Developmental Impairments of Working Memory:
Profiles and Interventions

by Susan E. Gathercole and Joni Holmes

Impairments of working memory (WM) are a feature of many of the most common cognitive disorders and have been suggested to contribute to many of the associated learning difficulties (McLoughlin & Leather, 2013; Rose, 2009). Understanding the origins of these problems is a vital step toward identifying ways of effectively supporting the struggling child. In this article we review recent developments in this field that have the potential to advance therapeutic and educational practice to improve learning outcomes for individual children.

WM provides the temporary storage of information necessary to support many everyday cognitive activities. This system involves the coordination of high-level executive control of attention with temporary storage, providing the ability to work with the items while they are in temporary storage. According to one influential model (Baddeley, 2000; Baddeley & Hitch, 1974), higher-level control is provided by the limited-capacity central executive. This is supplemented by specialized verbal and visuo-spatial stores, often referred to as short-term memory (STM).

The subcomponents of WM act in concert to provide consciously accessible representations of recent events that are vital to a wide range of cognitive abilities including mental arithmetic (Adams & Hitch, 1997), following instructions (Yang, Gathercole, & Allen, 2013), and the comprehension of language (Cain, Oakhill, & Bryant, 2004). Failures of WM are closely associated with inattentive and distractible behavior both in children and adults (Gathercole, Alloway, Kirkwood, Elliott, Holmes, & Hilton, 2008; Kane et al., 2007). This may reflect the loss of crucial task-relevant information from WM needed to guide goal-directed mental activity.

Profiles of Working Memory Impairments

Three profiles of impairment and their links with patterns of learning difficulties are described below.

Deficits in Verbal WM

Verbal WM is assessed by tasks such as reading span (a test in which the participant reads each of a succession of sentences and then attempts to recall the final word of each in the same sequence) and backward digit span (involving the immediate recall in reverse order of a sequence of spoken or written digits). Such tasks depend both on the storage of verbal material (STM) and the attentional control of working memory (Alloway, Gathercole, & Pickering, 2006; Kane et al., 2004). Deficits on these measures and also on verbal STM tasks have been widely reported in groups with Specific Language Impairment (SLI) (Archibald & Gathercole, 2006; Montgomery, 2000). The magnitude of the deficits in complex WM tasks is often greater than would be expected on the basis of the verbal STM problems alone (Majerus, Heiligenstein, Gautherot, Poncelet, & Van der Linden, 2009). One possible reason for this is that the low

quality of the temporary memory representations in STM requires executive involvement even in simple storage tasks. This may lead to even greater problems in complex tasks that place simultaneous demands on both the storage of verbal information and other processing too, which then must compete for limited executive resources (Archibald & Gathercole, 2006).

Deficits in Visuo-Spatial WM

A disproportionate impairment in WM for nonverbal information such as patterns, movements, and other detailed physical features has recently been reported for children with dyscalculia, a condition characterized by impaired mathematical abilities but age-typical reading (Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2013). However, domain-general impairments of WM are more typical of children whose academic learning difficulties extend across both reading and mathematics difficulties. There may therefore be two distinct pathways through WM to impaired mathematical learning.

General Deficits in WM

Some children have deficits extending across verbal and visuo-spatial WM, and these have been widely interpreted as arising from an impairment in the executive control of WM. Domain-general deficits of WM are characteristic of many children with ADHD (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and can also be detected through screening in the general school population (e.g., Archibald & Joanisse, 2009). Children with this profile are at high risk for poor academic progress in reading and mathematics (Gathercole, Pickering, Knight, & Stegmann, 2007; Swanson & Sachse-Lee, 2001).

Causes of WM Impairments

There is no single WM disorder, but multiple patterns of impairments that overlap across different specific learning difficulties many of which, such as reading difficulties and attention deficit and hyperactivity disorder (ADHD), co-occur. WM profiles provide important clues to the underlying cause of the child's cognitive problems but are not in themselves
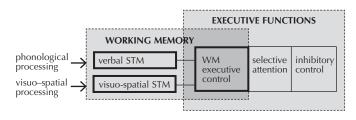

Figure 1. Working memory in its broader cognitive context. For the purposes of illustration, executive functions shown are restricted to working memory, selective attention, and inhibitory control.

sufficient to pinpoint the core deficit. This is because, as shown in Figure 1, working memory is an integral part of a broader cognitive system. It receives inputs from perceptual systems that process phonological and visuo-spatial material, and the quality of these inputs will inevitably have an impact on the quality of their representations in WM. For example, poor perceptual processing skills will lead to deficient storage in verbal STM, which will limit the ability to perform more complex verbal WM activities that depend in part on this system.

Phonological processing deficits have been extensively documented in SLI and dyslexia (Bishop & Snowling, 2004), and provide a plausible explanation for the associated verbal WM impairments. However, it cannot be assumed that impaired phonological inputs are invariably the cause of verbal WM impairments. In some cases, the deficit may originate specifically within WM. Direct testing of phonological processing abilities is therefore vital to establish whether verbal memory problems are the consequence of perceptual processing difficulties.

