INT. J. OF DEVELOPMENTAL DISABILITIES, Vol. 59 No. 1, March, 2013, 35–46

POINTS OF VIEW

Working memory and learning disabilities

Mokhtar Malekpour, Sara Aghababaei and Ahmad Abedi
Department of Children with Special Needs, University of Isfahan, Iran

Working memory is defined as a cognitive system which is responsible for temporary storage and information processing. In the development of working memory, normal children by age 4 demonstrate function of diverse working memory components and by age 16, all levels of working memory performance are established. Deficiency in working memory impacts learning. This memory is important in learning disabilities such as reading disability, mathematics disability, and written expression disability as well. With regard to children's difficulties with learning disabilities in working memory, research suggest some remedial strategies for improvement of working memory. This strategies include rehearsal, chunking, and meta-cognitive strategies.

KEYWORDS Working memory, Mathematics learning disability, Reading learning disability, Written expression learning disability

Introduction

In the study of human cognitive functions over the past 35 years, working memory has been one of the most influential constructs (Dehn, 2008). One area of executive functions is working memory. Working memory is considered as a component of executive functions due to its function in the organizational aspects of memory and the role it plays in goal-directed behaviour (Baltruschat *et al.*, 2011). The term working memory describes the ability to store (keep online) information and processing the information at the same time. Most researchers agree that working memory consists of several specialized components. However, there is little agreement on the exact nature and composition of these components (Gathercole *et al.*, 2006). Overall, working memory is viewed as a comprehensive system that unites various short- and long-term memory subsystems and their functions (Baddeley, 1986). The concept of working memory proposed by Baddeley and Hitch provided such a framework for conceptualizing the role of temporary information storage in the performance of a wide range of complex cognitive tasks (Dehn, 2008). The multiple component model of Baddeley captures

 DOI 10.1179/2047387711Y.0000000011

the idea that working memory is more than just a single short term store (Sayala, 2007). Baddeley (1986) defined working memory as 'a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as comprehension, learning, and reasoning'. As originally proposed, Baddeley and Hitch's multifaceted model comprised three aspects of working memory — a phonological loop, a visuospatial sketchpad, and a central executive that controlled the other two subsystems (i.e. phonological loop and visuospatial sketchpad) (Dehn, 2008). The phonological loop, originally referred to as the articulatory loop, is a limited capacity, speech-based store of verbal information (Baddeley, 1986). The visuospatial sketchpad is responsible for the short-term storage of visual and spatial information, such as memory for objects and their locations. It also plays a key role in the generation and manipulation of mental images (Baddeley, 2006). The central executive — what many consider the core of working memory, is responsible for controlling the other two subsystems and regulating and coordinating all of the cognitive processes involved in working memory performance, such as allocating limited attentional capacity (Dehn, 2008). To explain the influence of long-term memory on the contents of working memory, Baddeley (2000, 2006) recently added a fourth subcomponent — the episodic buffer — to his model. The episodic buffer is a limited-capacity subcomponent, consciously accessible, that interfaces with long-term episodic and semantic memory to construct integrated representations based on new information. The episodic buffer also provides direct encoding into long-term episodic memory (Pickering and Gathercole, 2004). The addition of the episodic component greatly increases the types of information, such as semantic information, that can be stored and processed in working memory (Dehn, 2008). Working memory has been linked to systems in the dorsolateral regions of the frontal lobes for monitoring the information, and the ventrolateral regions for maintaining the information (Semrud-Clikeman and Teeter Ellison, 2009).

The aim of this manuscript is to describe working memory as an important component of executive functions and the importance of working memory in learning disabilities (reading, mathematics and written expression), as well as the role of interventions in working memory.

