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Review

How does working memory work in the classroom?

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Working memory plays a key role in supporting children's learning over the school years, and beyond this into adulthood. It is proposed here that working memory is crucially required to store information while other material is being mentally manipulated during the classroom learning activities that form the foundations for the acquisition of complex skills and knowledge. A child with a poor working memory capacity will struggle and often fail in such activities, disrupting and delaying learning. The aim of this review is to present the case that working memory makes a vital contribution to classroom learning. Following a brief introduction to working memory and its assessment, links between working memory skills and scholastic progress is reviewed and illustrated. Next, the classroom behaviour of children with very poor working memory functions, and in particular their characteristic failures in learning activities, is described. Finally, the implications of this research for classroom practice is considered; this includes an intervention programme designed to improve learning outcomes for children with poor working memory function that is based on the theoretical analysis of working memory and learning advanced here.

Key words: memory, learning, reading, mathematics, general learning difficulties.

INTRODUCTION

Working memory

Working memory is the term used to refer to a system responsible for temporarily storing and manipulating information. It functions as a mental workspace that can be flexibly used to support everyday cognitive activities that require both processing and storage such as, mental arithmetic. However, the capacity of working memory is limited, and the imposition of either excess storage or processing demands in the course of an on-going cognitive activity will lead to catastrophic loss of information from this temporary memory system.

A good example of an everyday activity that uses working memory is mental arithmetic. Imagine, for example, attempting to multiply two numbers (e.g., 43, 27) spoken to you by another person, without being able to use a pen and paper or a calculator. First of all, you would need to hold the two numbers in working memory. The next step would be to use learned multiplication rules to calculate the products of successive pairs of numbers, adding to working memory the new products as you proceed. Finally, you would need to add the products held in working memory, resulting in the correct solution. To do this successfully, it is necessary to store the two numbers, and then systematically apply multiplication rules, storing the intermediate products that are generated as we proceed through the stages of the calculation. Without working memory, we would not be able to carry out this kind of complex mental activity in which we have to both keep in mind some information while processing other materials. Carrying out such mental activities is a process that is effortful and error-prone. A minor distraction such as an unrelated thought springing to mind or an interruption by someone else is likely to result in complete loss of the stored information, and so in a failed calculation attempt. As no amount of effort will allow us to remember again the lost information,

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the only course of action is to start the calculation afresh. Our abilities to carry out such calculations are limited by the amount of information we have to store and process. Multiplying larger numbers (e.g., 142 and 891) “in our heads” is for most of us out of the question, even though it does not require greater mathematical knowledge than the earlier example. The reason we cannot do this is that the storage demands of the activity exceed the capacity of working memory.

In an experimental setting, an individual’s working memory capacity is reliably assessed by tasks in which the individual is required to process and store increasing amounts of information until the point at which recall errors are made. An example of such a task is reading span, in which the participant makes judgments about the semantic properties of sentences while remembering the last word of each sentence in sequence (Daneman and Carpenter, 1980). Tasks of short-term memory, in contrast, place menial demands on processing and are often described as storage-only tasks. Verbal short-term memory is traditionally assessed using tasks that require the participant to recall a sequence of verbal information, such as digit span and word span (Baddeley et al., 1998). Visuo-spatial short-term memory tasks usually involved the retention of either spatial or visual information. For example, in the Visual Patterns Test, the participant is presented with a matrix of black and white squares and has to recall which squares were filled in (Della Sala et al., 1997). The Corsi blocks task is an example of a spatial memory task, and participants have to recall the sequence of blocks that are tapped (Milner, 1971).

