CHAPTER

10

Sources of Working Memory Deficits in Children and Possibilities for Remediation

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Much of our childhood is spent developing complex cognitive skills that as adults we may take for granted, including language, reading, mathematics, and reasoning. These are the very skills that allow us to reap the greatest benefits from education and from life in general. Psychologists have long been interested in trying to identify general cognitive mechanisms that may underlie such complex cognitive activities. One promising candidate is working memory (WM), most generally defined as the ability to actively maintain task-relevant information during the performance of a cognitive task (Baddeley & Hitch, 1976; Shah & Miyake, 1999).

WM has evolved from the earlier concept of short-term memory. Short-term memory provides temporary on-line storage of information that decays rapidly unless rehearsed. A standard measurement of short-term memory capacity is the digit span task, in which an individual is read a string of digits and is asked to repeat them back. The longest series of digits that can be accurately repeated is that individual's digit span. However, in the real world, short-term storage of information is frequently not so static. For example, when performing mental arithmetic one must not only store the numbers, but also transform them into a new number while still

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remembering the old numbers. WM measures are designed to assess an individual's ability to simultaneously store and process information. An example of a WM measure is the reading span task, in which an individual reads and judges the veracity of a series of sentences while at the same time remembering the last word from each sentence. The number of sentences for which an individual can both correctly judge the sentences and remember all of the words is that person's reading span score. Individual differences in WM measures such as reading span have been shown to predict performance on a wide variety of tasks including vocabulary acquisition (Gathercole & Baddeley, 1993), language comprehension (Daneman & Merikle, 1996), mathematics, (Bull, Johnston, & Roy, 1999), and reasoning (Kyllonen & Christal, 1990). Based on its predictive power, WM has been proposed to play an essential role in many school-based cognitive activities (Gathercole & Baddeley, 1993; Gathercole, Pickering, Knight, & Stegmann, 2004).

In the course of normal development, children show large increases in their WM capacity (Gathercole, 1999; Pickering, 2001). However, there are many children in whom the expected progression of some portion of WM appears to be either delayed or disrupted. WM deficits have been reported in a diverse array of populations ranging from children with developmental disorders with known etiologies such as Down syndrome (Hulme & Mackenzie, 1992), to those with specific learning disabilities (Swanson & Sachse-Lee, 2001a), to children who have survived chemotherapy treatments (Schatz, Kramer, Albin, & Matthay, 2000). Although these groups differ widely in the exact nature and the degree of cognitive impairment experienced, poor WM function has often been identified as playing an important role in these children's overall performance and as a target process in which to attempt remediation. Given the power of WM measures in predicting various indices of future educational achievement (Gathercole, Brown, & Pickering, 2003; Gathercole et al., 2004), even small increases in the efficacy of WM skills may significantly improve these children's performance in the classroom and in their daily lives.

In this chapter, we provide a broad overview of the different approaches taken in rehabilitating cognitive functioning that either target WM function directly or have been shown to improve WM function. We then examine the types of WM deficits identified in different populations of children who are learning impaired and the extent to which different forms of remediation have been attempted in each. Finally, we conclude with a summary of the general principles for remediation that can be drawn from the current evidence and suggest future directions for research.

THEORETICAL APPROACHES TO WORKING MEMORY REMEDIATION

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The standard model of WM proposed by Baddeley and Hitch (1976) is a three-part system consisting of a central executive (CE) and two peripheral systems: the phonological loop and the visuo-spatial sketchpad. The phonological loop and visuo-spatial sketchpad are temporary storage systems responsible for maintaining verbal and visuo-spatial information, respectively. Each can be divided into two basic subcomponents: a limited capacity store, which holds only a few items and decays rapidly without being refreshed by the second subcomponent, a rehearsal process (Baddeley, 1986). The CE has been broadly defined as the supervisory system that oversees and regulates the cognitive processes involved in WM performance (Baddeley, 1986). So-called "executive" processes thought to reflect the functioning of the CE include various forms of attentional control such as focusing attention, switching attention, and dividing attention as well as the ability to inhibit unwanted thoughts or actions and the ability to stay focused on a particular goal (Baddeley, 2002; Duncan, 1995; Miyake et al., 2001). 1

Therefore, within the Baddeley model, deficits in WM function have multiple possible origins, including differences in the size of the phonological or visuo-spatial stores, the efficiency of the rehearsal processes, or the integrity of higher-level processes of the CE. As a result, a continuum of WM measures exists, with very simple storage tasks at one end and complex problem-solving tasks at the other. Tasks along this continuum differ in the amount and type of CE processes required. An example of a task low in executive demand would be a simple span task in which an individual must remember a series of letters, movements, or sounds and repeat them back. An example of a task that requires one aspect of CE functioning, the inhibition of prepotent responses, is the Stroop task. The Stroop task requires participants to view color words written in different colors of ink and inhibit the well-practiced response of reading the words, instead naming the color of the ink (Stroop, 1935). Finally, an example of a task that involves multiple executive processes would be a problem-solving task such as the Tower of London/Hanoi, which consists of a puzzle in which a person must move a series of disks across a series of pegs. Such problem-solving tasks require storage of information in memory along with focusing attention, inhibitory processing, and maintaining and updating goals and subgoals.

Although most WM theorists usually agree on the existence of peripheral systems that process relatively domain-specific information (e.g., visual as opposed to verbal information), as well as centralized control mechanisms that may be more domain general, there are differences amongst theoretical approaches as to the source of individual variations in WM performance. For example, a number of researchers have proposed that capacity differences in the amount of "WM resources" or "controlled attention capacity" possessed by individuals predict individual differences in performance on a variety of WM measures, independent of the specific processing domain (Just & Carpenter, 1992; Kane & Engle, 2002; Daily, Lovett, & Reder, 2001). Although these theories of WM acknowledge that acquired knowledge and experience may have an impact on performance of individual tasks, they suggest a large proportion of the individual variability on many novel, intelligence-demanding tasks relevant for schooling may be accounted for by this general factor (Engle, Tuholski, Laughlin, & Conway, 1999). Therefore any intervention that could increase this capacity should have general effects on WM and tasks thought to require it.

However, other theories such as long-term WM (Ericsson and Kintsch, 1995) and connectionist approaches (MacDonald and Christansen, 2002; O'Reilly, Braver, & Cohen, 1999) emphasize the role of domain-specific knowledge and the importance of strategies in the performance of complex cognitive tasks that rely on WM. Individual differences in performance on WM tasks may not solely result from differences in capacity limitations; they also may result from differences in long-term memory and processing strategies gained through experience. These theories assume performance on tasks that demand WM can be improved but that this improvement is highly strategic and specific to the task practiced. For example, through training, one individual expanded his *digit* span to 79 continuous items by devising strategies to quickly remember numbers. This well exceeds the capacity limits of the phonological store (Ericsson, Chase, & Faloon, 1980). However, this extra capacity was not seen when the same individual was asked to remember a series of *letters,* in which he did no better than an average span. A more common example is experienced restaurant servers who may excel at remembering customer orders without writing them down but then may perform no better than anyone else on another WM demanding task, even if it is another verbal one (Ericsson & Polson, 1998).