Working Memory Development

By age 4, normal children demonstrate the functioning of diverse working memory components. At 16 years of age, adult levels of working memory performance are pretty much established. When working memory fails to unfold normally, the consequences can be profound. The pervasive influence of working memory on many diverse cognitive functions can mean only one thing — working memory is the linchpin of cognitive processing (Dehn, 2008). The development of working memory proceeds in conjunction with other related cognitive processes, such as executive functioning, which is one reason why working memory span continues to grow into adolescence (Dehn, 2008). Developmentally, verbal short-term and working memory spans increase two- to three-fold between the ages of 4 and 16, with more gradual improvement after age 8 (Gathercole, 1999). At age 4, the typical child can recall an average of three digits in order. By 12 years of age, the span has doubled to about six digits, and by 16, digit span has reached a plateau at

7–8 digits (Hulme and Mackenzie, 1992). Although the functioning of each dimension differs from that of adults, separable working memory components appear to be present in children as young as 4 years of age (Hitch, 1990). Gathercole *et al.*, (2004) have determined that Baddeley's tripartite working memory structure is basically in place by age 6. From 6 onward, there is no evidence of any significant change in structure; the working memory subsystems of childhood closely resemble those of adulthood. In early childhood, the three Baddeley components are relatively independent, but as executive functions of working memory mature, there is a greater degree of interdependence between the functioning of the executive and the short-term components. In the study by Gathercole and colleagues, the correlation between the central executive and phonological short-term memory increased from 0·73 at age 6 to 0·90 or greater for 10- to 15-year-olds (Gathercole *et al.*, 2004). Limitations in short-term span can constrain the development of working memory (Bayliss *et al.*, 2005). Most psychologists agree that increased use of sophisticated control processes and strategies can only enhance the operating efficiency of working memory (Dehn, 2008).

Working Memory Assessment

Since the early days of psychology, when more children began attending school for longer periods of time, the existence of individual differences in mental capabilities, including memory, has been apparent (Dehn, 2008). In 1905, Binet and Simon included short term memory subtests in their seminal intelligence scale (Binet and Simon, 1905). Wechsler did the same with the introduction of his first scale in 1939 (Wechsler, 1939). Despite the early start, the development of broad-based memory scales did not occur until nearly the end of the twentieth century. Within the past 15 years, interest in the measurement of working memory has corresponded with several new options. For example, the most recent revisions of intellectual scales have incorporated 'working memory' measures for the first time. Also, batteries designed for the comprehensive assessment of working memory have been introduced. Unfortunately, now that we have the measurement technology for working memory assessment, the usefulness of school-based cognitive testing is being challenged, especially in regard to assessment for learning disabilities. Although a comprehensive assessment of working memory and related cognitive processes is recommended when students are referred for learning problems, the informal methods and standardized tests should vary somewhat, depending on the specific referral concerns, the age of the student, and the measurement tools available. Since, there is no a standard battery for testing working memory, assessment procedures should be individualized for each case (Dehn, 2008). The Wechsler Memory Scale-Third Edition (WMS-III) is a comprehensive, in-depth memory assessment battery designed for adults and older adolescents. With the WMS-III, an examiner can assess both the visuospatial and verbal aspects of the three core memory systems: short-term, working, and long-term memory (Goldstein and McNeil, 2004).

Based on 25 years of working memory research, Working Memory Test Battery for Children (WMTB-C) is the only norm-referenced battery specifically designed to measure Baddeley's triarchic theory of working memory (Pickering and Gathercole, 2001). The WMTB-C measures the central executive, visuospatial sketchpad, and phonological loop, but excludes the episodic component (Pickering and Gathercole, 2001). The measurement was standardized on 750 children from seven schools in England. This measurement is useful for children age 4:7 to 15:9 years old (Dehn, 2008).

Another test in this field is Automated Working Memory Assessment (AWMA) which is a computer-based assessment of working memory skills that was developed in the United Kingdom. Its main purpose is to identify significant working memory problems in individuals between 4 and 22 years of age (Alloway, 2007). Most of the AWMA's subtests are modifications of WMTB-C subtests. However, the structure of AWMA is different from the WMTB-C and the AWMA includes several unique subtests (Alloway, 2007).

In order to assess verbal working memory, the following measurement can be used as well: Memory for sentences, Memory for stories, Reading span and Listening span. Visual–spatial working memory is measured via Counting span and Backward block-topping span and executive working memory is measured via Backward word span, Computation span and Trail-making Test (Dehn, 2008).