Performance on working memory tasks is subject to large degrees of individual variation. This is illustrated in Figure 1, which presents data from the listening recall test on the Automated Working Memory Assessment (AWMA) (Alloway et al., 2004). The standardisation sample consisted of 709 children attending state primary schools in the North-East of England, aged between 4 and 11 years (Alloway et al., in press). *Z*-scores were calculated using the trials correct measure of each test from all participating children; a score of 0 represents average performance on that measure across the entire age range. There was a steady developmental improvement in performance between 4 and 11 years. Comparable data collected for the Working Memory Test Battery for Children (Pickering and Gathercole, 2001) established that the linear increase in performance continues to about 12 years, with performance levelling off towards 15 years (Gathercole et al., 2004). Equally notable was the substantial degree of variability at each age, as reflected in the distance between the 10th and 90th centile bars for each measure. At 6.5 years, for example, the 10th centile is close to the mean for the 4.5 year old sample, and the 90th centile approximates to the mean performance level for 9.5 year old children. Thus, within an average class of 30 children, we would expect to see working memory capacity differences corresponding to 5 years of normal development between the three highest and three lowest scoring individuals.

Individual differences in the capacity of working memory appear to have important consequences for children’s ability to acquire knowledge and new skills. We review a number of studies in which working memory skills impact learning throughout the school years.

Working memory and reading

Reading disabilities can be characterized by marked difficulties in mastering skills including word recognition, spelling, and reading comprehension. Current evidence suggests that although verbal short-term memory is significantly associated with reading achievements over the early years of reading instruction, its role is as part of a general phonological processing construct related to reading development rather than representing a causal factor *per se* (Wagner et al., 1997; Wagner and Muse, in press). In a five-year longitudinal study of several hundred children who were followed from kindergarten through fourth grade, multiple measures of phonological awareness, verbal short-term memory, and rapid naming were administered (Wagner et al., 1997). A key finding was that at three different time periods, phonological awareness skills predicted individual differences in word-level reading, while verbal short-term memory skills did not. While studies such as these and others (Wagner et al., 1993; Wagner et al., 1994; Wagner et al., 1999) have found a high correlation between phonological awareness and short-term memory. Why is it that only phonological awareness ability predicts early reading skills? One explanation is that although the memory demands of phonological awareness tasks are similar to those of verbal memory tasks, letter knowledge and other aspects of lexical information play an important role in the performance of phonological awareness tasks (see Wagner and Muse, in press, for further discussion). Indeed, phonological short-term memory tasks that draw on lexical knowledge, such as nonword repetition, have a similarly close relationship to vocabulary acquisition (Gathercole and Baddeley, 1989; Gathercole et al., 1992; Hu, 2003; Swanson et al., 2004).

With respect to verbal working memory tasks, it is well established that children with reading disabilities show significant and marked decrements on such tasks relative to typically developing individuals (Siegel and Ryan, 1989; Swanson, 1994, 1999; Swanson et al., 1996). In typically developing samples of children, scores on working memory tasks predict reading achievement independently of measures of verbal short-term memory (Swanson and Howell, 2001; Swanson, 2003) and phonological awareness skills (Swanson and Beebe-Frankenberger, 2004). This dissociation in performance has been explained as the result of limited capacity for simultaneous processing and storage of information characteristic of working memory tasks, rather than a processing deficiency or specific problem with verbal short-term memory in poor readers (De Jong, 1998). It is important to note that studies have found that working memory skills of children with reading disabilities do not improve over time, indicating that a sustained deficit, rather than a developmental lag, best explains their memory impairment (Swanson and Sachse-Lee, 2001).

Working memory and mathematics

Associations between working memory and mathematical skills vary as a function of sample age as well as mathematical task. The age disparity in the contribution of working memory to mathematical skills is most pronounced with respect to verbal working memory tasks. For example, Bull and Scerif (2001) found a relationship between memory and math in 7-year olds (Gathercole and Pickering, 2000), but this association was no longer significant in an adolescent population (Reuhkala, 2001). One possibility is that verbal working memory plays a crucial role in mathematical performance when children are younger. However, as they get older, other factors such as number knowledge and strategies play a greater role (Thevenot and Oakhill, 2005). This view is supported by recent evidence that working memory is a reliable indicator of mathematical disabilities in the first year of formal schooling (Gersten et al., 2005).