There then exist multiple possible reasons why WM may be impaired and multiple routes by which intervention may be attempted. Damage may be localized to one of the peripheral systems, or it may have a more general effect through a failure of the CE. Within a system, possible underlying problems include reduced processing capacity, poor knowledge representations in long-term memory, failures to use efficient and appropriate strategies, or any combination with one deficit possibly causing or exacerbating another. For example, children with poor attentional capacity may have more difficulty self-initiating a rehearsal strategy that would improve their performance. Although training these children to use rehearsal strategies may improve WM performance, it may not be as effective as treating the underlying cause of the deficit. Therefore the success of a remediation attempt may depend on correctly targeting the locus or loci of impairment in a particular population of children.

Remediation of Peripheral Impairments

Specific impairments of peripheral systems have been hypothesized in a number of different developmental learning disorders ranging from severe intellectual disabilities to very specific learning difficulties without any other obvious intellectual impairment, such as dyslexia. The selective nature of many of these conditions has been used as evidence in support of the separability of the different peripheral systems such as the phonological loop

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and visuo-spatial sketchpad (Wang & Bellugi, 1994). In light of these patterns of impairment, a number of remedial approaches for children with developmental disorders have focused on the improvement of storage and processing in one or other of the peripheral WM components.

Of the two peripheral systems, the phonological loop has received the greatest amount of research both as a locus of deficit and as a target for remediation. Phonological WM is hypothesized to consist of two components: a phonological store, which holds only a few items and decays rapidly without being refreshed by the second component, a subvocal rehearsal process (Baddeley, 1986). This rehearsal process is also responsible for translating visual or written materials into phonologically based representations through a process known as phonological recoding (Gathercole & Baddeley, 1993; Palmer, 2000b). The visuo-spatial sketchpad has received comparatively less attention in terms of being specifically damaged and even fewer attempts at remediation. However, it is thought to be similar to the phonological loop in that there is also a store and rehearsal processes (Logie, 1995).

Strengthening Storage Representations

One proposed source of deficits specific to either the phonological or visuo-spatial storage systems is poor long-term memory representations or the inability to retrieve long-term representations. In the context of phonological representations, where this issue has been most extensively studied, listeners must code acoustic information into phonological codes that rely on the quality of information in long-term memory. Thus, crisp, highly distinguishable memory representations leading to greater WM capacity (Cowan, 1996). Conversely, poor and indistinct memory representations lead to 2
reduced WM capacity.

Auditory temporal processing deficits are frequently proposed as an underlying source of poor phonological representations (Tallal, 2003; Veale, 1999). Auditory temporal processing skills involve the ability to process rapidly presented stimuli. To develop distinct neural representations of phonemes in any language, the listener must first be able to distinguish between auditory input that is rapidly changing, often in less than 40 milliseconds (Tallal, 2003). Children who process speech sounds too slowly to identify and distinctly represent different phonemes (such as children with specific language impairment and dyslexia) also have impairments in phonological WM and other language skills (Montgomery, 2003). Thus, one approach to remediation has been to train children to process acoustic changes in speech more rapidly (Merzenich et al., 1996; Tallal et al., 1996; Veale, 1999). Although there has been little investigation as to whether improving the speed of auditory processing in children leads to improved performance on WM tasks *per se* (Deutsch, Miller, Merzenich, & Tallal, 1999), we include it nonetheless as a possible method for remediation in children with poor phonological WM, in light of the theoretical links between temporal processing, phonological representations, and WM (Downie, Jakobson, Frisk, & Ushycky, 2002). The fact that temporal training has also been shown to affect language processing and reading comprehension tasks that are problematic for children with poor WM is also promising (Tallal, 2003; Veale, 1999).

Phonological awareness is the conscious knowledge of the phonological structure of language and describes an individual's ability to recognize and manipulate the various components of words such as syllables and phonemes. Thus, phonological awareness has been identified as a construct highly related to phonological WM, with a number of studies demonstrating a correlation between phonological awareness and phonological WM (Gillam & van Kleeck, 1996; Leather & Henry, 1994; Oakhill & Kyle, 2000). One explanation is that phonological awareness tasks usually require active maintenance of information in WM to compare and process phonological information. Gillam & van Kleek (1996) argue that because phonological awareness tasks are demanding of phonological WM, training on phonological awareness may lead to improvements in WM. Another possibility is that better phonological awareness is a result of high-quality phonological representations in long-term memory that allow for easier storage and processing in WM. Phonological awareness training generally consists of repeated practice on a series of phonological awareness tasks such as judging the initial sound in a word, categorizing a particular sound, blending two phonemes together, and deleting a phoneme from a word. Such training has been shown to improve performance on a large number of related phonological awareness tasks (Downie et al., 2002; Torgesen & Davis, 1996) and on reading ability (Maridaki-Kassotaki, 2002; Wright & Jacobs, 2003).

Rehearsal

Deficits in WM may also arise from failures to use appropriate rehearsal strategies. Before the age of 7 years, children do not appear to use rehearsal consistently, and it is the development of rehearsal and other strategies that is thought to be at least partly responsible for increased WM span (Gathercole, 1999). Evidence that some children fail to develop rehearsal, or have poor organizational strategies, has led some to attempt to remediate WM by explicitly teaching children to rehearse or to use other strategies such as chunking words or digits into larger units, which are easier to remember. The training of even simple rote rehearsal strategies has been shown to improve WM performance in adults with low memory spans (McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). However, there is also evidence that, for these individuals, the teaching of more complex strategies may be less effective given the greater difficulty in mastering them (Turley-Ames & Whitfield, 2003). It may be that differences in strategy use may be more centrally based, with some individuals simply being more strategic overall, regardless of the processing domain (McNamara & Scott, 2001). However, rehearsal training has frequently been undertaken in the service of improving WM in the context of specific impairments in a peripheral system.

Centrally Based Processing and Remediation Approaches

A second approach to the remediation of WM difficulties in children has focused on possible impairments in the functioning of the CE. Three basic approaches have been proposed to remediate CE deficits in WM: the direct training of planning and metacognitive strategies, process specific training, and the use of pharmacologic agents intended to increase attentional capacity.

One method proposed to improve cognitive performance in children believed to have more global attentional or CE problems has been to teach them various planning strategies and better metacognitive awareness of their own performance (Marlowe, 2000; Ylvisaker & DeBonis, 2000). Although these interventions are not thought to have a direct effect on WM capacity (Mateer, Kerns, & Eso, 1996), they may allow children who are impaired to better manage the diminished attentional resources they do possess. In addition, such training has the potential to improve the efficacy of other remediation attempts when used in tandem. Training may include helping students to be more aware of which situations require executive processes and the teaching of strategies such the verbal mediation of performance, in which children are taught a sequence of orienting questions that allow them to identify the current goal and to benefit more from feedback (Sohlberg, Mateer, & Stuss, 1993). Although there is little evidence on how effective these approaches are for direct measures of WM performance such as the reading span, there is some work showing improvement on various educational measures such as reading comprehension and arithmetic performance, which are thought to rely on WM (Singer & Bashir, 1999).

