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Original Article

Updating and working memory training: Immediate improvement, long-term maintenance, and generalisability to non-trained tasks

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ABSTRACT

Despite the popularity of working memory (WM) and updating training, recent reviews have questioned their efficacy. We evaluated a computer-based training programme based on the Running Span and Keep Track paradigms. We assigned 111 7-year-olds with poor WM and mathematical performances to updating training, one of the two control groups, or a fourth group, who were administered Cogmed, a commercially available programme. At the immediate posttest, updating training produced only marginal improvements relative to control, but this was sustained and became significant six months post-training. Cogmed training resulted in substantial improvement at immediate posttest, but became marginal at delayed posttest. Neither type of training resulted in better performance in mathematics or generalised to other WM tasks that differed more markedly from those used during training. These findings suggest that relations between WM or updating capacity and mathematics performance may be moderated by factors that do not benefit directly from improved capacity.

1. Introduction

Working memory (WM) and updating predict children's performances in reading (e.g., Gathercole & Pickering, 2000) and mathematics (e.g., Bull & Scerif, 2001; Lee, Pe, Ang, & Stankov, 2009; St Clair-Thompson & Gathercole, 2006). WM, defined as processes or structures that allow information to be maintained and manipulated simultaneously (Baddeley, 2000), is often deemed a fundamental capacity that affects how well other higher cognitive functions are performed. Updating refers to the ability to monitor and refresh information in WM (Miyake et al., 2000). Although not conceptually synonymous, measures of WM and updating are highly correlated (Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009; St Clair-Thompson, 2011). In addition to correlational findings, experimental studies have found that accuracy of mathematical task performance is dependent on the availability of WM resources (Fürst & Hitch, 2000; Lee & Ng, 2009). A question of continuing interest is whether academic performance can be improved by increasing WM or updating capacity. In this study, we designed and evaluated the efficacy of a computerised updating training programme.

1.1. Improving working memory or updating capacities

In a seminal study, Klingberg et al. (2005) tested a computerised game-based training programme and found that it improved WM performances on both measures that were structurally similar and those that differed from tasks used during training (near and far transfer, respectively). The present version of the programme, Cogmed, consists of 12 visuo-spatial and verbal memory tasks. Because there are already a number of recent reviews on the efficacy of Cogmed and other WM related training (Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012; Wass, Scerif, & Johnson, 2012); here, we focused largely on studies conducted with children and which are of direct relevance.

A number of Cogmed studies have found near transfer effects, but far transfer effects have proven elusive. Dunning, Holmes, and Gathercole (2013), working with 8 year olds, found Cogmed improved performance on a range of untrained WM tasks, but not tasks based on classroom activities or other cognitive assessments. They also found improvement in verbal WM to be sustained for 12 months in a subgroup of participants. In contrast, Holmes, Gathercole, and Dunning (2009), working with 10 year olds, found no immediate far transfer effects to reading, mathematical

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reasoning, or intelligence, but found an improvement in mathematical reasoning scores six months after training. However, because their control group was not retested at delayed posttest, it is unclear whether the improvement can be attributed to training. Dahlin (2013) found that 9- to 12-year-old boys with attention deficits performed better than a control group in mathematics after Cogmed training. Improved posttest performance on visuo-spatial WM was also observed in the treatment group. Again, as the control group was not administered WM tasks at either pretest or posttest, it is not clear whether improvement in mathematics is due to improved WM.

A more recent study by Holmes and Gathercole (2014) found that teacher-administered Cogmed training improved performance on various WM tasks in 8 to 9 year olds. It also improved English and mathematics scores in low achieving 9 to 11 year olds. However, in their first experiment, they used a pretest–posttest design without a control group. This makes it difficult to attribute improvement in WM to training. In their second experiment, a matched group design was used without assessment of performances before and after training. Furthermore, WM was not assessed. Again, these methodological limitations make it difficult to know whether differences in the criterion measures are due to training. Bergman-Nutley and Klingberg (2014) found that Cogmed improved performances in WM, arithmetic, and a following-instructions task in 7 to 15 year olds with poorer WM and attention capacities. Their findings are encouraging, but the use of typically-developing children in the control group added some uncertainty to the interpretation of findings.