There is growing evidence that mathematical deficits could result from poor working memory abilities. For example, low working memory scores have been found to be closely related to poor computational skills (Wilson and Swanson, 2001), and reliably differentiate children with mathematical deficits from same-age controls (Geary et al., 1999; Bull and Scerif, 2001). Weak verbal working memory skills are also characteristic of poor performance on arithmetic word problems (Swanson and Sachse-Lee, 2001). Common failures include impaired recall on both word and number-based working memory stimuli and increased intrusion errors (Passolunghi and Siegel, 2001). As with reading deficits, mathematical abilities do not improve substantially during the course of schooling, suggesting that such deficits are persistent and cannot be made up over time (Geary, 1993).

Visuo-spatial memory is also closely linked with mathematical skills. It has been suggested that visuo-spatial memory functions as a mental blackboard, supporting number representation, such as place value and alignment in columns, in counting and arithmetic (Geary, 1990; McLean and Hitch, 1999; D'Amico and Gharnera, 2005). Children with poor visuo-spatial memory skills have less room in their blackboard to keep in mind the relevant numerical information (Heathcote, 1994).

Specific associations have been found between visuo-spatial memory and encoding in visually presented problems (Logie et al., 1994), and in multi-digit operations (Heathcote, 1994). Visuo-spatial memory skills also uniquely predict variability in performance in nonverbal problems (operands presented with blocks) in pre-school children (Rasmussen and Bisanz, 2005). In contrast, the role of verbal short-term memory is restricted to temporary number storage during mental calculation (Furst and Hitch, 2000; Hechet, 2002), rather than general mathematical skills (McLean and Hitch, 1999; Reuhkala, 2001).

Working memory and general learning difficulties

Many children recognised by their school as having learning difficulties in the areas of reading and mathematics have marked impairments of working memory (Siegel and Ryan, 1989; Swanson, 1994; Swanson et al., 1996; De Jong,1998; Mayringer and Wimmer, 2000; Bull and Scerif, 2001). There have been several studies investigating possible contributions of working memory abilities to learning problems in the classroom and whether these abilities differ as a function of severity of learning deficits.

In the UK, the Special Educational Needs Code of Practice is a guide for education settings such as nurseries and playgroups, state schools and local education authorities outlining how they should identify, assess and provide help for children with special educational needs (DfES, 2002). According to this guide, any pupil who requires extra support to succeed in a regular classroom is a child who has special education needs. The term 'special educational needs' reflects a broad spectrum of problems, including physical or sensory difficulties, emotional and behavioural difficulties, or difficulties with speech. As many children at some point during their school years have special educational needs, it is important to identify the cognitive mechanisms that underlie these learning difficulties.

Alloway et al. (2005) found that children with special educational needs had working memory deficits that varied in severity according to stage of the Code of Practice for special educational needs. In particular, children with statements of special educational needs performed at significantly lower levels than children at the School Action stage on such tasks. The magnitude of working memory deficits of the special needs children were never observed in a sample of over 600 children without learning difficulties. Further evidence that deficits in working memory appear to be unique to learning difficulties is provided by Pickering and Gathercole (2004). They found that children identified as having general learning difficulties that included both literacy and mathematics performed poorly in all areas of working memory, whereas children with problems of a behavioural or emotional nature performed normally on all of the memory assessments.

A key question regarding the relationship between working memory and learning disabilities is whether working memory is simply a proxy for IQ. There is some evidence that although working memory is dissociable from general abilities (Siegel, 1998; Nation and Bryant, 2004), it may still explain individual differences in memory and scholastic attainment (Stothard and Hulme, 1992; Nation et al., 1999). However, recent research has confirmed that the specificity of associations between working memory and attainment persist after differences in IQ have been statistically controlled in children with learning difficulties (Swanson and Saez, 2003; Gathercole et al., 2006). Further evidence that verbal working memory taps more than general ability is provided by reports of differences in working memory scores in children with reading comprehension problems and other learning disabilities even after verbal IQ has been accounted for (Siegel and Ryan,1989; Cain et al., 2004).

