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Chapter 4

Improving Short-Term and Working Memory: Methods of Memory Training

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Abstract

Short-term and working memory are temporary memory systems that play important roles in children's cognitive development. Marked impairments in these memory systems characterise both children with learning difficulties and children with neurodevelopmental disorders such as attention-deficit/ hyperactivity disorder (ADHD). The present chapter discusses two methods of improving short-term and working memory in typically developing children and children with ADHD. The first method involves working memory strategy training. Research has revealed that computerised training of strategies including rehearsal and visual imagery improves children's working memory. Training has also been found to improve performance on a task of remembering and following instructions, suggesting that memory strategy training has the potential to improve children's classroom performance. The second method involves providing direct training and practice on working memory tasks. Such training leads to gains in both short-term and working memory and reductions in teacher and child ratings of problem behaviours associated with ADHD. The effects of both memory training methods are discussed in terms of implications for educational practice and clinical policies relating to the management of children with memory problems.

Introduction

Researchers have long been concerned with identifying cognitive mechanisms that are important in supporting learning and development throughout the childhood years. Such mechanisms include short-term and working memory, systems responsible for maintaining information over brief periods of time. The term short-term memory is typically used to refer to systems specialised for the temporary storage of information within particular informational domains. In contrast, the term working memory is used to describe a more complex system responsible for both the processing and storage of information during cognitive tasks (e.g. Baddeley, 1986; Baddeley and Hitch, 1974). Working memory is thus essential for complex cognitive processes such as spoken and written language comprehension, mental arithmetic, reasoning, and problem solving (e.g. Baddeley, 1986).

There are several theoretical models of working memory which differ in their views of the nature, structure, and function of the memory system (e.g. for a review see Conway, Jarrold, Kane, and Towse, 2007; Miyake and Shah, 1999). However, according to one of the most widely accepted models (Baddeley, 2000; Baddeley and Hitch, 1974) working memory consists of four components. There are two domain specific short-term memory systems; the phonological loop that is responsible for the maintenance of auditory information, and the visuo-spatial sketchpad that is specialised for dealing with visual and spatial information. These are governed by a central executive system, often likened to a mechanism of attentional control (e.g. Engle and Kane, 2004; Engle, Kane, and Tuholski, 1999; Kane, Conway, Hambrick, and Engle, 2007, Kane and Engle, 2000; Kane, Hambrick, and Conway, 2005). This is a domain-general system responsible for holding and manipulating information from long-term memory, coordinating performance on separate tasks, switching between retrieval strategies, and inhibiting irrelevant information (e.g. Baddeley, 1996; Baddeley, Emslie, Kolodny, and Duncan, 1998). The fourth component, the episodic buffer, is responsible for integrating information from the subcomponents of working memory and long-term memory (Baddeley, 2000).

An individual's short-term memory is commonly assessed using tasks which require the immediate recall of information. For example, within the framework of the multiple-component model of working memory (Baddeley, 2000; Baddeley and Hitch, 1974) the phonological loop can be assessed using the digit recall task, in which participants are presented with series of digits and asked to recall them in the same order. The visuo-spatial sketchpad can be assessed using the block recall task, in which participants are asked to recall a sequence previously tapped by an experimenter on an array of wooden blocks. Working memory capacity, however, is assessed using tasks which require both the processing and storage of information. For example, in listening recall (Daneman and Carpenter, 1980) participants make judgments about the meaning of each of a series of sentences, and then attempt to recall the final word of each sentence in sequence. Within the multiple- component model of working memory (Baddeley, 2000; Baddeley and Hitch, 1974) storage is considered to employ the domain-specific storage systems with processing drawing upon executive attentional resources (e.g. Baddeley and Logie, 1999; Duff and Logie, 2001; LaPointe and Engle, 1990; Swanson and Howell, 2001).

Children's performance on measures of working memory serves as a useful predictor of a number of cognitive skills, including literacy (e.g. De Jong, 1998; Swanson and Berninger, 1995; Swanson, 1994), mathematics (e.g. Bull and Scerif, 2001; De Stefano and LeFevre, 2004**;** Mayringer and Wimmer, 2000; Siegel and Ryan, 1989), and comprehension (e.g. Cain, Oakhill and Bryant, 2004; Nation, Adams, Bowyer- Crain and Snowling, 1999; Seigneuric, Ehrlich, Oakhill and Yuill, 2000). Between the ages of 7 and 14 years working memory scores are also significantly related to performance on national curriculum assessments in England, in which all children in state schools are classified according to nationally expected standards in terms of their performance in English, mathematics, and science (Gathercole, Brown, and Pickering, 2003; Gathercole and Pickering, 2000; Gathercole, Pickering, Knight, and Stegmann, 2004; Jarvis and Gathercole, 2003; St Clair-Thompson and Gathercole, 2006). Scores on working memory tasks are typically more closely associated with measures of scholastic attainment than scores on short-term memory tasks (e.g. Daneman and Carpenter, 1980; Daneman and Merickle, 1996; Engle, Tuholski, Laughlin, and Conway, 1999). However, there is a specific link between verbal short-term memory and language acquisition in both the native and a foreign language (e.g. Baddeley, 2003; Baddeley, Gathercole, and Papagno, 1998; Gathercole, Hitch, Service, and Martin, 1997; Service and Craik, 1993; Service and Kohonen, 1995). Performance on measures of both verbal and visuo-spatial short-term memory are also related to arithmetic and mathematics (e.g. DeStefano and LeFevre, 2004; Swanson and Kim, 2007).

The links between working memory and academic attainment occur because working memory is used to store, process, and integrate information during complex and demanding activities (e.g. Just and Carpenter, 1992). Such activities are common in the school classroom. Imagine, for example, multiplying two numbers. The numbers need to be held in a short-term store whilst using learned multiplication rules to perform the calculation. Similarly, during reading comprehension text has to be maintained whilst it is processed to uncover its meaning. Other tasks that place heavy demands upon working memory include remembering and following lists of instructions and keeping track in complex tasks. Children with a poor working memory typically struggle in these activities and over time these learning failures disrupt the normal incremental process of acquiring skill and knowledge throughout the school years, leading to poor educational progress. (Gathercole, Lamont and Alloway, 2006).

Memory difficulties also accompany a wide range of learning and neurodevelopmental disorders. Children with learning difficulties typically perform poorly on both simple and complex span tasks designed to tap both the central executive and domain-specific storage components of working memory (Alloway, Gathercole, Adams and Willis, 2005). Furthermore, very low levels of performance on working memory tasks are common in children with specific difficulties in either reading or mathematics. Those with general reading difficulties typically struggle with tasks designed to tap the central executive (Gathercole, Alloway, Willis and Adams, 2006; Swanson, 1993), while those with dyslexia perform at or below average on both short-term memory and working memory tasks in the verbal domain (Jeffries and Everatt, 2003, 2004; Pickering and Chubb, 2005). Similar deficits are observed in children with specific language impairments (SLI) (Archibald and Gathercole, 2006; Ellis Weismer, Evans and Hesketh, 1999; Montgomery 2000a, 2000b). Children with mathematical difficulties also show signs of working memory deficits (Geary, 1993; Swanson and Beebe-Frankenberger, 2004). These children typically perform poorly on measures of visuo-spatial short-term memory and central executive functioning (Gathercole and Pickering, 2000; Geary, Hoard and Hamson, 1999; McLean and Hitch, 1999; Siegel and Ryan, 1989), but not on measures of verbal short-term memory (McLean and Hitch, 1999; Passolunghi and Siegel, 2004).