Working Memory and Learning Disabilities

In 2006, approximately 2·9 million children, or about 5·5% of the school-age population in the USA, received special education for a specific learning disability (US Department of Education, 2006). Many educators and psychologists acknowledge that individuals with learning disabilities are likely to have a deficiency in one or more cognitive processes, including phonological processing, auditory processing, long-term retrieval, attention, short-term memory, and working memory (Masoura, 2006). In particular, research (Swanson and Berninger, 1996) has consistently found that children with all types of learning disabilities display poor working memory performance, especially in verbal and executive working memory. When children with learning disabilities are matched with controls that have the same intelligence quotient, the learning disabilities group displays within-child deficits in specific aspects of working memory (Swanson and Alexander, 1997). Swanson and Siegel (2001) believe that intrinsic working memory limitations are the primary cause of learning disabilities. Some investigators (e.g. Korkman and Pesonen, 1994; Hanly, 2005; Swanson and Jerman, 2006) have shown that students with mathematics learning Disability in memory functions, for example, working memory, long term memory, memory for faces, memory for names, and visuospatial working memory, have low function as compared with normal students. Henry (2001) determined that children at 11- to 12 years old with a moderate learning disability could retain verbal instructions that contained up to three units of information, whereas normal children could manage five units of information. When students process other information while retaining verbal instructions (a typical classroom situation), those with learning disabilities can maintain only one item of information, whereas non-disabled students can handle an average of three units of information (Henry, 2001). A working memory deficit clearly puts those with learning disabilities at a significant disadvantage in the classroom (Dehn, 2008). The working memory deficits of those with learning difficulties seem to arise from neurobiological limitations in working memory and as well as inefficient use of working memory resources. Support for a neurological basis comes from evidence that working memory deficits are significantly resistant to change (Swanson, 2000). The strong relationships between working memory deficits and a wide range of learning disabilities suggest that working memory should be assessed whenever a child is referred for a possible learning disability. The empirical evidence indicates that working memory performance is one source of data that can reliably differentiate between students with a learning disability and those who are slow learners (Swanson *et al.*, 1990).

Working Memory and Mathematics Learning Disability

In regard to role of working memory in mathematics weakness, psychological research has indicated that there is a strong relationship between a mathematical function and working memory (Dehn, 2008). Hutton and Towse (2001) reported a correlation of 0·45 between digit span and performance on mathematical tests. Swanson and Beebe-Frankenberger (2004) reported a correlation of 0·54 between working memory and mathematics problem solving. Hitch *et al.* (1988) found that preschool children rely on visuospatial working memory more than older children do, and Rasmussen and Bisanz (2005) found visuospatial working memory to be the best and only unique predictor of preschool performance on standard non-verbal arithmetic problems. Children with mathematics learning disability have problems in verbal, visuospatial, and executive working memory (Bull *et al.*, 1999; Geary *et al.*, 2000). Wilson and Swanson (2001) found that verbal working memory is a better predictor of mathematical computation than visuospatial working memory. Executive working memory also plays an indispensable role during all types of mathematical computation and reasoning tasks (Andersson and Lyxell, 2007; Imbo and Vandierendonck, 2007). A study by Rossell and colleagues compared memory abilities in children with mathematics learning disability with children with reading and mathematics learning disability. Results showed that both groups in comparison with control group received lower scores in working memory (Rossell *et al.*, 2006). In an independent study, Mabbott and Bisanz (2008) also concluded that students with mathematics learning disability in calculation skills, working memory, and knowledge of perception were significantly lower than normal children.

Van der Sluis and co-workers found that deficits in the phonological loop may not be a defining characteristic for children with arithmetic learning disabilities (Van der Sluis *et al.*, 2005). Recent studies have also reported visual–spatial deficits in children with specific arithmetic disabilities (Geary *et al.*, 2000; Bull *et al.*, 1999). Van der Sluis *et al.* (2005) found a deficit only in the central executive that could be interpreted as combination of the minor deficits of reading disabled or arithmetically disabled children. Also central executive of working memory plays an important role in predicting arithmetical performance (Masoura, 2006). It seems that in children with arithmetic disabilities, the central executive system is unable to activate a sufficient amount of information from long-term memory and integrate this information from either phonological loop or the visuospatial sketchpad (Masoura, 2006).