Working memory in the classroom

An important question to consider is whether such marked working memory deficits affect classroom activities. A recent observation study of children with verbal working memory impairments can shed some light on this issue (Gathercole et al., in press). Children identified as having poor verbal working memory (i.e., standard scores <85) but normal nonverbal IQ in their first year of formal schooling were observed in the classroom one year later. These children struggled with tasks involving simultaneous storage and processing of information. Here is an example of such an activity (Gathercole and Alloway, 2004):

> The children in Nathan's class were asked to identify the rhyming words in a text read aloud by the teacher. They had to wait until all four lines had been read before telling the teacher the two words that rhymed: *tie*, and *fly*. This task involves matching the sound structures of a pair of words, and storing them.

Common failures for these children with working memory impairments included forgetting lengthy instructions, place-keeping errors (e.g., missing out letters or words in a sentence), and failure to cope with simultaneous processing and storage demands (see Gathercole and Alloway, 2005, for further discussion). One explanation for these failures is that the concurrent storage and processing demands of the activity were beyond the working memory capacities of these children. Although in isolation, it seems likely the child would be able to meet these storage requirements without difficulty. The added processing demands increased the working memory demands and so led to memory failure. This view is supported by the fact that all the children with working memory impairments were placed in the lowest ability groups in the class. Although the classroom teachers viewed their main problems as relating to lack of attention and motivation (e.g., "*He doesn't listen to a word I say*"), it is important to note that the children showed no consistent evidence of attentional deficits using the Conners' Teacher Rating Scale (1997), a diagnostic test based on teacher ratings of behaviour.

Why does working memory constrain learning? One suggestion is that working memory provides a resource for the individual to integrate knowledge from long-term memory with information in temporary storage (Swan and Saez, 2003; Swenze and Frankenberger, 2004). A child with weak working memory capacities is therefore limited in their ability to perform this operation in important classroom-based activities. A related suggestion is that poor working memory skills result in pervasive learning difficulties because this system acts as a bottleneck for learning in many of the individual learning episodes required to increment the acquisition of knowledge (Gathercole, 2004). Because low working memory children often fail to meet working memory demands of individual learning episodes, the incremental process of acquiring skill and knowledge over the school years is disrupted.

Practical Applications

Frequent failures of low memory children to meet the working memory demands of classroom activities may be at least one cause of the poor academic progress that they typically make. In order to reach expected attainment targets, the child has to succeed in many different structured learning activities designed to build up gradually across time the body of knowledge and skills that they need in areas of the curriculum such as literacy and mathematics. If the children frequently fail in individual learning situations simply because they cannot store and manipulate information in working memory, their progress is acquiring complex knowledge and skills in areas such as literacy and mathematics will be slow and difficult.

If this is the case, what can be done to ameliorate the learning difficulties resulting from impairments of working memory? While the ideal solution would be to remediate these memory impairments directly, there is little evidence that training working memory in children with low working memory skills leads to substantial gains in academic attainments (Turley-Ames and Whitfield, 2003). However, we suggest that the learning progress of children with poor working memory skills can be improved dramatically by reducing working memory demands in the classroom. As part of a large-scale project designed to identify and provide learning support in the classroom for children with working memory deficits, we recommend a number of ways to minimise via effective classroom management the memory-related failures in classroom-based learning activities frequently experienced by children with working memory impairments.