Impairments in memory are also associated with a variety of neurodevelopmental pathologies in children. These range from genetic disorders, such as Downs and Williams syndrome, to behavioural difficulties, such as attention-deficit hyperactivity disorder (ADHD). There is considerable evidence for marked deficits in verbal short-term memory among children with Down syndrome (e.g. Jarrold, Baddeley and Hewes, 1999). These children typically perform at age-appropriate levels on visuo-spatial short-term memory tasks and do not appear to have deficits in working memory when compared to controls (Numminen, Service, Ahonen and Ruoppila, 2001; Pennington, Moon, Edgin, Stedron and Nadel, 2003). In marked contrast to children with Down syndrome, those with Williams syndrome have much stronger verbal short-term memory than visuo-spatial short-term memory skills (Jarrold, Baddeley, Hewes, and Phillips, 2001). Alloway (2007) found that children with developmental co-ordination disorder (dyspraxia) also show deficits in the visuo-spatial domain. She reported that this population performed significantly worse on visuo-spatial short-term memory and working memory tasks than on verbal short-term memory tasks. A similar pattern of memory deficits has also been observed in children with ADHD, a disorder which is the focus of one of the memory training studies discussed in this chapter.

Attention deficit hyperactivity disorder (ADHD), defined by developmentally inappropriate levels of inattentive and/or hyperactive/impulsive behaviour, is primarily associated with cognitive impairments in executive function (Barkley, 1997). Crucially, these impairments include substantial deficits in working memory. Although children with ADHD typically perform within age-expected levels on tasks that require the immediate recall of letters (Benezra and Douglas, 1988), digits (Rucklidge and Tannock, 2002) or words (Roodenrys, Koloski and Grainger, 2001), they perform below expected levels on tasks designed to measure visuo-spatial short-term memory (Karatekin and Asarnow, 1998; McInnes, Humphries, Hogg-Johnson and Tannock, 2003; Mehta, Goodyear, Sahakian, 2004; Tripp, Ryan and Pearce, 2002). These difficulties have been shown to persist after controlling for individual differences in age and IQ (Barnett, Maruff, Vance, Luk, Costin, Wood et al., 2001). Individuals with ADHD tend to perform below age-expected levels on working memory tasks that measure their ability to control and sustain attention in the face of interference or distraction, independent of IQ or co-morbid language difficulties (e.g. Barnett et al., 2001; Martinussen and Tannock, 2006; McInnes et al., 2003; Willcutt, Pennington, Chhabildas, Olson and Hulslander, 2005). These impairments are typically more severe in the visuo-spatial than the verbal domain (e.g. Martinussen, Hayden, Hogg-Johnson and Tannock, 2005; Roodenrys, 2006).

In summary, short-term and working memory play important roles in children's learning and scholastic attainment. Working memory deficits are also associated with a wide range of learning and neurodevelopmental disorders, such as ADHD. This is important as poor working memory function can pose a huge challenge for learning in the classroom. Recent research has therefore been concerned with identifying methods of ameliorating the difficulties that arise from poor short-term or working memory.

One approach to minimising the chance of children failing on learning activities due to poor working memory is for teachers to manage memory loads in the classroom. The storage demands of classroom tasks can be reduced by restructuring multiple step tasks into separate independent steps, frequently repeating important information, and using external memory aids such as notes on the teacher's board or useful spellings (e.g. Alloway, 2006; Gathercole and Alloway, 2004). The demand of tasks upon the processing components of working memory can also be reduced by simplifying linguistic structures or reducing the length of sentences used, and increasing the meaningfulness and familiarity of material to be processed.

A related approach, which has been researched in education, is to minimise the executive demands of tasks by reducing the need for inhibitory processes (for a review see Dempster and Corkhill, 1999). This can involve exposing children to information in depth, encouraging them to form links between existing and new knowledge (e.g. Dempster, 1993; Eylon and Linn, 1988; Newmann, 1988; Porter, 1989), and completing one topic before moving on to the next (e.g. Reder and Anderson, 1980). Teachers can also teach strategies to help students discriminate similar material. For example, different teaching methods can be used for similar information or students can be encouraged to think about material in different ways. This helps to provide cues that enable children to selectively access relevant information (e.g. Chandler and Gargano, 1995).

An alternative approach to dealing with poor working memory, which is the main focus of this chapter, is to remediate working memory directly. One method of doing so is to teach children to use memory strategies that allow them to use memory more efficiently. A second method involves providing direct training and practice on working memory tasks. Each of these methods will be discussed in turn.

Memory Strategy Training

Background

Strategies are mentally effortful, goal-directed processes that are adopted to enhance memory performance. Employing strategies can result in improved performance on measures of both short-term and working memory. For example, a number of studies have demonstrated improvements on short-term memory tasks when participants engage in rehearsal (e.g. Broadly, MacDonald, and Buckley, 1994; Gardiner, Gawlick, and Richardson-Klavehn, 1994; Rodriguez, and Sadoski, 2000), visual imagery (e.g. De La Iglesia, Buceta, and Campos, 2005), creating stories from information to be remembered (e.g. McNamara and Scott, 2001) and grouping of items in to conceptual categories (e.g. Black and Rollins, 1982; Carr and Schneider, 1991; Lange and Pierce, 1992). Studies with adults have also revealed beneficial effects of strategy use on working memory tasks, involving both processing and storage. For example, Turley-Ames and Whitfield (2003) instructed participants to use either rehearsal, visual imagery, or a semantic strategy during an operation span task. Working memory scores increased as a result of each strategy (see also McNamara and Scott, 2001).

Strategies are thought to be at least partly responsible for developmental increases in working memory (e.g. Gathercole, 1999). Young children do not spontaneously employ strategies. For example, rehearsal does not emerge until about 7 years of age (e.g. Gathercole, 1998; Gathercole, Adams, and Hitch, 1994; Gathercole and Hitch, 1993), with strategies such organisation, grouping (e.g. Bjorkland and Douglas, 1997) and chunking (e.g. Ottern Lian, and Karlsen, 2007) not developing until later. However, children will attempt to employ strategies when explicit instructions are given (e.g. Ornstein, Baker-Ward and Naus, 1988; Ornstein and Naus, 1985), and are able to transfer their strategies and use them in non-trained tasks when instructional procedures include metacognitive and motivational components (e.g. Cox, 1994; Lange and Pierce, 1992; Pierce and Lange, 2001). Thus training young children to employ memory strategies could facilitate their ability to remember information across a variety of cognitive tasks.

One way of providing memory strategy training involves computer-based teaching and practice of memory strategies. For example, *Memory Booster* (Leedale, Singleton, and Thomas, 2004) is an enjoyable adventure game for children that teaches and encourages the use of rehearsal, visual imagery, creating stories, and grouping. Rehearsal is the simple repetition of verbal information. Visual imagery involves creating pictures in the mind to represent information that has to be remembered. Creating stories refers to generating a narrative that links together information in the form of a story. Finally, grouping involves using higher-order conceptual categories such as 'living things' to group items together. The program can be used with children aged four and over and is also suitable for children with special educational needs who have problems with memory and learning.