A second approach to remediation is process-specific training, in which the repeated practice of a particular cognitive process is hypothesized to lead to an improvement and reorganization of that process. This approach was originally developed for the rehabilitation of cognitive deficits in adults with brain injury and was thought to be especially useful for the rehabilitation of attentional abilities (Sohlberg & Mateer, 1987). Attention process training (APT) is a process-specific approach in which individuals receive repeated practice on tasks in five areas of attention: focusing, selecting, sustaining, switching, and dividing attention (Sohlberg & Mateer, 1987). A number of studies have reported improvements in attention or executive function in adults who have been brain injured (Park, Proulx, & Towers, 1999; Sohlberg & Mateer, 1987; Sohlberg et al., 2000) and in adults with

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schizophrenia (Lopez-Luengo & Vazquez, 2003). However, many of these studies have been criticized for the small sample size and limited generality of the improvements reported (Park & Ingles, 2001). Although APT was originally developed for adults, there is a growing interest in adapting this procedure for use in children.

A third approach to the remediation of the CE has been to try to improve the underlying efficiency of the neural systems involved by targeting the neurotransmitter systems on which they are thought to depend. Drugs that act on the catecholamine system have been shown to affect WM performance both in animals (Solanto, 2002) and humans (Mehta et al., 2000). Several studies have demonstrated improvements in the visuo-spatial WM performance of adults with the administration of methylphenidate (Ritalin) and other agents that increase dopaminergic and cholinergic function (Elliott et al., 1997; Furey, Pietrini, & Haxby, 2000; Kempton et al., 1999; Mehta et al., 2000). Therefore, for children in whom WM difficulty may have a clear neurochemical basis, pharmacologic approaches to remediation may hold a great deal of promise.

REMEDIATION APPROACHES IN DIFFERENT WORKING MEMORY IMPAIRED POPULATIONS

In the next section of the chapter we shall examine the types of remediation approaches taken in different populations of children with WM impairment. WM impairments are reported in a number of different developmental disorders and conditions. However, the exact nature of the deficit in a particular disorder is frequently a source of great debate. Naturally, understanding the source of a deficit would seem to lead to better interventions. However, it may be that the type of interventions that are successful will also be informative about the type of deficit present in a given population of children.

Children Who Are Intellectually Disabled

In the United States, individuals are classified as having intellectual disability (ID) if their IQ (intelligence quotient) is measured as being below 70. This includes individuals for whom the source of their disability is known, such as those individuals with Down syndrome, and those for whom there is no clear etiology. A number of studies have found that children with ID appear to be disproportionately impaired in measures of verbal WM, whereas their performance on visuo-spatial WM measures is relatively spared (Jarrold, Baddeley, & Hewes, 1999; Rosenquist, Conners, & Roskos-Ewoldsen, 2003; Wang & Bellugi, 1994). One hypothesis for this pattern of impaired and spared abilities is that children with ID fail to develop verbal rehearsal. A frequently cited piece of evidence indicating a lack of rehearsal in these children is a reduced or absent word-length effect compared to age-

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matched, or vocabulary-matched, controls (Hulme & Mackenzie, 1992). The word-length effect is the finding that immediate recall is usually better for words that take less time to pronounce than longer words, even when the number of syllables is held constant (e.g., "bishop" is recalled better than "harpoon") (Baddeley, Thomson, & Buchanan, 1975). A failure to find the word-length effect has been reported both in children with Down syndrome (Hulme & Mackenzie, 1992; Jarrold, Baddeley, & Hewes, 2000) and with individuals whose ID is of unknown origin (Rosenquist et al., 2003). Given the evidence for a specific deficit in rehearsal, a number of studies have examined the possibility of improving verbal WM performance in these children by training them explicitly in the use of rehearsal (Broadley, MacDonald, & Buckley, 1994; Comblain, 1994; Hulme & Mackenzie, 1992; Laws, MacDonald, & Buckley, 1996) and other organizational strategies, such as chunking (Broadley et al., 1994). Such remediation programs have been shown to significantly improve WM performance (Conners, Rosenquist, & Taylor, 2001), although the gains have been criticized for being fairly small in magnitude, with only a half to one memory item improvement (Jarrold et al., 2000). There is also some question as to how long these improvements are maintained once the training is completed, with some studies reporting sustained benefits weeks and months later (Bowler, 1991; Broadley et al., 1994), whereas others found these benefits to diminish with time (Comblain, 1994, Laws et al., 1996).

Although rehearsal training does appear to be helpful, at least in the short term, there is growing evidence that a lack of rehearsal alone does not explain the WM deficits reported. Jarrold, Baddeley, & Hewes (2000) found that children with Down syndrome had poorer verbal WM scores even when compared with matched children with learning disabilities. In this study, neither group was observed to be using a rehearsal strategy, but the children with Down syndrome still showed significantly greater impairment. Similar findings were reported by Vicari, Marotta, & Carlesimo (2004) using a control group matched for mental age. They concluded that lack of rehearsal was not a sufficient explanation for the differences between the two groups (neither of which used rehearsal) and that other possibilities, such as reduced capacity in the phonological store or a more general impairment of the CE, must be examined. Indeed, a study of the structure of WM in individuals with ID identified a general WM factor composed of performance on CE measures and dissociable from a separate phonological factor (Numminen et al., 2000). This general factor was related to performance on an intelligence test and various academic measures such as reading, writing, and mathematic performance. The phonological factor, however, was related to reading, writing, and sentence comprehension, but not with intelligence or measures of everyday cognitive performance. The authors interpreted these results as indicative of a separate CE deficit in ID that appears to be relatively independent of impairments in the phonological loop (Numminen et al., 2000). Unfortunately, to date there have been no attempts to apply

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more general capacity–based remediation methods to the proposed CE deficits in ID.

Specific Language Impairment

Specific language impairment (SLI) is a term used to describe children who exhibit a delayed development of language, both in comprehension and production, without other obvious intellectual impairments (Bishop, 2004). Related to their specific language impairments, these children have also been found to be impaired on various WM tasks, especially those thought to measure the effectiveness of the phonological loop (Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990; Montgomery, 1995).

It has been hypothesized that the phonological loop plays an important role in language acquisition because it allows auditory input to be transformed into a phonological representation and then held temporarily for analysis and transferred to long-term memory (Gathercole, Baddeley, & Papagno, 1998). Phonological WM capacity in children has been shown to predict their ability both to acquire (Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Service, Hitch, Adams, & Martin, 1999) and produce language (Adams & Gathercole, 1995). Thus, one specific hypothesis about the role of WM in the language deficits seen in children with SLI is that they have some impairment in the functioning of the phonological loop. Explanations of the role of phonological problems in children with SLI have focused on the capacity of the short-term phonological store rather than the rehearsal process because deficits in the use of rehearsal do not appear to be present in children with SLI (Gathercole & Baddeley, 1990; Montgomery, 1995). This view of SLI leads to a number of possible interventions, which include giving children practice with encoding and maintaining phonological representations and encouraging the use of strategies that use long-term memory, or other components of WM, to compensate for the reduced storage (Gathercole, 1993; Montgomery, 2003). For example, Gill and colleagues (Gill, Klecan-Aker, Roberts, & Fredenburg, 2003) found significant and lasting improvements in the ability to follow instructions in children who were taught a rehearsal strategy that involved visualizing the different instructions.