Working Memory and Reading Learning Disability (Dyslexia)

Several recent studies have shown that differences between less skilled readers and skilled readers on measures of cognitive function are related to limitations in working memory (e.g. Passolunghi and Siegel, 2001). Impairments in working memory have been described as one of the major defining characteristics of dyslexia, and memory difficulties will have a significant impact on a dyslexic individual throughout life (Dehn, 2008). Verbal working memory span, also referred to as complex span, correlates highly with children's reading abilities, especially their reading comprehension (Hulme and Mackenzie, 1992). Hutton and Towse (2001) reported a correlation of 0·45 between digit span and tests of reading. Pickering and Gathercole (2001) have also found dyslexic children show, on average, lower reverse digit span scores and other findings support larger levels of interference amongst dyslexic children. Further support for the role of working memory in reading disabilities comes from several studies that have found a deficiency in working memory capacity to be one of the variables that differentiates between normal and dyslexic readers (Swanson *et al.*, 1990). Although working memory deficits have not yet been identified as the only cause of reading disabilities, however, it is clear that working memory contributes a significant role in reading (McCallum *et al.*, 2006).

The following studies provide examples of deficiencies in working memory components with regard to reading disability. Researchers believe that children with dyslexia have deficiencies in verbal working memory (Pickering and Gathercole, 2004) phonological processing (Maehler and Schuchardt, 2009), central executive functioning (Landerl *et al.*, 2004), and visual–spatial working memory (Kibby *et al.*, 2004). Children with reading disabilities have difficulty with visuospatial sketchpad; they may have difficulty performing spatial tasks, reading and following maps, or coping items down from the board (Kibby *et al.*, 2004). If a child has a dysfunction in the central executive, he or she would have difficulty performing two simultaneous tasks, such as trying to remember what he or she has read while engaged in the task of decoding. Although the child may be able to decode novel words successfully, the demands placed on the limited-capacity central executive would not leave additional resources free to retain information for comprehension (Kibby *et al.*, 2004). Several studies suggest that children with reading disabilities suffer working memory deficits related to the phonological loop (Swanson *et al.*, 2010), although children with reading disabilities do not suffer deficits in all aspects of the phonological loop or the executive system. Those aspects of the phonological system that appear problematic for children with reading disabilities were related to the accurate access to speech codes, and those aspects of the executive system that appear faulty were related to the concurrent monitoring of processing and storage demands (Swanson *et al*, 2009).

Working Memory and Written Expression Learning Disability

Written expression is a complex cognitive activity that requires the integration of several cognitive processes and memory components (Kehler, 2006). Compared to reading and mathematics, there have been fewer scientific inquiries into the relationship between working memory and written language. Despite the limited research, there can be little doubt that written language production depends heavily on working memory and all that aspects of verbal and executive working memory are fully involved, even in proficient writers (Dehn, 2008). Similar to the relationship between reading decoding proficiency and the working memory resources available for reading comprehension, it appears that mastery of elementary writing processes, such as punctuation, spelling, and transcribing, allows greater working memory capacity for the higher level writing processes of generating, organizing, and revising (Swanson and Berninger, 1996). Kellogg's study (2001) supported the notion that planning, translating and reviewing in text production complete for a common working memory resource. All of the writing steps place very heavy demands on working memory, especially on the executive and verbal components. In addition to substantial reliance on executive and verbal working memory, phonological short-term memory contributes to writing by briefly storing phonological representations of the words or sentence under construction. Also, visual working memory is involved in the planning phase of written expression production and during recalling definitions of concrete nouns (Kellogg *et al.*, 2007). Overall, written expression places so many demands on working memory that several aspects of written language production are probably competing for the same working memory resources (Kellogg *et al.*, 2007).

It is proposed that working memory plays a role in coordinating all the processes in writing, such as setting goals, generating ideas, planning words, sentences and text structure, monitoring, and revising (Kehler, 2006).

Interventions in Working Memory

Interventions for cognitive and working memory processing deficiencies have mostly been researched and developed within the fields of neuropsychology, cognitive psychology, educational psychology, and special education. After introducing the constructs of information processing and working memory, cognitive psychologists were instrumental in promoting early research on compensatory strategies for working memory limitations (Dehn, 2008). Educational psychologists and special educators followed investigations in order find out how strategic processing and effective teaching practices might enhance encoding and retrieval of information (Swanson and Hoskyn, 1998). More recently, neuroscientists have been using neuroimaging technology to reveal the various brain processes involved in learning (Berninger and Richards, 2002), and neuropsychologists have been developing new treatments for working memory deficits associated with attention deficit hyperactivity disorder (ADHD) (Klingberg *et al.*, 2002) and acquired brain injury (Eslinger, 2002).