As Figure 1 shows, interactions between WM and the broader cognitive system extend beyond the interface with perception. The attentional control of WM is part of a broader network of executive functions mediated by frontal networks in the brain. Other functions include selective attention, inhibitory control, set switching, and planning (Miyake et al., 2000; Pennington & Ozonoff, 1996). Weak or inefficient frontal networks will disrupt multiple executive functions, including the executive component of WM. A domain-general deficit in WM is therefore not in itself sufficient to conclude that the source of the performance impairment originates within the memory system.

Broad impairments of WM characterize many children with ADHD and also some individuals with low WM identified through community screening (Archibald & Joanisse, 2009; Gathercole, Alloway et al., 2008). Could their problems be a consequence of more pervasive executive function deficits? Evidence on this issue is mixed. Studies of children with general deficits in WM, reported impairments in shifting between response sets and planning, but not in inhibitory control (St Clair-Thompson, Stevens, Hunt, & Bolder, 2011) or teacher ratings of other aspects of executive control (Gathercole, Alloway et al., 2008). In children with ADHD, the greatest executive function impairments are found in WM, planning and response inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Thus, problems in the executive control WM appear to lack specificity and are associated with impairments in at least some other executive functions. This raises important issues concerning the extent to which learning difficulties are consequences of problems in working memory *per se*, or in the broader network of executive functions.

Interventions for WM Problems

The past decade has seen an explosion of interest in whether working memory can be enhanced through intensive training regimes that adapt continuously to maintain challenge as performance improves through repeated practice. In adults, WM performance shows sustained improvement after adaptive training, and is associated with changes following training in the fronto-parietal network serving WM (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Westerberg & Klingberg, 2007).

The Cogmed® WM Training (CWMT) program employs intensive adaptive training of multiple visuo-spatial and verbal working memory tasks over 25 days. Suitable for children from 4 years, it is effective in boosting performance both on the trained activities and on other similarly structured tasks (Klingberg, 2010). These gains have been found to persist for up to a year after training in children with ADHD (Chacko et al., 2013; Dunning, Holmes, & Gathercole, 2013; Klingberg et al., 2005) and in children with low working memory (Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009). However, the functional gains following CWMT are disappointingly limited. Gains are largely restricted to tasks similar to the trained activities, with little evidence of more consistent transfer either to tasks approximating more closely to classroom activities that tax WM or to educational attainments in key areas such as reading and mathematics (Diamond, 2011; Dunning et al., 2013; Melby-Lervag & Hulme, 2013).

Another approach is to encourage children to use effective mnemonic strategies that might relieve the pressure on relatively low memory capacities. St Clair Thompson and colleagues (2010) reported promising findings using the Memory Booster program to teach typically developing five- to eight-year-old children to use strategies such as rehearsal, visual imagery, creating stories, and grouping. It is also valuable to target the classroom environment of the child with poor WM more broadly to minimize the adverse educational consequences of WM overload (Elliott, Gathercole, Alloway, Holmes, & Kirkwood, 2010). A key step is boosting teacher understanding of WM involvement in classroom learning and of practical issues such as the warning signs of WM failure (failing to see multistep tasks through to completion, inattention, and distractibility). When these warning signs are detected, the WM loads of classroom activities can often be reduced. This can be achieved by reducing the length or complexity of verbal information to be remembered (e.g., breaking down multistep instructions or having the children write down things they need to remember). External memory aids for the child (such as digital audio recorders or personalized mini whiteboards) can also be useful, as well as practice in using mnemonic strategies in areas of strength (Archibald & Gathercole, 2006). Further information on classroom-based approaches is provided by Gathercole and Alloway (2008).

For children with core WM deficits, the most promising approach may be to combine intensive training, strategy training, and classroom-based support. For other children, such as those with verbal WM deficits associated with phonological processing difficulties, training may be of less value as it fails to address the likely underlying deficit of analyzing and representing phonological forms. Instead, phonologically based training is a priority (Hulme & Snowling, 2009) and may indeed boost verbal WM (Melby-Lervag & Hulme, 2010). However, these benefits will take time to accrue and may not be sufficient to enable children with phonological deficits to match the WM capabilities of their typical peers. This will cause continuing problems in meeting the high memory

demands of the classroom and is likely to result in inattentiveness and difficulties in following instructions (Gathercole, Darling, Evans, Jeffcock, & Stone, 2008), as well as problems in language understanding (Pimperton & Nation, 2012). Classroom-based support and strategy training may therefore be valuable adjuncts to phonological training for these children.

Overview

Impairments of WM are common and are linked with problems in learning and academic attainment. They take several different forms and may reflect deficits either within WM, in earlier perceptual processes, or in the network of executive functions. A broad assessment of cognitive functions including but not limited to WM is therefore vital. Methods of supporting children with WM problems include intensive training, practice in using mnemonic strategies, and modulating the classroom environment to avoid WM overload. Choice of suitable methods of support is best guided by an understanding of the child's core deficit. Although this deficit will be the priority target for interventions, effective management of WM loads may improve classroom functioning while interventions targeting the core deficits are ongoing.

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