First, it is important to ensure that the child can remember what he or she is doing. On many occasions, children with low working memory simply forget what they have to do next, leading to failure to complete many learning activities. Children's memory for instructions will be improved by using the instructions that are as brief and simple as possible. Instructions should be broken down into individual steps where possible. One effective strategy for improving the child's memory for the task is frequent repetition of instructions. For tasks that take place over an extended period of time, reminding the child of crucial information for that particular phase of the task rather than repetition of the original instruction is likely to be most useful. Finally, one of the best ways to ensure that the child has not forgotten crucial information is to ask them to repeat it .Our observations indicate that the children themselves have good insight into their working memory failures.

Second, in activities that involve the child in processing and storage information, working memory demands and hence task failures will be reduced if the processing demands are decreased. For example, sentence writing was a source of particular difficulty for all of the children with low working memory that we observed. Sentence processing difficulty can be lessened by reducing the linguistic complexity of the sentence. This can be achieved in a variety of ways, such as simplifying the vocabulary, and using common rather than more unusual words. In addition, the syntax of the sentence can be simplified, by encouraging the child to use simple structures such as active subject-verb-object constructions rather than sentences with a complex clausal structure. The sentences can also be reduced in length. A child with poor working memory skills working with short sentences, relatively unfamiliar words and easy syntactic forms are much more likely to hold in working memory the sentence form and to succeed in a reasonable attempt at writing the sentence.

Third, the problem of the child losing his or her place in a complex activity can be reduced by breaking down the tasks into separate steps, and by providing memory support. External memory aids such as useful spellings displayed on the teacher's board or the classroom walls and number lines are widely used in classrooms. In our observational study, however, we found that children with poor working memory function often chose not to use such devices, but gravitated instead towards lower-level strategies with lower processing requirements resulting in reduced general efficiency. For example, instead of using number aids such as Unifix blocks and number lines that are designed to reduce processing demands, these children relied on more error-prone strategies like simple counting instead. In order to encourage children's use of memory aids, it may be necessary to give the child regular periods of practice in the use of the aids in the context of simple activities with few working memory demands.

Difficulties in keeping place in complex task structure may also be eased by increasing access to useful spellings. This will also help prevent them losing their places in writing activities. Reducing the processing load and opportunity for error in spelling individual words will increase the child's success in completing the sentence as a whole. However, reading of information from spellings on key words on the teachers' board was itself observed to be a source of error in low memory children in our study, with children commonly losing their place within the word. Making available spellings of key words on the child's own desk rather than a distant class board may reduce these errors by making the task of locating key information easier and reducing opportunities for distraction. It may also be beneficial to develop ways of marking the child's place in word spellings as a means of reducing place-keeping errors during copying.

A final recommendation for improving the learning successes of individuals with poor working memory skills is to develop in the children effective strategies for coping with situations in which they experience working memory failures. Strategies may include encouraging the child to ask for forgotten information where necessary, training in the use of memory aids, and encouragement to continue with complex tasks rather than abandoning them even if some of the steps are not completed due to memory failure. Arming the child with such self-help strategies will promote their development as independent learners able to identify and support their own learning needs.

Conclusions

Impairments of working memory are closely associated with learning deficits, as well as daily classroom activities. Without early intervention, memory deficits cannot be made up over time and will continue to compromise a child's likelihood of academic success. A classroom-based intervention designed to reduce memory-related failures that lie at the root of substantial learning difficulties is strongly recommended.

REFERENCES

Alloway TP, Gathercole SE, Pickering SJ (2004). The Automated Working Memory Assessment. Test battery available from authors.

Alloway TP, Gathercole SE, Pickering SJ (in press). Verbal and visuo-spatial short-term and working memory in children: Are they separable? Child Development.

Alloway TP, Gathercole SE, Willis C, Adams AM (2005). Working memory and special educational needs. Educ. Child Psychol. 22:56-67.

Baddeley AD, Gathercole SE, Papagno C (1998). The phonological loop as a language learning device. Psychol. Rev. 105, 158-173.

Bull R, Scerif G. (2001). Executive functioning as a predictor of children's mathematics ability. Shifting, inhibition and working memory. Developmental Neuropsychol, 19:273-293.