Memory Booster begins with an introductory story and then provides instructions about the strategy of rehearsal. Each player is then asked to remember, over a short delay, an item specified verbally by the computer. They respond by using the computer mouse to select the target amongst a number of distracters (targets and distracters are all pictures). After a number of trials instructions about visual imagery are provided and then players are asked to remember two objects on each trial using this strategy. Instructions to a third memory strategy, creating stories, are then followed by trials which involve remembering three items. If a child successfully progresses through the program the levels then increase, to remembering 4, 5, or 6 items. Children who perform particularly well also progress to being taught the strategy of grouping. Throughout *Memory Booster* children receive verbal encouragement and feedback from the computer, and upon completing each level they gain rewards in the form of watching cartoons.

In a recent study (St Clair-Thompson, submitted) we explored the effects of *Memory Booster* on children's short-term and working memory. *Memory Booster* was found to be beneficial to working memory in children aged 6-7 years. In a second study we then explored the effects of *Memory Booster* on an everyday classroom task, involving remembering and following instructions. Memory strategy training was found to improve performance, suggesting that *Memory Booster* has the potential to improve performance on classroom tasks. The data presented here are a summary of the two studies.

Study 1

Method

The participants were forty four children aged 6-7 years (mean 6 years 8 months, SD 4 months) and forty three children age 7-8 years (mean 7 years and 8 months SD 3 months). Each participant completed four measures of memory, designed to tap the phonological loop, visuo-spatial sketchpad and central executive components of working memory. The measures were taken from the Working Memory Test Battery for Children (WMTB-C, Pickering and Gathercole, 2001).

The phonological loop was assessed using the digit recall task, in which participants were asked to recall sequences of digits spoken aloud by the experimenter. The visuo-spatial sketchpad was measured using the block recall task, which requires participants to recall sequences tapped out on blocks by the experimenter.

Two tasks were used to tap the central executive; listening recall and counting recall. In the listening recall task participants heard a series of sentences and were asked to judge the veracity of each. At the end of each trial they were asked to recall the final word from each sentence in sequence. In the counting recall test participants were asked to count the number of items in a series of arrays and then recall the successive tallies of each array. In each of the four tasks testing began with a list length of one item to remember. This was then increased by one item every six trials, or after four correct responses at a list length. Testing was discontinued when three incorrect responses were given within a block. Standardised scores were then calculated for each participant.

Each participant completed the memory measures twice, with a period of 12 weeks in between. During the 12 weeks half of the children used *Memory Booster* whilst the other received no intervention. Each child in the intervention group used the *Memory Booster* program on 18 occasions whilst being supervised by the class teacher.

In order to minimise instructional differences between classes that were not due to *Memory Booster* the teachers were asked not to actively encourage children to use the strategies from the program outside of the training sessions. In addition, the teachers of both the intervention and control group reported both before and after the study that they did not teach memory strategies in the classroom.

Results

A series of 2x2 ANOVAs were conducted to examine the effects of memory strategy training on both short-term and working memory in the intervention and control groups. For children aged 6-7 years *Memory Booster* did not result in any significant improvements on the tasks assessing short-term memory ($p > .05$ in each case). However, contrasting findings emerged for the tasks assessing working memory. For the listening recall task there was no significant effect of group, $F\ (1, 38) = 3.40$, $p > .05$, η^2 .08. However, performance improved from stage 1 to stage 2 of the study, $F\ (1, 38) = 16.55$, $p <.01$, η^2 .30, (means of 95.45 and 104.05 respectively), and there was a significant interaction between stage of testing and group, $F\ (1, 38) = 5.99$, $p < .05$, η^2 .14. As shown in Figure 1 there was a greater improvement in scores between stage 1 and stage 2 in the intervention group than in the control group.

For the counting recall task there was no significant effect of group, $F\ (1, 38) = 3.32$, $p > .05$, η^2 .08, nor a significant difference between scores at stage 1 and stage 2 of the study, $F\ (1, 38) = 2.64$, $p >.05$, η^2 .07. There was, however, a significant interaction, $F\ (1, 38) = 4.05$, $p < .05$, η^2 .10. As shown in Figure 2 there was an improvement in scores between stage 1 and stage 2 in the intervention group but not in the control group.

In contrast to the results for children aged 6-7, *Memory Booster* did not lead to significant improvements in either short-term or working memory in children aged 7-8 years ($p > .05$ in each case).

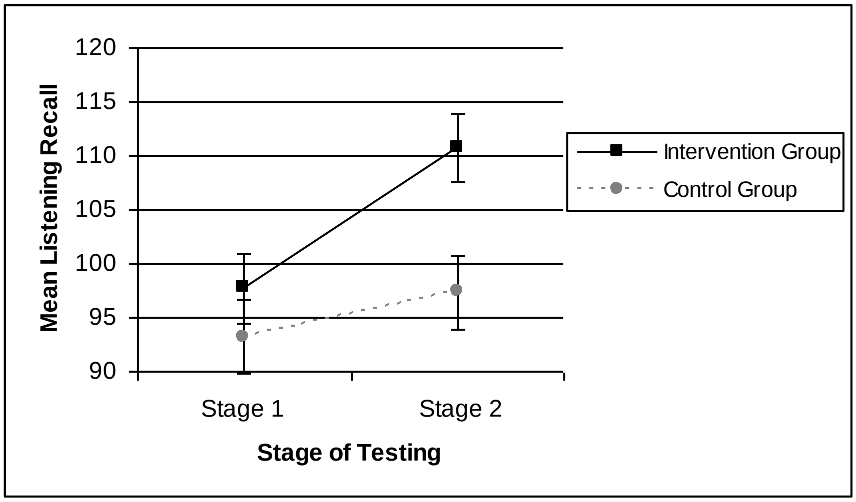


Figure 1. Interaction between stage of testing and group for listening recall.

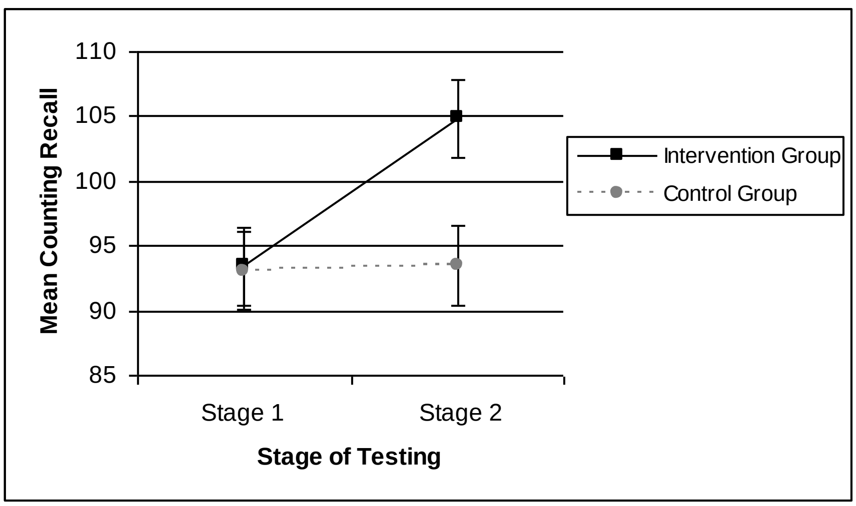


Figure 2. Interaction between stage of testing and group for counting recall.