Teaching strategies to improve performance in working memory tasks, such as rehearsal, chunking, and meta-cognitive strategies. Rehearsal, simply saying, the material over and over to oneself, is the first and most basic component to improve memory, and is usually develops without any explicit instruction or training (Dehn, 2008). Rehearsal, a serial repetitive process, allows information to be maintained in working memory for a longer period of time (Gathercole, 1999). Meta-cognitive strategy training typically involves the teaching of strategies relating to a specific cognitive, behavioral and academic task (Dehn, 2008). Interventions for working memory involve the teaching of a strategy or mnemonic as well (Dehn, 2008).

A number of studies have evaluated approaches to improving working memory, often focusing on children with ADHD or Down's syndrome (Baltruschat *et al.*, 2011). Farb and Throne (1978) found that a rehearsal training program effectively improved the mnemonic performance of a child with Down syndrome. Baltruschat *et al.* (2011) examined the use of positive reinforcement for improving performance on counting span tasks which are said to measure the central executive component of working memory. Results of this study showed that basic behavioural intervention procedures may be successful in improving performance on complex behaviours such as those labelled as 'working memory'.

Aghababaei and Malekpour (2010) investigated the impact of training in executive functions (in relation with working memory and response inhibition) on children with spelling learning disability. Findings of this research indicated that executive functions (such as working memory) training can improve spelling performance of children. Abedi and Aghababaei (2011) investigated the effect of training in working memory on children with mathematics learning disability as well. Findings of this research showed that working memory training can improve mathematics performance of children. In another study involving seven children with ADHD, Klingberg *et al.* (2002) found a significant treatment effect for a reasoning task and non-practiced visuospasial working memory task, as well as significant increase in working memory capacity for trained tasks. Studies have found that computerized working memory training increases working memory capacity and to bring about changes in relation to brain activity (Klingberg *et al.*, 2002, 2005). Olesen and colleagues found that brain activity related to working memory is increased after working memory training as well (Olesen *et al.*, 2004).

In general, students with low working memory spans can be expected to benefit the most from training in working memory strategies, even though if they are slower to learn the strategies than trainees with high working memory spans (Turley-Ames and Whitfield, 2003). The results of various studies showed that training on working memory induced plasticity in regions that are thought to be critical in working memory (Takeuchi *et al.*, 2010). These studies have shown that training on working memory tasks and on other cognitive tasks can improve performance on trained tasks and untrained cognitive tasks (Perrig *et al.*, 2009).

Many other investigations have confirmed that working memory capacity, especially working memory span, can be increased through strategy training

(Comblain, 1994; McNamara and Scott, 2001; Minear and Shah, 2006) and that the improvement often generalizes to untrained working memory tasks and related cognitive processes, such as reasoning (Klingberg *et al.*, 2002).

Conclusion

Working memory is one of important aspects of cognitive functions. The term 'working memory' describes the ability to store information and processing the information. According to Baddeley (1986), working memory is defined as a system for the temporary holding and manipulation of information. In development of working memory, normal children by age 4 demonstrate function of diverse working memory components and by age 16, all levels of working memory performance are established. The development of working memory proceeds in conjunction with other related cognitive processes, such as executive functions. In assessment of working memory within the past 15 years, interest in the measurement of working memory has resulted in several new options. For example, the most recent revisions of intellectual scales have incorporated 'working memory' measures for the first time. Two common measurements are AWMA and WMTB-C.

Regarding learning disabilities, working memory plays an important role. For example, Swanson and Siegel (2001) believe that intrinsic working memory limitations are the primary cause of learning disabilities. The strong relationships between working memory deficits and a wide range of learning disabilities suggest that working memory should be assessed whenever a child is referred for a possible learning disability.

With regard to difficulties which children with learning disabilities have in working memory, researches suggest some remedial strategies for improvement of working memory. These strategies include rehearsal, chunking, and meta-cognitive strategies.

References

Abedi, A. and Aghababaei, S. 2011. Effectiveness of working memory training on improving academic performance of children with mathematics learning disability, *J. Clin. Psychol.*, 4, 73–81.

Aghababaei, S. and Malekpour. M. 2010. Effectiveness of executive functions training (in relation with working memory & response inhibition) on improvement of executive functions and academic performance of students with spelling learning disability, University of Isfahan, Isfahan, Iran.