It has also been suggested that the phonological store may be impaired in SLI because the phonological representations to be stored in memory suffer from a lack of distinctiveness and are therefore difficult to distinguish from one another (Elbro, 1996). One reason that these representations may be incomplete is the presence of a deficit in phonological awareness, the conscious knowledge of phonological structure (Gillam & van Kleek, 1996). Therefore, training of phonological awareness is another form of remediation frequently used in children with SLI. However, although such training has been shown to lead to improvements on tests of phonological awareness, only one study has found any evidence of transferable improvement

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to a measure of phonological WM. In this study, Gillam & van Kleeck (1996) reported improvements after a course of phonological awareness training in children's performance on nonword repetition tasks that are frequently used to measure the performance of the phonological loop. They hypothesized that the training was beneficial for two reasons. First, the intervention improved the children's ability to translate a phonological representation into WM, and second, the phonemic awareness tasks themselves were WM demanding and thus the phonological intervention provided direct practice on WM.

A related hypothesis concerning the quality of phonological representations is that poor representations in children with SLI may result from a deficit in processing and producing brief sequential events in sensory domains such as vision and audition (Tallal, 1998). According to this model of SLI, slow auditory processing speed may lead to the inability to encode phonemic information rapidly and accurately. Tallal and colleagues (Tallal et al., 1996) have developed a computer-based intervention called "Fast ForWord" for children hypothesized to have slowed auditory processing; it consists of a number of video games, primarily designed to improve processing speed and accuracy. In a typical task, children are presented with artificially slowed speech, allowing them to detect relevant information and distinguish between phonemes in the context of a computer game. As children get better at performing the task, the duration of the presentation of the sounds is reduced. "Fast ForWord" has been highly successful in improving the performance of children with SLI on a wide variety of language comprehension and reading measures (Tallal, 2003). Furthermore, in the one preliminary study that we are aware of, children's performance in WM was improved after participation in the training program (Deutsch et al., 1999).

It should be noted that it is not clear which aspects of the "Fast ForWord" program lead to children's improvements and, specifically, whether increasing auditory processing speed benefited children on WM tasks. In addition to tasks designed specifically to support temporal processing of auditory information, "Fast ForWord" also includes language comprehension tasks that involve listening to phrases of increasing syntactic complexity and short-term storage tasks that involve remembering phonemes for brief periods of time. Thus, any improvements in WM seen after training using "Fast ForWord" may directly result from practice on the comprehension and storage tasks, rather than improved auditory processing.

A final view of SLI is that WM deficits may be the result of more centrally based processing limitations (Ellis Weismer, 1996; Montgomery, 2002), as evidenced by studies demonstrating disproportionate impairment on tasks with high executive processing demands (Ellis Weismer, 1996; Montgomery, 2000). If the WM deficits in children with SLI are the result of a more general executive deficit, then remediation approaches that have been effective in improving the function of the CE may also be helpful for 3

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SLI. However, to date there have been no attempts at remediating central attentional processing capacity in these children.

Reading Disability

Reading disabilities have long been associated with WM impairments (Cain, Oakhill, & Bryant, 2004; Chiappe, Siegal, & Hasher, 2002; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003; Swanson & Howell, 2001, and Chapters 2 and
4 3 of this book). This is true both in individuals identified as dyslexic (in whom poor reading performance is not accompanied by any other intellectual difficulties) and in "garden variety" poor readers (in whom intellectual performance is poor overall). Although there have been many attempts at improving the reading performance of these children, only a few studies have examined the possible role of WM in the remediation of reading disability by including WM tasks as either part of the training or as an outcome measure. Those that have fall into two basic categories: remediation targeting the properties of the phonological loop and the remediation of deficits in more general attentional processing.

Children with reading disorders are most commonly hypothesized to have problems specifically in the phonological loop component of WM because they evidence impaired performance on tasks such as digit or letter span (Cain et al., 2004; Smith-Spark et al., 2003; Swanson & Howell, 2001). Therefore attempts at remediation in these children have frequently focused on improving the function of the phonological loop in ways similar to the intervention programs seen in children with specific language disorders, such as improving auditory temporal processing, phonological awareness, and repeated practice on phonological WM tasks.

Deficits in both auditory temporal processing and phonological awareness have been reported in children with reading impairments (Cacace & McFarland, 2000; Carroll & Snowling, 2004; Cormier & Dea, 1997; Goswami & Bryant; 1990); training in auditory temporal processing as typified by the "Fast ForWord" program and training targeting phonological awareness alone have both been shown to be effective in improving reading performance in children with dyslexia (Lovett et al., 1994; O'Shaughnessy & Swanson, 2000, Temple et al., 2003). In addition, there is evidence that patterns and activity levels of brain areas hypothesized to play a role in WM processing are affected by such training manipulations, with improved frontal and temporoparietal activity seen in children with dyslexia after auditory temporal process training (Temple et al., 2003) and changed activity seen in the left occipitotemporal areas of children with dyslexia after training on phonological awareness (Shaywitz et al., 2004). However, the little research that has directly examined the effect of phonological awareness training on WM performance is equivocal. O'Shaughnessy & Swanson (2000) reported significant improvements in the verbal WM of children with

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reading disabilities after lengthy training on phonological awareness using two measures of verbal WM (recall of similar sounding words and reading span). However, a second study reported no improvement on a verbal WM task as measured by reading span after a similar course of phonological awareness training (Gonzalez, Espinel, & Rosquete, 2002).

Only one study has investigated the extent to which training directly on a phonological WM task will lead to improvements in reading performance. Maridaki-Kassotaki (2002) gave schoolchildren a course of training on phonological WM using repeated practice on nonword repetition. Training was administered 15 minutes a day, 4 days a week, for the duration of a school year (7 months). Both a training and control group were tested pre- and post-training on nonword repetition and on a measure of reading comprehension. There were no group differences before the training intervention. However, post-training, the training group showed significantly better performance on both nonword repetition and reading comprehension. Although these results are preliminary, they do suggest that children who are reading impaired may benefit from interventions that provide direct practice on verbal WM tasks. However, the extent to which this is true for tasks other than nonword repetition is unclear.

Other researchers have focused on the possibility of deficits in the CE component of WM and have hypothesized that at least in some children who are reading disabled, more general attentional capacity limitations underlie deficits in reading performance (Palmer, 2000a; Swanson, 1999). For example, dyslexic readers have been shown to be impaired on a number of executive tasks including the Wisconsin Card Sorting Task (WCST), a measure of inhibitory processing and switching (Palmer, 2000a); reading span (Cain et al., 2004; Chiappe et al., 2002; Swanson & Sachse-Lee, 2001b; Swanson & Howell, 2001); and letter updating (Smith-Spark et al., 2003). Therefore remediation approaches targeting CE processing constitute another means by which performance may be improved in children who are reading disabled.