Discussion

The results revealed that for children aged 6-7 years *Memory Booster* lead to significant improvements on working memory tasks, assessing both the storage and processing components of working memory (Baddeley, 2000; Baddeley and Hitch, 1974). The performance gains observed approached one memory item. Given that the mean score of 6-7 year olds on listening recall is only 1-2 items, and their mean score on counting recall is 2-3 items (e.g. Pickering and Gathercole, 2001) then this improvement is relatively large. This gain is also consistent with that found in previous studies that have encouraged strategy use (e.g. Conners, Rosenquest, and Taylor, 2001).

Although there were significant improvements on working memory tasks, however, there were no significant improvements on short-term memory tasks, assessing the phonological loop and visuo-spatial sketchpad components of working memory (Baddeley, 2000; Baddeley and Hitch, 1974). The improvements in digit recall in the intervention group compared to the control group were approaching significance. However, there were no improvements in performance on the block recall task. It is likely that this is a result of the strategies taught in *Memory Booster* exhibiting a degree of domain specificity.

The program teaches the strategies of rehearsal, visual imagery, creating stories and grouping. However, each time a child practices using a strategy they are presented with information in a verbal format. Children may not be able to generalise strategies from one domain to another (e.g. Brown, Bransford, Ferrara, and Campione, 1983), or alternatively the strategies might not be appropriate for the block recall task. For example, one effective strategy during block recall is spatial chunking (e.g. De Lillo, 2004; Gobet, Lane, Crocker, and Cheng et al., 2001; Ridgeway, 2006), which is distinct from the strategies taught in *Memory Booster.*

The findings that memory strategy training improved children's performance on non-trained working memory tasks has important implications for education. Given the theoretical links between working memory and children's learning and school attainment (e.g. Gathercole et al., 2003; Gathercole and Pickering, 2000; Gathercole et al., 2004; Jarvis and Gathercole, 2003; St Clair-Thompson and Gathercole, 2006), it seems reasonable to suggest that strategy based improvements in working memory have the potential to improve children's scholastic performance.

For example, improvements in working memory may allow children to better remember task instructions (e.g. Engle, Carullo, and Collins, 1991; Gathercole and Alloway, 2004), leading to tasks being completed more efficiently. Previous research has explored this suggestion in children with Specific Language Impairment. Gill, Klecan-Aker, Roberts, and Fredenburg (2003) found significant and lasting improvements in the ability to follow instructions in children who were taught a rehearsal strategy that involved visualising the instructions. However, the extent to which memory strategy training could improve classroom performance for all children is unclear. This issue is explored in study 2.

It is, however, important to note that in contrast to the findings from children aged 6-7 years, in the current study memory strategy training did not improve memory for children aged 7-8. There were no significant improvements on tasks assessing the phonological loop, visuo-spatial sketchpad, or central executive. One possible reason for this finding is that these children already employed effective memory strategies before using *Memory Booster*. There is evidence to suggest that children start to use rehearsal from 7 years of age (e.g. Gathercole, 1998; Gathercole, et al, 1994; Gathercole and Hitch, 1993).

Other memory strategies also increase with age so may have been employed more frequently by children in the older age group, including organisation and grouping (e.g. Bjorkland and Douglas, 1997) and chunking (e.g. Ottern Lian, and Karlsen, 2007). If the children were already employing effective memory strategies before the training then *Memory Booster* is unlikely to have lead to any further benefits. This possibility is explored in study 2.

Study 2

Method

The participants were thirty six children aged 6-7 (mean 7 years 2 months, SD 3 months) and forty one children age 7-8 (mean 8 years 3 months, SD 3 months). Each participant completed three working memory tasks. Digit recall was administered to assess the phonological loop, and backwards digit recall and listening recall were administered to assess both the storage and central executive components of working memory. The structure of testing for the digit recall and listening recall tasks was the same as that described in study 1. The backwards digit recall task (WMTB-C, Pickering and Gathercole, 2001) required participants to recall series of digits in reverse order. Tasks tapping the visuo-spatial sketchpad were not included based on the findings of the previous study.

Participants also completed a task involving remembering and following instructions. The task was constructed for the purposes of the study, based on measures used by Kaplan and White (1980) and Engle et al. (1991). The instructions consisted of classroom directions that were classified according to the number of behaviours and qualifiers that an individual was required to follow. For example, “point to the picture at the top of page three and copy it twice” is a 2 + 3 instruction (i.e. an instruction based on two behaviours and three qualifiers), where “point” and “copy” are the behaviours and “at the top”, “page three” and “twice” are qualifiers. Following two practice trials, 25 instructions of various lengths were given. The participants were instructed to listen to each instruction read by the experimenter and then try to follow it as best as they could. The test was discontinued if a child made errors in completing more than half of the behaviours and qualifiers in three consecutive trials. The score awarded was the total number of behaviours and qualifiers performed. Test- retest reliability calculated as the correlation between scores at stage 1 and stage 2 of testing was .71. Split- half reliability, calculated as the correlation between scores on odd and even numbered trials, was .67.

After completing each of the working memory tasks and the instructions task participants were then asked how they had attempted to remember the information required. Based on the procedure used by McNamara and Scott (2001) strategies were rated on a five point scale: 0 = no strategy used, 1 = rehearsal, 2 = visualisation, 3 = a combination of rehearsal with more semantic processing, 4 = semantic processing such as relating words to self or making up stories. The number of participants in both the control and intervention groups employing each strategy was then examined.

Each participant completed all the measures twice, 6 weeks apart. During the 6 weeks each participant used *Memory Booster* on 12 occasions. As in study 1, teachers were asked not to actively encourage children to use the strategies from *Memory Booster* outside of the training sessions and teachers of both the intervention and control group reported that they did not usually teach memory strategies in the classroom.

Results

Regarding performance on the working memory tasks, the pattern of results was similar to that found in study 1. For children aged 6-7 years *Memory Booster* did not result in any significant improvements on the digit recall task ($p > .05$). However, contrasting findings emerged for the tasks assessing working memory. For the backwards digit recall task there was a significant effect of group, F (1, 34) = 7.96, $p < .01$, η^2 .19, with the intervention group achieving higher scores than the control group (means of 90.80 and 79.19). There was a significant effect of time, F (1, 34) = 19.31, $p < .01$, η^2 .36, with performance improving from stage 1 to stage 2 (means of 82.10 and 87.89 respectively). There was also a significant interaction between time and group, F (1, 34) = 26.18, $p < .01$, η^2 .44. As shown in Figure 3, there was a greater improvement in scores from stage 1 to stage 2 of the study in the intervention than the control group.

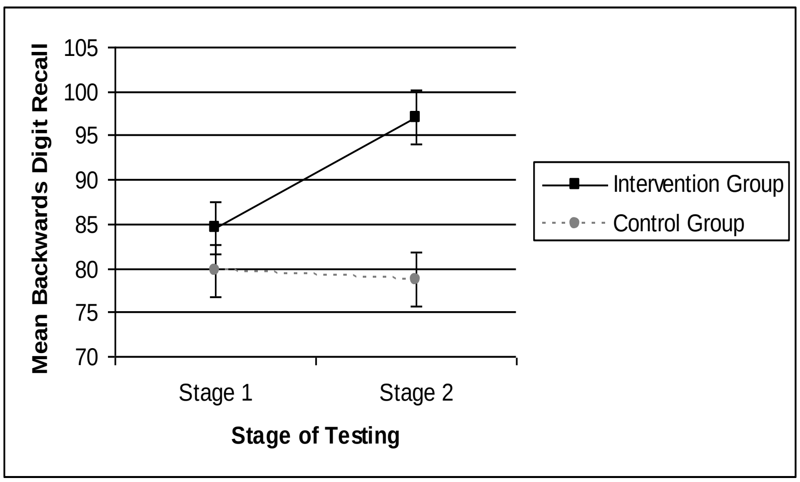


Figure 3. Interaction between stage of testing and group for backwards digit recall.