Cain K, Oakhill J, Bryant P (2004). Children's reading comprehension ability: concurrent prediction by working memory, verbal ability and component skills. J. Educ. Psychol. 96:31-42.

Conners K (1997). Conners' Teacher Rating Scale - Revised (S). New

York: Multi-Health Systems Inc.
Daneman M, Carpenter PA (1980). Individual differences in working memory and reading. J. Verbal Learning and Verbal Behavior, 19:450–466.
De Jong PF (1998). Working memory deficits of reading disabled children. J. Exp. Child Psychol. 70:75-96.
Della Sala S, Gray S, Baddeley AD, Wilson L. (1997). Visual Patterns Test. London: Thames Valley Test Publishing.
DfEE (2002). Special Educational Needs - A guide for parents and carers. London: Department for Education and Employment.
Fürst AJ, Hitch GJ (2000). Different roles for executive and phonological components of working memory in mental arithmetic. Memory and Cognition. 28:774–782.
Gathercole SE (2004). Working memory and learning during the school years. Proc. British Acad. 125:365-380.
Gathercole SE, Alloway TP (2004). Working memory and classroom learning. Dyslexia Review, 15:4-9.
Gathercole SE, Alloway TP (2005). Understanding working memory: A classroom guide. Medical Research Council.
Gathercole SE, Alloway TP, Willis C, Adams AM (2006). Working memory in children with reading disabilities. J. Exp. Child Psychol. 93:265-281.
Gathercole S, Baddeley A (1989). Evaluation of the Role of STM in the Development of Vocabulary of Children: A Longitudinal Study. J. Memory and Language. 28:200-213.
Gathercole SE, Lamont E, Alloway TP (2005). Working Memory in the Classroom. In S.Pickering (Ed.). Working Memory and Education. Elsevier Press.
Gathercole SE, Pickering SJ (2000). Assessment of Working Memory in Six- and Seven-year Old Children. J. Educ. Psychol. 92:377-390.
Gathercole SE, Pickering SJ, Ambridge B, Wearing H (2004). The structure of working memory from 4 to 15 years of age. Developmental Psychol. 40:177-190.
Gathercole S, Willis C, Emslie H, Baddeley A (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychol. 28:887-898.
Geary DC (1990). A componential analysis of an early learning deficit in mathematics. J. Exp. Child Psychol. 49:363-383.
Geary DC, Hoard MK, Hamson CO (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. J. Exp. Child Psychol. 74:213-239.
Gersten R, Jordan NC, Flojo JR (2005). Early identification and interventions for students with mathematics difficulties. J. Learning Disabilities, 38, 293-304.
Heathcote D (1994). The role of visuo-spatial working memory in the mental addition of multi-digit addends. Current Psychology of Cognition. 13:207-245.
Hechet SA (2002). Counting on working memory in simple arithmetic when counting is used for problem solving. Memory and Cognition, 30:447–455.
Hu C (2003). Phonological memory, phonological awareness, and foreign language word learning. Language Learning. 53:429-462.
Logie RH, Gilhooly KJ, Wynn V (1994). Counting on working memory in arithmetic problem solving. Memory and Cognition. 22:395-410.
Mayringer H, Wimmer H (2000). Pseudoname learning by German-speaking children with dyslexia: Evidence for a phonological learning deficit. J. Exp. Child Psychol. 75:116-133.
McLean JF, Hitch GH (1999). Working memory impairments in children with specific mathematics learning difficulties. J. Exp. Child Psychol. 74:240-260.
Milner B (1971). Interhemispheric differences in the localization of psychological processes in man. Brit. Med. Bull. 27:272–277.
Nation K, Adams JW, Bowyer-Crane CA, Snowling MJ (1999). J. Exp. Child Psychol. 73:139-158.
Passolunghi MC, Siegel LS (2001). Short term memory, working memory, and inhibitory control in children with specific arithmetic learning disabilities. J. Exp. Child Psychol. 80:44-57.