Deficits in the ability to inhibit have been hypothesized as one source of executive impairment in reading disability (Chiappe et al., 2002; Palmer, 2000a), with some researchers proposing that reading problems in dyslexia may be the result of impaired spatial attention processing ultimately derived from an inhibitory deficit (Facoetti, Lorusso, Paganoni, Umilta, & Mascetti, 2003). For example, Facoetti et al. (2003) found that children with dyslexia failed to demonstrate normal inhibitory processing in a covert visual attention task. They then used an intervention called "visual hemisphere specific function" (VHSS; developed by Bakker, 1992), in which they stimulated either the right or left hemisphere (depending on the type of dyslexia) with words presented in the left or right visual field for 32 training sessions across 4 months. Participants in the intervention performed better on spatial attention tasks at post-test compared to a control group, who received a traditional intervention for dyslexia, such as phonological awareness training or individual reading tutoring. Furthermore, they were also better on measures of reading accuracy and reading speed.

A final possibility is that WM difficulties in at least some children with reading disorders may result in part from a lack of vocabulary knowledge. In general, children with reading disorders tend to have less knowledge about print, story structure, and vocabulary (Cain et al., 2004; Hecht, Burgess, Torgesen, Wagner, & Rachotte, 2000). In addition, McDougall & Donohoe (2002) found that children with reading difficulties performed equally as well as children without reading difficulties on span tasks that used high-frequency words, but they performed worse than children without reading difficulties on span tasks that used low-frequency words. This result is in line with results from studies of long-term WM that show a relationship between how much information can be actively maintained and the organization and quantity of long-term knowledge (Ericsson & Kintsch, 1995). Results such as these suggest another possible approach to remediation may be to expand these children's knowledge bases.

Attention Deficit/Hyperactivity Disorder

Attention deficit/hyperactivity disorder (ADHD) is a developmental disorder characterized by inattention, overactivity, and impulsive behavior (see also Chapter 6 of this volume). It is believed to be fairly common, with estimates
5 as high as 3–5% of all children affected (American Psychiatric Association, 1994). Whereas a number of WM and executive function deficits have been reported in children with ADHD, the primary impairment has widely been hypothesized to be a failure of inhibitory processing (Barkley, 1997; Schachar, Tannock, & Logan, 1993), which is then believed to lead to poor performance on WM and executive function tasks. Deficits have been reported for both verbal and visuo-spatial measures of WM (Karatekin & Asarnow, 1998; Mariani & Barkley, 1997; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003, but see Pennington & Ozonoff, 1996; Shue & Douglas, 1992) and a wide array of executive tasks including WCST (Pineda et al., 1998; Reeve & Schandler, 2001; Seidman et al., 1997), verbal fluency (generating as many items that meet some criterion, such as starting with the letter R or belonging to the category flower, in a short time frame; Pineda et al., 1998), the Stroop Task (Reeve & Schandler, 2001; Seidman et al., 1997), switching between tasks (Cepeda, Cepeda, & Kramer, 2000), and Tower of London (Cornoldi, Barbieri, Gaiani, & Zocchi, 1999).

Naturally, clinical interventions often focus on the remediation of the behavioral problems seen in children with ADHD. However, there is evidence that the WM problems seen in these children may also be responsive to treatment. Three major approaches have been proposed in the remediation of WM and executive function impairments in ADHD. These are process-specific training, instruction in metacognitive strategies, and medication.

In process-specific training, a damaged cognitive process is rehabilitated by repeated practice on tasks that exercise the damaged processes. One example is the APT described earlier, which was developed originally to help rehabilitate adults with brain injuries with attentional and executive function deficits s (Sohlberg & Mateer, 1987). However, several preliminary studies have begun to examine the potential of modified forms of APT in children with ADHD. In Kerns, Eso, & Thomson (1999), children with ADHD aged 5–10 years were given training on both visual and auditory versions of sustained, selective, alternating, and divided attention tasks for two 30-minute sessions a week for 8 weeks. Each task used materials that had been modified from earlier APT work so that they would be more interesting and appropriate for children. The performance of the trained children was compared to a control group pre- and post-training on 6 tasks thought to reflect attentional and executive abilities. Although not all the measures used showed evidence of transfer, the authors did report training-related improvements on a measure of sustained auditory attention, a measure of sustained visual attention, and a variant of the Stroop task commonly thought to require inhibition and selective attention. However, they did acknowledge that the small sample size (7 children) and the lack of follow-up testing limited the conclusions that could be drawn.

A second study investigating the effectiveness of APT in ADHD used a combination of metacognitive and process-specific methods. Semrud-Clikeman et al. (1999) trained a group of children with ADHD on two tasks taken from the APT program (Sohlberg & Mateer, 1987)—a visual attention task in which children had to find a target in an array of distracters and an auditory task in which they counted targets presented in an auditory stream of stimuli such as certain letters of words beginning with a specific sound. They were also given specific guidance and practice on the use of effective strategies and goal setting in the performance of the training tasks. The training intervention consisted of two 1-hour training sessions a week, for a total of 18 weeks. At the end of the training period, the children who had been trained showed significantly more improvement on both an unpracticed selective visual attention measure and an unpracticed auditory divided attention measure, in comparison to a control group of children with ADHD who had not received the training. Although this study found clear improvements, the extent to which the training benefits would generalize was uncertain and the contribution of each form of remediation (process specific and learning of strategies) to the gains seen was unclear. Additionally some of the children were taking medication at the time of training, and others were not. Unfortunately, as noted by the authors, there were not enough children taking traditional stimulant medications to be able to compare the efficacy of this form of training in children both undergoing and not undergoing pharmacologic therapy (Semrud-Clikeman et al., 1999).

A third study by Klingberg, Forssberg, & Westerberg (2002) combined basic principles from both process-specific training and sensory discrimination training in training WM in children with ADHD. In this program, children were given repeated practice on a computerized version of a visuo-spatial WM task, Backward Digit Span, Letter Span, and a go/no-go reaction time task (in which participants must inhibit a frequent response given a "no-go" signal). The difficulty for each individual subject was adaptable on a trial-by-trial basis, with each child receiving 20 minutes of training a day, 4–6 days a week, for 5 weeks. A control group of children received a lesser version of the same training tasks in which the difficulty was not adjusted, but it was for less than 10 minutes a day. Group differences in pre- and post-training improvement between training and control groups were reported on an untrained visuo-spatial WM task; Raven's Progressive Matrices, a common measure of fluid intelligence; and the Stroop task (Klingberg et al., 2002). In a later neuroimaging study, Olesen, Westerberg, & Klingberg (2003) found increases in prefrontal and parietal areas associated with WM after a similar course of WM training in normal young adults.

Another form of remediation proposed to have possible effects on WM and executive performance in children with ADHD is the teaching of organizational strategies such as self-monitoring, verbal mediation, and various higher level problem-solving strategies (Marlowe, 2000; Wasserstein & Lynn, 2001). No studies have directly examined the extent to which such a program alone would remediate WM. However, such training has been proposed as an important addition to process-specific training and other forms of remediation (Sohlberg & Mateer, 2001) as seen in Semrud-Clikeman et al. (1999).