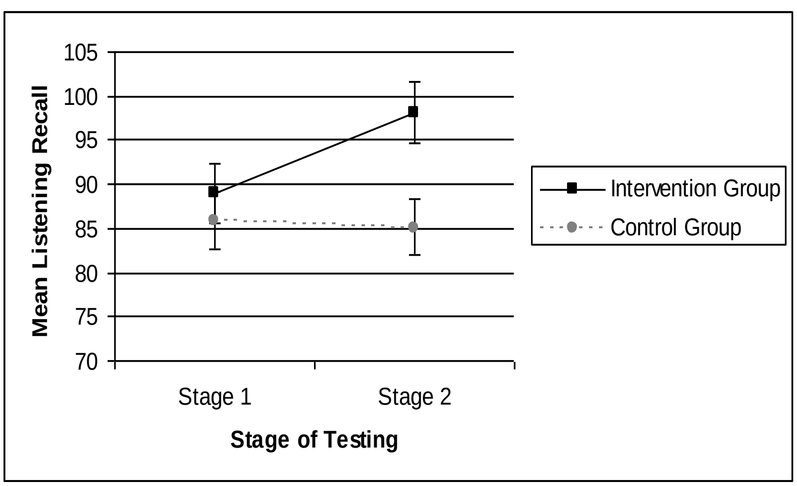


Figure 4. Interaction between stage of testing and group for listening recall.

For the listening recall task there was no significant effect of group ($p < .05$). There was, however, a significant effect of time, F (1, 34) = 5.10, $p < .05$, η^2 .13, with performance improving from stage 1 to stage 2 of the study (means of 87.32 and 91.57 respectively). There was also a significant interaction, F (1, 34) = 6.96, $p < .05$, η^2 .17. As shown in Figure 4, this resulted from a greater improvement in scores from stage 1 to stage 2 of the study in the intervention than the control group.

For the following instructions task there was a significant effect of group, F (1, 34) = 7.74, $p < .01$, η^2 .19, with the intervention group achieving higher scores than the control group (means of 114.37 and 104.48). There was a significant effect of time, F (1, 34) = 62.79, $p < .01$, η^2 .65, with performance improving from stage 1 to stage 2 of testing (means of 105.48 and 113.36). There was also a significant interaction between time and group, F (1, 34) = 29.50, $p < .01$, η^2 .47. As shown in Figure 5, there was a greater improvement in scores from stage 1 to stage 2 of the study in the intervention than the control group.

In order to examine whether the performance gains observed in the 6-7 year old children were indeed a result of the children learning to use memory strategies the self-reports of strategy use were then examined. In the first stage of testing 15 participants in the control group reported using no strategy. 4 participants reporting using rehearsal and 2 participants reported using visualisation. None of the participants reported using semantic strategies. Strategy use remained unchanged between stage 1 and stage 2. In the intervention group at stage 1 of testing 12 participants reported using no strategy and 3 reported using rehearsal. None of the children reported using visualisation or semantic strategies. At stage 2 of testing, however, strategy use had increased and only 2 participants reported using no strategies. Nine participants reported using rehearsal, and 4 reported using visualisation.

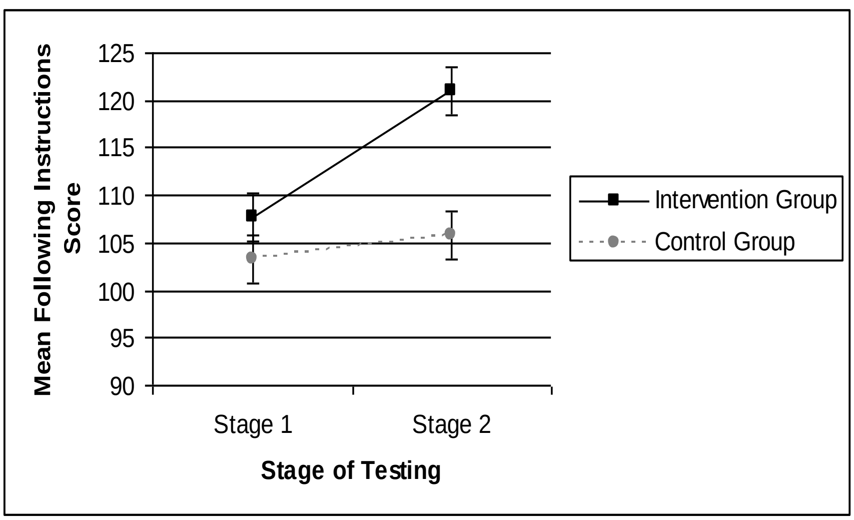


Figure 5. Interaction between stage of testing and group in the instructions task.

In contrast to the results for children aged 6-7, *Memory Booster* did not lead to significant improvements in short-term memory, working memory, or following instructions in children aged 7-8 years ($p > .05$ in each case). Regarding the reports of strategy use more children in this group reported using a strategy than in the 6-7 year old group. At stage one of testing 7 participants in the control group reported using no strategy. Ten participants claimed to have used rehearsal and 8 participants reported using visualisation. No participants reported using semantic strategies. This pattern remained unchanged between stages 1 and 2 of testing. In the intervention group at stage 1 of testing 3 participants reported using no strategies, 7 reported using rehearsal, and 6 reported using visualisation. At stage 2 of testing all the participants reported using some form of strategy with 9 using rehearsal and 7 using visualisation.

Discussion

The results revealed that for children aged 6-7 years *Memory Booster* led to significant improvements on working memory tasks, and a task involving remembering and following instructions. There were no significant improvements on the digit recall task, requiring only the storage of information. These findings are consistent with the findings of study 1 and further suggest that an improved working memory can result in enhanced classroom performance when children are required to engage in demanding tasks such as remembering and following instructions (see also Gill et al., 2003). Working memory strategy training therefore provides a potential method of remediation for working memory related failures in the classroom.

It is important to note, however, that memory strategy training did not result in improved performance on the working memory task or instructions task for children aged 7-8 years. One possible reason for this finding, as suggested in study 1, is that children in this age group were already employing effective memory strategies before the *Memory Booster* training. The self- reports of strategy use in the present study support this suggestion. For children aged 6-7 only 9 of 36 children reported using memory strategies at the first time of testing. However, for children aged 7-8 years 31 out of 41 children claimed to have used some form of strategy. This suggests that children begin to employ strategies at about 7 years of age, (see also Gathercole, 1998; Gathercole et al., 1994; Gathercole and Hitch, 1993) and that children already using strategies are unlikely to achieve higher working memory scores as a result of further memory strategy training.

The findings of the study therefore demonstrate that *Memory Booster* could provide a means of remediating working memory related failures in the classroom, but only for young children who have not acquired the use of efficient memory strategies. It may therefore be beneficial for teachers to use *Memory Booster* in schools for children aged 7 years and younger. However, it is worthy of note that in the present studies it is unclear whether the performance gains observed in 6 and 7 year olds were due to *Memory Booster per se*, or could result from any instructional program targeting strategy use. It could be beneficial for teachers to instruct children to use memory strategies in the classroom, and allow practice on appropriate tasks. For example, teachers could instruct children to use memory strategies within their curriculum subjects, to remember problem information or task instructions. Further research is therefore needed to elucidate the elements of *Memory Booster* that are effective in improving working memory and to establish whether improvements can also result from teacher-led strategy instruction.