Pickering SJ, Gathercole SE (2001). Working Memory Test Battery for Children. Psychological Corporation Europe.
Pickering SJ, Gathercole SE (2004). Distinctive working memory profiles in children with special educational needs. Educ. Psychol. 24:393-408.
Rasmussen C, Bisanz J (2005). Representation and working memory in early arithmetic. J. Exp. Child Psychol. 91:137-157.
Reuhkala M (2001). Mathematical Skills in Ninth-graders: Relationship with visuo-spatial abilities and working memory. Educ. Psychol. 21:387-399.
Siegel LS (1988). Evidence that IQ scores are irrelevant to the definition and analysis of reading-disability. Canadian J. Psychol. 42:201-215.
Siegel LS, Ryan EB (1989). The development of working memory in normally achieving and subtypes of learning disabled children. Child Development. 60:973-980.
Stothard SE, Hulme C (1992). Reading comprehension difficulties in children. Reading and Writing: An Interdisciplinary J. 4:245-256.
Swanson HL (1994). Short-term memory and working memory - Do both contribute to our understanding of academic achievement in children and adults with learning disabilities? J. Learning Disabilities. 27:34-50.
Swanson HL (1999). What develops in working memory? A life span perspective. Developmental Psychol. 35:986-100.
Swanson HL (2003). Age-related differences in learning disabled and skilled readers' working memory. J. Exp. Child Psychol. 85:1-31.
Swanson HL, Ashbaker MH, Lee C. (1996). Learning disabled readers working memory as a function of processing demands. J. Exp. Child Psychol. 61:242–275.
Swanson HL, Beebe-Frankenberger M (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for math disabilities. J. Educ. Psychol. 96:471–491.
Swanson HL, Howell M (2001). Working memory, short-term memory, and speech rate as predictors of children's reading performance at different ages. J. Educ. Psychol. 93:720-734.
Swanson HL., Sachse-Lee C (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. J. Exp. Child Psychol. 79:294-321.
Swanson HL, Saez L (2003). Memory difficulties in children and adults with learning disabilities. In H.L. Swanson, S. Graham, KR Harris (Eds.), Handbook of learning disabilities, pp. 182-198. New York: Guildford Press.
Swanson HL, Saez L, Gerber M, Leafstedt J (2004). Literacy and cognitive functioning in bilingual and nonbilingual children at or not at risk for reading disabilities. J. Educ. Psychol. 96:3-18.
Thevenot C, Oakhill J (2005). The strategic use of alternative representations in arithmetic word problem solving. Qtrly J. Exp. Psychol. 58A:1311-1323.
Turley-Ames K, Whitfield MM (2003). Strategy training and working memory task performance. J. Memory and Language. 49:446-468.
Wagner RK, Muse A (in press). Working memory deficits in developmental dyslexia. In TP Alloway, TP, SE Gathercole (Eds), working memory in neurodevelopmental conditions. Psychology Press.
Wagner RK, Torgesen JK, Laughon P, Simmons K, Rashotte CA (1993). Development of young readers’ phonological processing abilities. J. Educ. Psychol. 85:83-103.
Wagner RK, Torgesen JK, Rashotte CA (1994). Development of reading-related phonological processing abilities: New evidence of bi-directional causality from a latent variable longitudinal study. Developmental Psychol. 30:73-87.
Wagner R, Torgesen J, Rashotte C (1999). Comprehensive Test of Phonological Processing. Austin, TX: Pro-Ed.
Wagner RK, Torgesen JK, Rashotte CA, Hecht SA, Barker TA, Burgess SR, Donahue J, Garon T (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. Developmental Psychol. 33:468-479.
Wilson KM, Swanson HL (2001). Are mathematical disabilities due to a domain-general or a domain-specific working memory deficit? J. Learning Disabilities 34:237-248.