Alloway, T. P. 2007. Automated Working Memory Assessment; London, Harcourt Assessment.

Andersson, U. and Lyxell, B. 2007. Working memory deficit in children with mathematical disabilities: a general or specific deficit?, *J. Exp. Child Psychol.*, **96**, 197–228.

Baddeley, A. D. 1986. Working memory; New York, Oxford University Press.

Baddeley, A. D. 2000. The episodic buffer: a new component in working memory?, *Trends Cogn. Sci.*, **4**, 417–423.

Baddeley, A. D. 2006. Working memory: an overview, in Working memory and education, (ed. S. J. Pickering), 1–31; Burlington, MA, Academic Press.

Baltruschat, L., Hasselhorn, M., Tarbox, J., Dixon, D. R., Najdowski, A. C., Mullins, R. D. and Gould, E. R. 2011. Addressing working memory in children with autism through behavioral intervention, *Res. Autism Spectr. Disord.*, **5**, 267–276.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M. and Leigh, E. 2005. Mapping the developmental constraints on working memory span performance, *Dev. Psychol.*, **41**, 579–597.

Berninger, V. W. and Richards, T. L. 2002. Brain literacy for educators and psychologists; San Diego, CA, Academic Press.

Binet, A. and Simon, T. 1905. Sur le nécessité d'établir un diagnostique scientifique des états inférieurs de l'intelligence, *L'Anée Psychol*, **12**, 191–244.

Bull, R., Johnston, R. S. and Roy, J. A. 1999. Exploring the roles of the visual–spatial sketchpad and central executive in children's arithmetical skills: views from cognition and developmental neuropsychology, *Dev. Neuropsychol.*, **15**, 421–442.

Comblain, A. 1994. Working memory in Down's syndrome: training the rehearsal strategy, *Down Syndr. : Res. Pract.*, **2**, 123–126.

Dehn, M. J. 2008. Working memory and academic learning; Hoboken, NJ, Wiley.

Eslinger, P. J. 2002. Neuropsychological interventions: clinical research and practice; New York, Guilford.

Farb, J. and Throne, J. 1978. Improving the generalized mnemonic performance of a Down syndrome child, *J. Appl. Behav. Anal.*, **11**, 413–419.

Gathercole, S. E. 1999. Cognitive approaches to the development of short-term memory, *Trends Cogn. Sci.*, **3**, 410–419.

Gathercole, S. E., Alloway, T. P., Willis, C. S. and Adams, A. M. 2006. Working memory in children with reading disabilities, *J. Exp. Child Psychol.*, **93**, 265–270.

Gathercole, S. E., Pickering, S. J., Ambridge, B. and Wearing, H. 2004. The structure of working memory from 4–15 years of age, *Dev. Psychol.*, **40**, 177–190.

Geary, D. C., Hamson, C. O. and Hoard, M. K. 2000. Numerical and arithmetical cognition: a longitudinal study of process and concept deficits in children with learning disability, *J. Exp. Child Psychol.*, **77**, 236–263.

Goldstein, L. H. and McNeil, J. E. 2004. Clinical neuropsychology: a practical guide to assessment and management for clinicians; London, Wiley.

Hanly, T. V. 2005. Commentary on early identification and intervention for students with mathematical difficulties: make sense — do the math, *J. Learn. Disabil.*, **38**, 355–364.

Henry, L. A. 2001. How does the severity of a learning disability affect working memory performance?, *Memory*, **9**, 233–247.

Hitch, G. J. 1990. Developmental fractionation of working memory, in Neuropsychological impairments of short-term memory, (ed. G. Vallar and J. Shallice), 221–246; New York, Cambridge University Press.

Hitch, G. J., Halliday, S., Schaafstal, A. M. and Schraagen, M. C. 1988. Visual working memory in young children, *Mem. Cogn.*, **16**, 120–132.

Hulme, C. and Mackenzie, S. 1992. Working memory and severe learning difficulties; East Sussex, Lawrence Erlbaum.

Hutton, U. M. Z. and Towse, J. N. 2001. Short-term memory and working memory as indices of children's cognitive skills. *Memory*, **9**, 383–394.