Using computerised memory strategy training, however, may have a number of advantages. *Memory Booster* can be used by entire classes of children without teacher input.

The program also automatically adjusts the difficulty of tasks according to a child's progress, helping to maintain the correct degree of challenge and maximising children's learning. In contrast, teaching memory strategies by other methods can be a time- consuming task, and can be made difficult by children's varying degrees of ability.

Other outstanding issues which need to be addressed in further research include examining the range of classroom tasks upon which *Memory Booster* can improve performance. The present study examined children's ability to remember and follow instructions. It is also possible that improvements in working memory might result in young children being more able to sound and blend phonemes, an ability which is vital in learning to read (e.g. Goswami, 2002; Johnston and Watson, 2004). Improvements could occur in numeracy as a result of being better able to maintain numbers whilst processing, or in comprehension as a result of being better able to maintain sentences whilst writing them down. Further research is also needed to examine whether memory strategy training provides a means of improving working memory in children with special educational needs, who typically have a poor working memory (e.g. Gathercole and Pickering, 2001; Alloway, 2006).

In conclusion, the present findings suggest that memory strategy training via *Memory Booster* can improve children's working memory and can facilitate children's classroom performance. This highlights the importance of teaching memory strategies in school, particularly for children aged 7 and younger who have not yet developed the use of efficient memory strategies. Future research addressing the range of tasks upon which strategy based working memory improvements can facilitate children's classroom learning could prove productive in education.

Direct Training of Working Memory

Background

While there is now some evidence that training participants to use memory strategies improves working memory task performance, few previous studies have examined the effect of directly training working memory through repeated practice on working memory tasks.

Studies that attempted to improve working memory using this method in the 1970's and 1980's only reported moderate training gains (Kristofferson, 1972; Phillips and Nettlebeck, 1984). These were in the form of faster reaction times, not increases in working memory capacities *per se*, and there was no evidence that any gains were transferable to non-trained working memory tasks or to other cognitive measures. However, in a series of exciting new studies, Klingberg and colleagues have developed and evaluated an adaptive computerised working memory training programme, which is designed to improve working memory directly (e.g. Klingberg, Fernell, Olesen, Johnson, Gustafsson, and Dahlstrom et al., 2005). The programme works by regular participation in sessions that involve remembering sequences of verbal and spatial information, at levels of difficulty that are continuously calibrated to match a participant's memory span. To date, Klingberg and his colleagues at the Karolinska Institute have trialled the programme with three populations in Sweden, with promising results.

In their first study, Klingberg, Forssberg and Westerberg (2002) evaluated the working memory training programme in children with ADHD (*n*=7) and young adults without ADHD (*n*=4). Training enhanced performance on trained and untrained visuo-spatial working memory tasks, and on a nonverbal complex reasoning task in both groups. In comparison to a control group, motor activity, as measured by the number of head movements during a computerised test, was significantly reduced in the ADHD group, and their performance on a response inhibition task significantly improved following training. Klingberg, et al. (2005) later extended their work to evaluate the effects of training in a larger group of children with ADHD (*n*=42). Again, they reported significant increases in performance on trained and untrained visuo-spatial working memory tasks, a response inhibition task and a complex reasoning task. In addition, they reported significant reductions in parent ratings of inattention and hyperactivity / impulsivity and increased performance on a verbal working memory task. Importantly, these effects remained relatively stable for several months. Their most recent study examined the benefits of this systematic working memory training in adults more than one year after a stroke. As before, they saw significant improvements in trained and untrained working memory tasks and there was also a significant decrease in the patients' ratings of cognitive problems (Westerberg, Jacobaeus, Hirvikoski, Clevberger, Östensson, Bartfai et al., 2007).

We recently (Holmes, Gathercole, Place, Dunning, Hilton, and Elliott, submitted) conducted the first evaluation of this training programme in the UK. The primary aim of this study was to explore whether direct training could lead to generalised improvements in working memory in children prescribed stimulant medication for ADHD. To date, the programme has only been trialled with children with ADHD in Sweden in samples of children who are not on prescribed medication for their condition. It was therefore important to evaluate the effectiveness of the programme in children who receive medication to test the utility of the intervention for UK-based children with ADHD. In the Klingberg et al. (2005) training study, outcome memory measures were non-standardised tests of verbal and visuo-spatial storage, and did not include working memory span tasks that involve both processing and storage and which are most highly associated with children's learning abilities (e.g. Alloway et al., 2005). We therefore aimed to test the specificity of training effects to separate subcomponents of working memory. To this end, we systematically evaluated the benefits of training across all four major aspects of working memory; both verbal and visuo-spatial short-term memory and working memory performance, using the Automated Working Memory Assessment (AWMA Alloway, 2007; Gathercole and Pickering, 2004). This test battery provides multiple assessments of both storage-only and complex span tasks using verbal and visuo-spatial materials, and has high reliability and validity. It was therefore highly suitable to test the specificity of training effects to separate subcomponents of working memory in this study. The standardisation of the test also enabled us to quantify training gains relative to the population mean. Secondary aims of our study were to investigate the impacts of training on IQ, and on teacher assessments of problem behaviours. The data presented here are a summary of a subset of the data presented in Holmes et al. (submitted).

Method

The study was carried out in primary schools across the North East of England. Twenty-five children (21 boys, 4 girls), aged 8 – 11 years (mean 9 years, 9 months, *SD* 11 months), with a clinical diagnosis of combined-type ADHD participated in the study. All children were recruited through paediatric psychiatrists and community paediatricians according to the following inclusion criteria: i) a DSM-IV diagnosis of ADHD for six months or longer ii) receiving quick release psycho stimulant medication for ADHD (immediate release methylphenidate *n*=12; dexamfetamine *n*=3, extended release methylphenidate *n*=10). Children continued to take their medication for ADHD throughout the assessment and training sessions.

Participating children completed working memory and IQ assessments in two individual testing sessions prior to training. In the first session, children completed eight working memory tasks from the AWMA (Alloway, 2007). They completed two standardised tests each of verbal short-term memory (Digit Recall and Word Recall), visuo-spatial short-term memory (Dot Matrix and Block Recall), verbal working memory (Backwards Digit Recall and Counting Recall) and visuo-spatial working memory (Mr X and Spatial Span). All tests, presented on a laptop computer, were administered in the same order. For each task, instructions were presented as a sound file while the screen was blank. A set of practice trials followed the instructions. The test trials were then presented in blocks of six trials, starting at a span length of 1 item and increasing in difficulty by a span of 1 item every six trials. If 4 correct responses were given within in a block, the test proceeded to the next block, giving credit for any omitted trials. Testing continued until 3 incorrect responses were given in a block. The total number of correct trials was logged by the programme and standard scores were generated automatically for each task. A composite score was calculated for each aspect of working memory by averaging standard scores on the two tests.

Children completed all four subtests of the Wechsler Abbreviated Scales of Intelligence (WASI) (Wechsler, 1999) in a second pre-training session. Two of the subtests, Vocabulary and Similarities, measured verbal IQ. The other two, Block Design and Matrix Reasoning, measured performance IQ. As per the manual, the sum of verbal IQ and performance IQ *T*-scores was used to derive a full-scale IQ score.