A third possibility in the remediation of WM and executive deficits may lie in the stimulant medications traditionally used to reduce hyperactivity in ADHD because there is growing evidence that they may also improve certain aspects of WM function. Methylphenidate is the most commonly prescribed stimulant medication used to treat ADHD and has been shown to increase dopamine levels in normal subjects (Solanto, 2002; Volkow, Fowler, Wang, Ding, & Gatley, 2001). Behaviorally, treatment with methylphenidate appears to reduce problems in children with ADHD (Whalen et al., 1987), and it has also been reported to improve performance on a number of school-related activities (Douglas, Barr, O'Neill, & Britton, 1986). A number of studies have reported improvements with the use of methylphenidate on both WM and executive tasks. Two studies comparing children treated with methylphenidate to unmedicated children and normal controls found no difference between the medicated and control groups' performance on spatial WM and executive function tasks, whereas unmedicated children were impaired on both (Barnett et al., 2001; Kempton et al., 1999). Other studies have directly compared the performance of children with ADHD, both taking and not taking medication, and found better performance while medicated on measures of verbal WM (Tannock, Ickowicz,

& Schachar, 1995), visuo-spatial WM (Bedard, Martinussen, Ickowicz, & Tannock, 2004), focused and sustained attention (Konrad, Gunther, Hanisch, & Herpertz-Dahlmann, 2004), and task switching (Kramer, Cepeda, & Cepeda, 2001).

Another pharmacologic agent that has shown promise in improving WM function is modafinil. This drug is different from methylphenidate and related compounds in that it is not thought to affect dopaminergic systems; instead, it affects an individual's level of arousal. Therefore it is often used in the treatment of narcolepsy. However, two studies have reported improvements of clinical features of ADHD with modafinil use in children (Rugino & Copley, 2001) and adults with ADHD (Taylor & Russo, 2000). Although the direct action of modafinil on cognitive dysfunction in ADHD has not been directly tested, it has been shown to improve cognitive performance in animals (Beracochea et al., 2001) and in humans, with enhanced performance on tasks requiring WM and inhibitory processing (Turner et al., 2003).

As we have seen, there are several approaches targeting the CE that appear to hold promise in the remediation of the WM and CE deficits seen in ADHD. However, one factor that has not been considered in the remediation attempts to date is the large comorbidity of ADHD with other learning impairments and conditions such as reading disability (Dykman & Ackerman, 1991) and anxiety disorders (Tannock et al., 1995). The extent to which the efficacy of these different programs of remediation is changed in these subpopulations of children with ADHD is a topic for further research.

Childhood Schizophrenia

Schizophrenia is another relatively common disorder in which WM impairment has been hypothesized to constitute a core deficit. Poor WM performance, in both the verbal and spatial domains, has been reported in children with schizophrenia (Asarnow et al., 1994; Karatekin & Asarnow, 1998) and adults (Barch & Csernansky, 2002; Goldman-Rakic, 1994; Huguelet, Zanello, & Nicastro, 2000; Silver, Feldman, Bilker, & Gur, 2003). Individuals diagnosed with schizophrenia also perform poorly on a variety of executive function measures including the WCST (Goldman-Rakic & Selemon, 1997), verbal fluency (Bokat & Goldberg, 2003), and the Tower of London (Andreasen et al., 1992; Morris, Rushe, Woodruffe, & Murray, 1995). Although the remediation of WM has yet to be attempted in children with schizophrenia, there are a growing number of studies in which the amelioration of WM deficits has been undertaken in adults, using cognitive training techniques or new pharmacologic treatments.

Two cognitive training programs that have shown promise in the remediation of WM deficits in schizophrenia are the frontal/executive program (FEP) developed by Delahunty and Morice (1996) and neurocognitive enhancement therapy (NET) developed by Bell et al. (2001). In the first program, FEP, patients with schizophrenia are given targeted training on a series of paper and pencil tasks in three different domains of executive function: cognitive flexibility, WM, and planning (Delahunty & Morice, 1996). Training in each of these domains emphasizes errorless learning, immediate feedback, and explicit instruction in various strategies for each domain. Wykes et al. (Wykes, Reeder, Corner, Williams, & Everitt, 1999) trained schizophrenic individuals using this program for approximately 40 days, with three to five 1-hour sessions of training per week. They measured a variety of cognitive and social measures, both before and after the training, and compared the amount of improvement seen to a control group of patients who received a more traditional occupational therapy. They found improvements in performance in a planning task, digit span, and WCST for both therapies, with a significantly larger advantage for the group receiving the FEP. In addition, there is early evidence that this training may have demonstrable effects on areas of the brain shown to be involved in WM processing. In a preliminary study, Wykes et al. (2002) reported increased frontal activation during the performance of an untrained WM task after an extended course of FEP training in several patients with schizophrenia. However, although increased activation was seen in areas associated with WM processing, it was not correlated with any improved performance on the task.

A second approach to the remediation of WM deficits in schizophrenia has been more process specific in nature because patients are given repeated practice with an increasing level of difficulty on various tasks but are not explicitly taught any particular strategy for improvement. This approach has been termed neurocognitive enhancement therapy (or NET; Bell et al., 2001). Two studies have compared the cognitive benefits of a course of work therapy to a course of work therapy *augmented* with a course of NET training, in which patients were given lengthy training (up to 5 hours a week for 26 weeks) on 4 computer-based programs, 2 visual tracking tasks requiring sustained attention, practice at a computerized versions of digit and word spans, and a planning task similar to the Tower of London (Bell et al., 2001; Bell, Bryson, & Wexler, 2003). In the first study, the group that received neurocognitive training in addition to work therapy showed greater levels of improvement on both an executive measure (WCST) and a common measure of WM (Backward Digit Span) (Bell et al., 2001). This was replicated in a later study, with the same benefit found for the training group on the Backward Digit Span (Bell et al., 2003), and training benefits enduring for at least 6 months after training had concluded (Fiszdon, Bryson, Wexler, & Bell, 2004). There is evidence that this form of remediation also has the potential to affect patterns of brain activity measurably. In a study in which verbal WM was targeted for training, 8 patients with schizophrenia were scanned while performing an auditory serial position memory task both before and after 10 weeks of intensive training on auditory verbal

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serial position memory tasks (Wexler, Anderson, Fulbright, & Gore, 2000). Although not all of the patients showed significant improvements with training, those who did showed increased task-related activity in the left inferior frontal cortex, shown to be active in normal control participants in performance of the task. One patient who received an additional 5 weeks of training was shown to have a normalization of brain activity after training, so that his pattern of activation was virtually the same as that of the controls.

Although the efficacy and the generalizability of cognitive remediation in schizophrenia is debated (Krabbendam & Aleman, 2003; Pilling et al., 2002), there is growing evidence that, in the treatment of WM and executive problems, it can have some positive impact. However, the degree to which WM can be remediated, and improvements generalized to real-life activities, is still unknown. In addition, the effect of these programs on children with schizophrenia, which is thought to be more severe in nature than adults, is still not yet known.