In at least one study, updating abilities were found to predict mathematics performance better than did WM (Lee et al., 2012). In updating tasks, participants are typically asked to monitor, remember, and make decisions regarding stimuli that are presented sequentially. In the n-back task, for example, participants are asked to indicate whether the current stimulus is the same as the one that appeared *n* items earlier. Jaeggi, Buschkuehl, Jonides, and Shah (2011) trained 9 year olds using a programme based on a spatial n-back task and found improved performance on the training task. However, compared to an active control group trained on general knowledge and vocabulary questions, there were no post-training differences in fluid intelligence. In contrast, their earlier studies conducted with adults using single and dual n-back tasks found far transfer effects on fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi et al., 2010). The efficacy of n-back training is controversial. A number of researchers (Chooi & Thompson, 2012; Redick et al., 2013; Thompson et al., 2013) have not been able to replicate Jaeggi et al.'s (2008) findings. Furthermore, methodological limitations in Jaeggi et al. (2008) render the findings difficult to interpret (for details, see Moody, 2009; Redick et al., 2013).

Other training studies have utilised a running span paradigm. Typically, participants are asked to recall the last items at the end of a sequence of presented stimuli. Because participants are not told the length of the sequence, updating of old with new is needed for successful performance. Working with adults, Dahlin, Nyberg, Bäckman, and Neely (2008) found training improved performance on both a running span task (similar to that used in training) and on an untrained n-back task. Zhao, Wang, Liu, and Zhou (2011) used non-adaptive running memory span training and found improvements in 9 to 11 year olds' performances on a fluid intelligence task.

In a recent study, Karbach, Strobach, and Schubert (in press) trained 8 year olds using two adaptive WM complex span tasks. They found that the training group performed better on an untrained visuo-spatial WM task and a reading ability task compared to a control group trained on a non-adaptive version of the tasks. The effect on the visuo-spatial WM task was sustained for three months. However, there were no training effects on switching, inhibition or mathematics performance.

1.1.1. Improving capacities in young children

Few studies have examined WM or updating training effects in younger children. In recent reviews, both Wass et al. (2012) and Melby-Lervåg and Hulme (2013) found that younger children benefited more from such training. However, both reviews located only a handful of studies that involved younger children. Thorell, Lindqvist, Bergman-Nutley, Bohlin, and Klingberg (2009) administered a Cogmed-based WM training programme to 4 year olds and found improvement in both trained and untrained tests of WM and attention. Bergman-Nutley et al. (2011) administered the same WM training programme to another sample of 4 year olds and found that it improved performance on WM tasks, but not on fluid intelligence measures. They did, however, find that training using non-verbal reasoning tasks improved fluid intelligence.

In more recent studies, Chacko et al. (2014) and van Dongen-Boomsma, Vollebregt, Buitelaar, and Slaats-Willemse (2014) evaluated the effects of Cogmed on children with attention deficit and hyperactivity disorder. Although Chacko et al. found improvement in short-term memory performance, neither study found improvement in WM. Another recent study on 5 year olds by Foy and Mann (2014) found that Cogmed improved visuo-spatial and verbal WM performance and self-regulation as measured by the Head-Toes-Knees-Shoulders test, but not on measures of emergent reading skills.

Apart from Cogmed training, two recent studies have examined the efficacy of other training modalities. Kroesbergen, van't Noordende, and Kolkman (2014) trained 5 year olds using WM games that were either domain general or that contained numerical content. They found both types of training improved performances on one of the WM measures and speed of quantity discrimination. Numerical WM training also improved performances on an early numeracy test. Goldin et al. (2014) trained 6 year olds on WM, planning, and inhibition. They found that compared to an active control group, trained children performed better in a cognitive flexibility measure, but not an inhibitory measure. This finding is unexpected because children were not specifically trained on cognitive flexibility. The trained children also performed better on school based language and mathematics tasks than did children in the control condition. Notably, no tests of WM were administered.

1.2. The current study

Despite a number of positive findings, there are significant concerns over the replicability of findings and the methodology used in some of the studies (e.g., Gibson, Gondoli, Johnson, Steeger, & Morrissey, 2012; Shipstead, Hicks, & Engle, 2012; Shipstead, Redick, et al., 2012). Shipstead, Redick, et al. (2012), for example, argued that a number of studies failed to provide adequate measures of WM by indexing it with only one task, confusing short-term with working memory, and using only subjective measures. They also questioned the adequacy of control groups that failed to control for the kind of sustained attention needed for WM training. One of the gaps in the literature is the relatively small number of longer term studies. Because an improvement in WM or updating capacities may only improve children's capacities to learn, longer term evaluation is needed to test whether better learning results in better academic performance. Furthermore, as pointed earlier, there is a dearth of studies on very young children, who are most likely to benefit from WM or updating training.