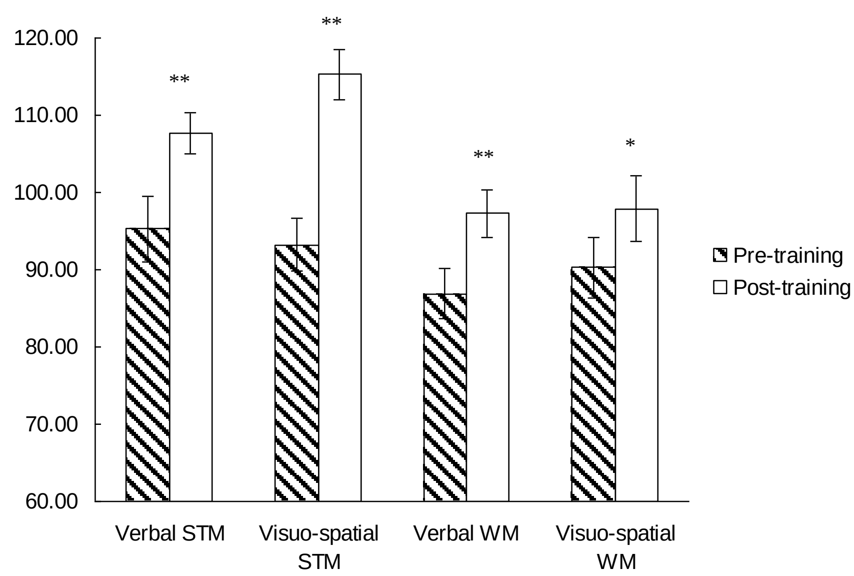
Prior to training, teachers of the participating children were asked to complete the ADHD Rating Scale (DuPaul, Power, Anastopoulos and Reid, 1998) to provide an index of problem behaviours. The children also completed a short behaviour checklist from the Robomemo (Cogmed, 2006) pack assessing everyday experience of problems known to relate to working memory.

Children then completed training on computerised working memory tasks every day for 20-25 days. These tasks entailed, for example, remembering a series of locations (e.g. lamps) that lit up one at a time on the screen. The children were required to remember the location of the objects, as well as the order in which they were highlighted. After presentation, children indicated the correct positions in the correct order by clicking with a computer mouse. Correct responses resulted in increased scores, and positive verbal feedback was given on some trials to encourage the children. The difficulty of the training tasks was automatically adjusted on a trial-by-trial basis to match children's current working memory capacities to maximise the training benefits. Other working memory tasks included remembering digits or letters. The children's scores were saved in a rank-ordered list to encourage them to perform at their best and each day after completing their training a reward game was played, in which they controlled a robot racing through a track of obstacles. This game did not require working memory, but was included as an incentive to increase compliance. Each child completed 115 trials across eight tasks each day for a minimum of 20 days (maximum was 25 days).

Upon completion of the training programme, children completed 8 subtests of the AWMA (Alloway, 2007). Four tests had been administered pre-training; the remaining four (Nonword Recall, Mazes Memory, Listening Recall and Odd-One-Out) had not. These tests yielded post training composite scores for each aspect of working memory. The WASI (Wechsler, 1999) was also administered, and teachers were asked to complete the ADHD Rating Scale (DuPaul et al., 1998) based upon the child's behaviour since completing the programme. Children also completed a behaviour checklist about their working memory problems since completing the training programme.

Results

The results of the study were remarkably clear. Training led to significant gains in non-trained working memory tasks (see Figure 6), which extended across all four aspects of working memory (verbal STM, $t(24) = 2.93$, $p < .01$, $d = .68$; visuo-spatial STM, $t(24) = 6.86$, $p < .01$, $d = 1.13$; verbal WM, $t(24) = 2.55$, $p < .01$, $d = .59$; visuo-spatial WM, $t(24) = 2.07$, $p < .05$, $d = .37$). Training took the children's scores from the below-average to the typical range for visuo-spatial short-term memory, verbal working memory and visuo-spatial working memory.



NB. ** $p < .01$, * $p < .05$.

Figure 6. Working memory training gains.

Training did not have an effect on verbal IQ,performance IQ, nor full-scale IQ scores (all *p*s>.05, see Figure 7). Descriptive statistics for the behaviour ratings are shown in Table 1. Both teacher ratings of inattentivity, $t(19)=3.00$, $p<.01$, $d=.26$, and hyperactivity, $t(19)=2.42$, $p<.05$, $d=.32$, were significantly reduced following training, as were the children's own ratings of working memory difficulties, $t(24)=3.29$, $p<.01$, $d=.70$.

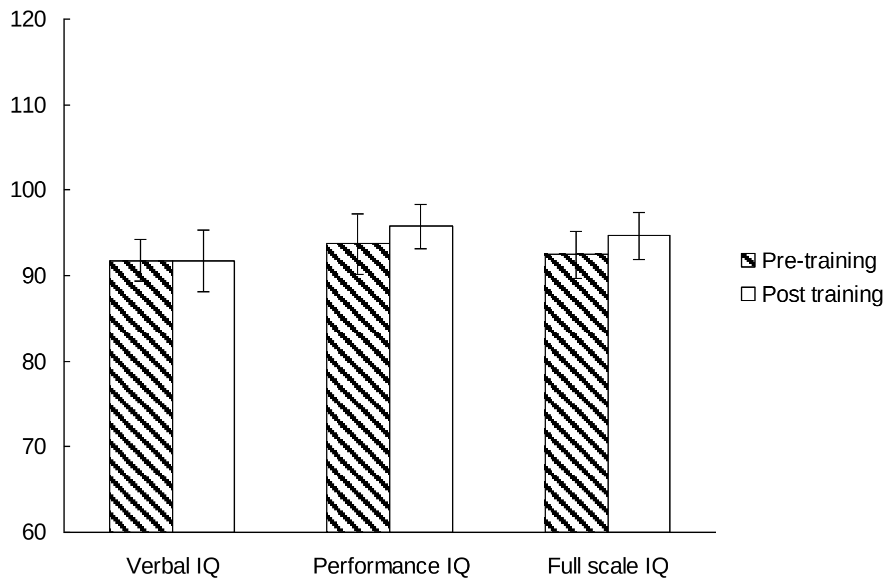


Figure 7. IQ scores pre- and post-training.

Table 1. Effect of training on problem behaviour

Measure	Pre-training ratings	Post-training ratings
Teacher-rated Inattentivity	69.84 (23.33)	58.21 (20.27)**
Teacher-Rated Hyperactivity	81.15 (21.69)	70.31 (23.87)*
Child self-rated WM problems	17.60 (5.72)	13.25 (6.00)**

Note. Only 19 post-training questionnaires were returned by teachers. * denotes significant at the p<.05 level, ** denotes significant at the p<.01 level.

Discussion

Our findings show that performance on working memory tasks can be enhanced through direct training in children with ADHD who receive stimulant medication. Uniquely, our data show that repeated practice leads to substantial gains that generalise across all aspects of working memory, and that these training effects are specific to working memory as they do not extend to performance on IQ tasks. Our data showed that training also significantly reduced ratings of problem behaviours, which is consistent with previous studies in the area (e.g. Klingberg et al., 2005).