Another approach that holds promise for the remediation of cognitive deficits, and WM dysfunction in particular, lies in new drug therapies being developed to treat schizophrenia. Although early descriptions of schizophrenia emphasized the importance of the cognitive dysfunction seen in patients (Andreasen, 1999), traditional drug treatments such as haloperidol have focused on relieving the positive symptoms of schizophrenia, such as hallucinations. These early treatments were not effective in treating the cognitive deficits of the disease and may have, in fact, worsened WM performance (Castner, Williams, & Goldman-Rakic, 2000). However, there is growing evidence that some of the newer drug therapies, the so-called "atypical" neuroleptics, may improve WM performance by increasing dopaminergic activity in the prefrontal systems identified as being important for WM performance (Gemperle, McAllister & Olpe, 2003; Hertel et al., 1996). Abnormal activity in these same areas has been found repeatedly in neuroimaging studies of schizophrenia and WM (Barch & Csernansky, 2002; Callicot et al., 2003; Manoach et al., 2000). One drug, risperidone, has been shown to improve WM performance (Green et al., 1997; Harvey, Green, McGurk, & Meltzer, 2003) as well as increase activation in several brain areas associated with WM, including the right prefrontal cortex (Honey et al., 1999). Three other "atypical" drugs that have shown some promise in treating WM deficits are clozapine (Meltzer & McGurk, 1999), olanzapine (Harvey et al., 2003), and iloperidone (Gemperle et al., 2003). In addition to direct improvements in WM and executive performance, another possible benefit to these drug treatments is that they may enhance the effectiveness of other forms of remediation, such as cognitive training (Wykes et al., 1999).

Cognitive remediation of WM deficits is an important goal in the treatment of schizophrenia, especially in light of the evidence that it is the resolution of these deficits rather than more dramatic symptoms (such as hallucinations) that best predict a patient's long-term social outcome (Green et al., 2000). Another possible area of investigation is in the remediation of deficits in children who are genetically at greater risk of developing schizophrenia because they have been shown to have poorer WM function (Davalos, Compagnon, Heinlein, & Ross, 2004; Erlenmeyer-Kimling et al., 2000), and the extent of deficit has been shown to be predictive of the likelihood of their later developing the disorder (Erlenmeyer-Kimling et al., 2000). Therefore, it is possible that early intervention and improvement of cognitive function may have some effect on whether and how severely the disease manifests itself. Although this proposition is highly speculative, given the devastating effects of schizophrenia, it is worth future investigation.

Autism

Autism is another developmental condition in which executive function has been hypothesized as playing an important role (Pennington & Ozonoff, 1996) and for which the remediation of the CE has been proposed as a treatment strategy (Ozonoff, 1998). However, the exact nature of the WM and executive deficits seen in autism is not entirely clear and is currently the topic of some debate. Several studies have reported finding WM deficits in children with autism (Bennetto, Pennington, & Rogers, 1996; Luna et al., 2002; Minshew & Goldstein, 2001; Pennington & Ozonoff, 1996), whereas others have not (Russell, Jarrold & Henry, 1996). A similar situation exists for different measures of executive function, with some studies reporting impaired performance (Ozonoff, 1998), and others not (Griffith, Pennington, Wehner, & Rogers, 1999). One explanation for these inconsistent findings is that children with autism have impaired development and use of organizational strategies and that their performance suffers in situations where planning and strategy are important for optimal performance (Minshew & Goldstein, 2001).

Minshew & Goldstein (2001) studied WM span in individuals with autism using letter sequences, word sequences, and a sequence of directions. The subjects with autism were not significantly impaired on the letter sequences but were significantly worse for both word and direction sequences, with performance decreasing as opportunity to benefit from strategy use increased. The authors interpreted this as support for the hypothesis that as the complexity of the material increases and lends itself more to strategies, the more impaired individuals with autism are. A related proposition is that individuals with autism have poor or nonexistent inner speech, which would curtail any attempts to verbally mediate an organizational approach to the material, and that performance deficits will be the greatest on tasks in which there are arbitrary rules that must be followed, such as in planning tasks like WCST and the Tower of London/Hanoi (Russell et al., 1996). This theory may also help to explain the findings of Griffith et al. (1999), who reported finding no differences between autistic and age- and ability-matched children on eight separate measures of executive function. The

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children in this study were tested between the ages of 4 and 5 years, before reliable rehearsal and strategy use appears to develop in children (Gathercole, 1999). If poor performance on executive tasks in children with autism results in part from a failure to use organizational strategies, differences may not become apparent until children are older.

Although little has been attempted in the specific remediation of WM and executive function deficits, some of the same approaches used in other impaired populations have been proposed for children with autism. These have included stimulant medications such as methylphenidate, metacognitive training to increase organizational skills and strategies, and process-specific training in areas such as cognitive flexibility (Ozonoff, 1998). Currently there are no published studies evaluating the effectiveness of each of these approaches in children with autism. However, in addition to the possible rehabilitative benefits of such interventions being tested, there is also the possibility that the success or failure of different remediation attempts may be informative about the underlying deficits in autism. One prediction is that if the main deficit is the organization and utilization of strategies, then the direct instruction in the development and use of metacognitive strategies may be most effective.

Traumatic Brain Injury

WM and executive function deficits are frequently reported outcomes of traumatic brain injury in both adults and children (Levin et al., 1988; Levin et al., 2004; Roncadin, Guger, Archibald, Barnes, & Dennis, 2004; Slomine et al., 2002; Thompson et al., 1994). Although traumatic brain injuries can result from several different causes, such as infections, vascular accidents, and tumors, the most common cause is closed head injury, to which the frontal lobes appear to be especially vulnerable (Levin et al., 1997). The remediation of WM deficits has thus focused on the executive processes theorized as relying on frontal integrity. In a similar manner to that for developmental disorders in which the nature of WM impairments is hypothesized as lying in the CE, three forms of intervention have been presented as methods by which the attentional functions of the CE in individuals who have been brain injured can be improved. These are process-specific training, metacognitive approaches, and the use of stimulant medications.

Several studies have attempted to assess the extent to which patients who have been brain injured can benefit from process-specific training and the degree to which the improvements seen will generalize to new tasks. Interventions using programs such as APT (Sohlberg et al., 2000) and other forms of repeated practice on executive tasks, such as random number generation (which requires participants to generate a list of random, unrelated digits and inhibit well-learned sequences and recent responses), dual task performance, and n-back (which requires participants to remember and

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update a sequence of digits or letters and judge whether a particular item is the same as one presented a certain number of items previously) (Cicerone, 2002), have shown some limited promise in adult patients. However, a recent meta-analysis of the effectiveness of different attentional rehabilitation programs for patients with brain injuries found little evidence of generalized benefits from direct retraining efforts such as APT (Park & Ingles, 2001). A similar situation exists in the research on APT in children with brain damage, with preliminary results suggesting possible improvements with training (Mateer, Kerns, & Eso, 1996). Further controlled research is necessary to thoroughly assess the benefits of this approach in children.

Metacognitive deficits have also been reported in children with severe traumatic brain injuries (Dennis, Barnes, Donnelly, Wilkinson, & Humphreys, 1996; Hanten, Bartha, & Levin, 2000; Hanten, Levin, & Song, 1999). In adults with brain damage, the ability to improve with practice has been linked to their ability to develop and use strategies (Dirette, Hinojosa, & Carnevale, 1999). Therefore metacognitive training may be of benefit to children who are brain injured and may allow them to benefit more from other forms of training. A program attempting to rehabilitate memory and attention in children with brain injuries used a combination of process-specific and metacognitive training (van't Hooft, Andersson, Sejersen, Bartfai, & von Wendt, 2003). The Amsterdam Memory and Attention Training program has been formulated as a multi-pronged approach in which children are given both process-specific training on various attentional and memory tasks and metacognitive training focusing on the learning of specific performance strategies. In addition, children also receive social and therapeutic counseling. Pilot data obtained from three children with traumatic brain injuries who completed this program of training found weak evidence for improvements on selective attention as measured by the Stroop task and WM as measured by digit span (van't Hooft et al., 2003). However, considerably more research is necessary to establish the effectiveness of this program and the extent to which any improvements will generalize to other tasks.

