026131715856

Tabak, R. G., Hook, M., Chambers, D. A., Brownson, R. C., Colditz, G. A., and Proctor, E. K. (2018). "Conceptual Basis for Dissemination and Implementation Research" in *Disseminati on and Implementation Research in Health: Translating Science to Practice*. eds. R. C. Brownson, G. A. Colditz and E. K. Proctor. *2nd* ed (Oxford: Oxford University Press), 73–88.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., and Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Dev. Sci.* 12, 106–113. doi: 10.1111/j.1467-7687.2008.00745.x

Unsworth, N., and Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychol. Rev.* 114, 104–132. doi: 10.1037/0033-295X.114.1.104

van Atteveldt, N., van Kesteren, M. T. R., Braams, B., and Krabbendam, L. (2018). Neuroimaging of learning and development: improving ecological validity. *Frontline Learn. Res.* 6, 186–203. doi: 10.14786/flr.v6i3.366

Van Snellenberg, J. X., Girgis, R. R., Horga, G., van de Giessen, E., Slifstein, M., Ojeil, N., et al. (2016). Mechanisms of working memory impairment in schizophrenia. *Biol. Psychiatry* 80, 617–626. doi: 10.1016/j.biopsych.2016.02.017

Verhagen, J., and Leseman, P. P. (2016). How do verbal short-term memory and working memory relate to the acquisition of vocabulary and grammar? A comparison between first and second language learners. *J. Exp. Child Psychol.* 141, 65–82. doi: 10.1016/j.jecp.2015.06.015

Volckaert, A., and Noël, M. (2015). Training executive function in preschoolers reduce externalizing behaviors. *Trends Neurosci. Educ.* 4, 37–47. doi: 10.1016/j.tine.2015.02.001

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

Warren, E., Melendez-Torres, G. J., Viner, R., and Bonell, C. (2020). Correction to: using qualitative research to explore intervention mechanisms: findings from the trial of the learning together whole-school health intervention. *Trials* 21:806. doi: 10.1186/s13063-020-04753-w

Westerberg, H., Hirvikoski, T., Forssberg, H., and Klingberg, T. (2004). Visuo-spatial working memory span: a sensitive measure of cognitive deficits in children with ADHD. *Child. Neuropsychol.* 10, 155–161. doi: 10.1080/09297040409609806

Xiu, L., Wu, J., Chang, L., and Zhou, R. (2018). Working memory training improves emotion regulation ability. *Sci. Rep.* 8:15012. doi: 10.1038/s41598-018-31495-2

Xu, J., Deng, M., Nan, W., and Cai, D. (2021). The effects of working memory training in children revealed by behavioral responses and ERP. *Brain Behav.* 11:e2310. doi: 10.1002/brb3.2310