The primary aim of our study was to explore whether direct training could lead to generalised improvements in working memory in children prescribed stimulant medication for ADHD. Consistent with previous studies, such as those conducted by Klingberg et al. (2005), we found significant improvements in untrained verbal and visuo-spatial simple span tasks following training. Importantly, we found that these gains generalised to untrained complex verbal and visuo-spatial working memory tasks, but that they did not extend to IQ tasks. These results suggests that specific gains in working memory capacities can be achieved through practice, which has important implications both for the management of children with disorders of attention and memory, and for our current theoretical understanding of working memory.

The systematic evaluation of all major components of working memory in the present study, assessing both verbal and visuo-spatial storage and complex span performance, provided the first opportunity to identify which elements of working memory capacity have a degree of modifiability. Our results indicated that all aspects have a similar degree of modifiability, which was unexpected given the prior assumption that individuals have a limited, fixed amount of general capacity with which to process and store information (Engle, Cantor and Carullo, 1992).

So why might working memory capacities increase in a generalised way following a period of intensive training? One possibility is that training did not lead to increases in working memory capacities *per se*, but that it improved skills such children's attentional control and resistance to distraction from irrelevant stimuli that are related to working memory, and in particular the central executive component of Baddeley and Hitch's (1974) working memory model (Engle et al, 1999; de Fockert, Rees, and Lavie, 2001). Engle and colleagues have demonstrated that individuals with poor working memory show greater attentional interference in non-memory tasks, such as paired-associate tasks (Rosen and Engle, 1998) and antisaccade trials that involve the inhibition of a prepotent response (Unsworth, Schrock and Engle, 2004), in comparison to individuals with high working memory spans. These differences are likely to be related to the low working memory individuals' poorer ability to actively maintain task goals in the face of distracting stimuli, which leads them to rely more on automatic responses to guide behaviour (Unsworth and Engle, 2007). Practice on attentionally-demanding computer-based working memory tasks may therefore have improved the children's ability to resist distraction and maintain access to task goals. This may have included increased volitional control of attention, such as clearing their minds of distracting thoughts and sitting calmly to focus on the to-be-remembered information, or the development of working memory strategies to compensate for weaknesses in basic processes. Some support for this position was provided by a post-training interview in which the children were asked to describe what had helped them to improve on the training activities. Of the fifteen children who answered this question, four reported concentrating harder by closing their eyes or focussing more on the presented information, and a further ten children reported using a variety of other strategies that included rehearsing the information or tracing the patterns on the computer screen with their eyes. These reports suggest that training may indeed enhance attentional focus and stimulate a range of possibly idiosyncratic strategies. This hypothesis can account for the generality of the gains across all aspects of STM and WM, and seems plausible given the sample of children who were trained, who have a clinical problems with attention. Although evidence from Klingberg's laboratory shows significant training effects in verbal and visuo-spatial STM in healthy adults, further work is needed to clarify whether these training effects generalise to all aspects of working memory in populations who do not have specific attentional problems.

An important aspect of our study was to examine the effect of training on ratings of problem behaviours. We found that training significantly reduced teacher ratings of inattentivity and hyperactivity, and also that the children's ratings of their working memory difficulties were significantly reduced following training. The children's increased working memory skills may have impacted on their behaviour in several ways. Firstly, improved attentional control, or resistance to distraction, is likely to have increased teacher perceptions of concentration in the classroom. Poor working memory is associated with high ratings of inattentivity (e.g. Aronen, Vuontela, Steenari, Salmi and Carlson, 2005), probably because restricted working memory resources cause forgetting in complex and demanding classroom activities. This is likely to lead to poor focus and non-goal directed behaviour, which will be perceived by others as inattentive and distractible behaviour (Gathercole, Alloway, Kirkwood, Elliott, Holmes and Hilton, in press). Training might have ameliorated some of the difficulties remembering information in the classroom, leading to more focussed task completion,which would explain why the children reported fewer problems in response to questions such as "Do you find it hard to follow instructions in the classroom?", and also why teachers rated levels of inattentivity as lower. Secondly, improved working memory function may have increased the children's executive skills, such as inhibition, that are commonly associated with the central executive component of working memory (Baddeley, 1996; 2000) and also with poor working memory function (Gathercole et al., in press). Indeed, there is evidence to suggest that individuals with ADHD have marked impairments in inhibition (Sonuga-Barke, Berker, Dalen, Daley and Remington, 2002) and that it can be significantly improved in children with ADHD following direct working memory training (Klingberg et al., 2005). In terms of behavioural control, increased inhibition may have enabled the children to more easily inhibit responses to distracting stimuli and also to inhibit impulsive or hyperactive behaviours, which may have impacted upon ratings of problem behaviours. More detailed studies will of course be needed to further investigate the impact of training on behaviour.

Although the reason for the increase in children's working memory capacities is not yet clear, the finding that working memory can be improved in a significant and generalisable way through training has important implications for clinical and educational practice. This study has shown that both the verbal and visuo-spatial working memory deficits associated with ADHD can be improved through training. Importantly, the programme effectively increased working memory scores from the below-average to the average range across all aspects of working memory, even when the children were receiving stimulant medication for ADHD. This suggests that working memory training significantly improves cognitive function beyond the effects of medication. More generally, in terms of remediation these findings suggest that the memory deficits that accompany many learning and developmental disorders may be alleviated through direct training. Working memory is a fundamental cognitive resource, deployed in many everyday mental activities where information processing is required (e.g. reasoning, solving problems and learning complex skills), and impairments in working memory function are known to cause a bottleneck in learning, which can lead to educational underachievement (Gathercole et al., 2006). Therefore, if the training gains observed in this study are both sustainable and transferable to children with other developmental disorders where memory impairments are evident, substantial improvements in both the children's quality of life and learning are anticipated.

Several outstanding issues arise from this study, which will need to be addressed in future research. Perhaps the most important step to take is to extend the use of the working memory training programme to children who do not have a clinical diagnosis of any developmental disorder to provide a direct test of the utility of the programme to train working memory that, unlike the previous studies with children, cannot be attributed to possible mediating effects of a co-morbid condition. The extent to which children transfer gains in working memory to everyday contexts, such as learning in the classroom, it is not yet known. Therefore, an important outstanding issue to resolve is to measure whether training results in better learning, higher academic achievements and improved quality of life. A final issue to address is to examine theoretically how working memory capacity might be increased. Importantly, we need to identify where the training effects have the biggest impact and why they have these impacts. A combination of brain imaging and further cognitive-behavioural studies, which include measures of sustained attention, may provide a good starting point.

Conclusion

The studies presented in this chapter have discussed two contrasting methods of working memory training. The first, memory strategy training, has been found to be beneficial to both working memory and a task involving remembering and following instructions in children aged 6-7 years. This method, however, only appears to be beneficial in children aged 7 and younger, or those who have not yet developed the efficient use of memory strategies. The second method, involving the direct training of working memory, has been found to lead to gains in both short-term and working memory and reductions in teacher and child ratings of problem behaviours associated with ADHD. This method, however, has not been used with children who do not have a clinical diagnosis. Further research is therefore needed to establish the applicability of both methods to wider populations. That said, both studies provide key evidence that there are opportunities for improving children's working memory and minimising working memory related failures in the school classroom. If combined with other methods of remediation, including managing working memory loads in the classroom (e.g. Gathercole and Alloway, 2004), both memory strategy training and the direct training of working memory could be particularly beneficial for educational and clinical practitioners attempting to ameliorate the working memory deficits associated with a wide range of neurodevelopmental and genetic disorders of learning (e.g. Alloway and Gathercole, 2006).

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