The attentional deficits frequently seen in patients who are brain injured have led to investigations of the efficacy of stimulant medications such as methylphenidate in remediating these impairments. However, both the pediatric and the adult literatures are mixed, with some studies reporting improvement in attention and memory function after treatment with methylphenidate in children with brain injuries (Hornyak, Nelson, & Hurvitz, 1997; Mahalick et al., 1998) and in adults with brain injuries (Kaelin, Cifu, & Matthies, 1996; Plenger et al., 1996), and other studies with no such reports (Speech, Rao, Osmon, & Sperry, 1993; Williams, Ris, Ayyangar, Schefft, & Berch, 1998). A review of methylphenidate use in treating brain injuries concluded that, although there is evidence to support the effectiveness of the drug on behavioral problems such as impulsivity, the support for cognitive improvements is weak (Jin & Schachar, 2004).

Unlike adults, children may appear to have recovered from a brain injury only to manifest deficits months or even years later (Mateer & Williams, 1991; Thompson et al., 1994). This phenomenon by which children appear to grow into a deficit is likely to be a result of the increased WM and executive function demands of school and other activities as children age. Therefore, it is possible that successful remediation given shortly after the injury may help prevent or alleviate these later impairments. Although the possibility of such benefits is only speculative at this time, given the cognitive difficulties faced by these children, it is worth further investigation.

Chemotherapy and Cranial Radiation Treatments

Children treated with chemotherapy and cranial radiation therapy manifest a pattern of WM and executive impairments similar to children with traumatic brain injuries, including the delayed onset of deficits, which may not appear until 2 or 3 years after a child begins treatment (Butler, Kerr, & Marchand, 1999; Copeland et al., 1988; Mulhern & Palmer, 2003; Schatz et al., 2000). This unintended side effect to these life-saving measures is thought to arise from radiation damage to white matter and other subcortical areas such as the basal ganglia (Mulhern et al., 1999).

In light of the deficits suffered by these children, an ambitious rehabilitation program has been developed to treat them. Butler & Copeland (2002) have developed the cognitive remediation program in which children receive a combination of APT (Sohlberg & Mateer, 1987), explicit instruction in metacognitive strategies and cognitive-behavioral therapy in which children learn and practice strategies to resist distraction, and mnemonic strategies such as chunking. Training consists of 50 hours of treatment, with children receiving treatment 2 hours a week for 6 months. A pilot study of the effectiveness of this study found significant improvements on measures of WM (digit span and sentence memory) and sustained attention (the continuous performance test) for a group of young cancer survivors who completed the training, compared to a control group who did not receive treatment (Butler & Copeland, 2002). However, a fourth measure, a test of arithmetic achievement, did not show differential improvement. Although the lack of transfer to an academic measure correlated with WM performance was disappointing, the authors conceded that the data are preliminary and that more research is necessary before the true efficacy of the program can be evaluated. Therefore, they are conducting a large multi-site study to evaluate this program of cognitive remediation (Butler & Copeland, 2002). This is the most comprehensive and ambitious exploration of the possibilities of cognitive remediation to date.

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CONCLUSION

In this chapter, we have documented an increasing interest in the remediation of WM impairments in children. Multiple forms of remediation have been attempted, with the type of intervention dependent on the hypothesized source of the deficit in a particular population of children. Taken as a whole, these studies suggest that at least some form of WM improvement is possible, although the specific mechanisms responsible for any changes have not been precisely identified. Thus, the extent to which different theoretical approaches to remediation are most appropriate in a given population of children is uncertain because there has so far been no systematic approach to research on cognitive remediation. There do, however, appear to be a few general principles that can be distilled and used in future attempts at remediation.

The first general principle is the importance of variability in training. Although not always desirable when trying to determine the possible causes of improvement in any given situation, it has been well established in the skill-acquisition literature that variability in training promotes greater transfer than training on a single task (Schmidt & Bjork, 1992). This also appears to be true when training is applied toward remediation, with the more successful programs reported here (such as Klingberg et al., 2002, Semrud-Clikeman et al., 1999, and Tallal et al., 1996) combining different tasks and types of training interventions. Two additional general principles for successful training are the length of training and the adaptability of difficulty. Most remediation programs reported here consisted of at least 1 hour of training a week for weeks or months. In addition, most programs had some form of difficulty adaptation. Klingberg, Forssberg, & Westerberg (2002) demonstrated the importance of difficulty manipulations and length of training by including a control group that received training on the same tasks for far less time and without individual trial-by-trial adaptations of difficulty for those who did not show improvement. A final general observation is that there is a growing use of neuroimaging techniques such as functional magnetic resonance imaging to demonstrate and measure the effects of training interventions on neural activity. However, until there is a clearer understanding and set of expectancies for how compensatory processing is accomplished in the brain, these results should be interpreted with caution.

It should be noted that the previous discussion of children with WM deficits is naturally limited by the extent to which attempts at remediating WM have so far been made. There are a number of additional populations of children who may also benefit from WM interventions including children with low birthweight (Harvey, O'Callaghan, & Mohay, 1999), phenylketonuria (Welsh, Pennington, Ozonoff, Rouse, & McCabe, 1990), fetal alcohol syndrome (Connor, Sampson, Bookstein, Barr, & Streissguth, 2000), arithmetic disability (Bull & Johnston, 1997), and epilepsy (Kadis, Stollstorff,

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Elliott, Lach, & Smith, 2004). The inclusion of these different populations in future research will help to broaden our understanding of what types of WM remediation are possible and the mechanisms by which they can occur.

Summary Box

- Deficits in WM, the cognitive system involved in the active maintenance of task-relevant information, have been reported as a consequence of a diverse array of childhood disorders.
- WM ability may not be entirely fixed, and numerous interventions have shown promise in improving performance on different kinds of WM tasks.
- A number of approaches have been used to improve WM; these approaches include ones that focus on the ability to maintain specific kinds of information such as phonological or visuo-spatial information and those that focus on executive/attentional control skills.

- Children with intellectual disabilities such as Down syndrome have benefited from training in rehearsal strategies.
- Successful remediation of WM problems in children with language and reading impairments has often focused on teaching compensatory strategies, improving phonological awareness, and improving auditory processing speed.
- Children with ADHD suffer from impairments in executive functioning, and research suggests that such processes may be improved by process-specific training (repeated practice on impaired skills) and stimulant medications.
- Although remediation of children with schizophrenia has not been attempted, process-specific training and medications have improved executive functions in adult with schizophrenia; such approaches may be beneficial for childhood schizophrenia.
- Process-specific training and metacognitive strategy training have also been successfully used to treat WM deficits in children with traumatic brain injury and brain injury from chemotherapy and cranial radiation.
- Although our review of the literature suggests the potential for remediation of WM, much more research is necessary to establish the extent to which WM can be improved and what types of remediation are most effective for different populations.

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