Imbo, I. and Vandierendonck, A. 2007. The development of strategy use in elementary school children: working memory and individual differences, *J. Exp. Child Psychol.*, **96**, 284–309.

Kehler, P. M. 2006. Strategy training and working memory task performance in students with learning disabilities, University of California, Los Angeles, CA, USA.

Kibby, M., Marks, W., Morgan, S. and Long, C. 2004. Specific impairment in developmental reading disabilities: a working memory approach, *J. Learn. Disabil.*, **37**, 349–363.

Klingberg, T., Forssberg, H. and Westerberg, H. 2002. Training of working memory in children with ADHD, *J. Clin. Exp. Neuropsychol.*, **24**,781–791.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlstrm, K., Gillberg, C. G., Forssberg, H. and Westerberg, H. 2005. Computerized training of working memory in children with ADHD: a randomized, controlled trial, *J. Am. Acad. Child Adolesc. Psychiatry*, **44**, 177–186.

Kellogg, R. T. 2001. Competition for working memory among writing processes, *Am. J. Psychol.*, **114**, 175–191.

Kellogg, R. T., Olive, T. and Piolat, A. 2007. Verbal, visual and spacial working memory in written language production, *Acta Psychol.*, **124**, 297–382.

Korkman, M. and Pesonen, A. E. 1994. A comparison of neuropsychological test profiles of children with attention deficit-hyperactivity disorder and/or learning disorder, *J. Learn. Disabil.*, **27**, (60), 383–392.

Landerl, K., Bevan, A. and Butterworth, B. 2004. Developmental dyscalculia and basic numerical capacities: a study of 8–9-year old students. *Cognition*, **93**, 99–125.

Mabbott, D. J. and Bisanz, J. 2008. Computational skills, working memory, and conceptual knowledge in older children with mathematics learning disabilities, *J. Learn. Disabil.*, **41**, 15–28.

Maehler, C. and Schuchardt, K. 2009. Working memory functioning in children with learning disabilities: does intelligence make a difference?, *J. Intell. Disabil. Res.*, **53**, (1), 3–10.

Masoura, E. V. 2006. Establishing the link between working memory function and learning disabilities, *Learn. Disabil: Contemp. J.*, **4**, 29–41.

McCallum, R. S., Bell, S. M., Wood, M. S., Below, J. L., Choate, S. M. and McCane, S. J. 2006. What is the role of working memory in reading relative to the big three processing variables (orthography, phonology, and rapid naming)?, *J. Psychoeduc. Assess.*, **24**, 243–259.

McNamara, D. S. and Scott, J. L. 2001. Working memory capacity and strategy use, *Mem. Cogn.*, **29**, 10–17.

Minear, M. and Shah, P. 2006. Sources of working memory deficits in children and possibilities for remediation, in Working memory and education, (ed. S. J. Pickering), 273–307; Burlington, MA, Academic Press.

Olesen, P. J., Westerberg, H. and Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory, *Nat. Neurosci.*, **7**, 75–79.

Passolunghi, M. C. and Siegel, L. S. 2001. Short-term memory, working memory, and inhibitory control in children with difficulties in arithmetic problem-solving, *J. Exp. Child Psychol.*, **80**, 44–57.

Perrig, W. J., Hollenstein, M. and Oelhafen, S. 2009. Can we improve fluid intelligence with training on working memory in persons with intellectual disabilities, *J. Cogn. Educ. Psychol.*, **8**, 148–164.

Pickering, S. J. and Gathercole, S. E. 2001. Working memory test battery for children; London, Psychological Corporation Europe.

Pickering, S. J. and Gathercole, S. E. 2004. Distinctive working memory profiles in children with special educational needs, *Educ. Psychol.*, **24**, 393–408.

Rasmussen, C. and Bisanz, J. 2005. Representation and working memory in early arithmetic, *J. Exp. Child Psychol.*, **91**, 137–157.

Rossell, M., Matute, E., Pinto, N. and Aridila, A. 2006. Memory abilities in children with subtypes of dyscalculia, *Dev. Neuropsychol.*, **30**, 807–809.

Sayala, S. (2007). The effects of working memory practice on information representation, PhD thesis, University of Johns Hopkins, Baltimore, MD, USA.

Semrud–Clikeman, M. and Teeter Ellison, P. A. 2009. Child neuropsychology: Assessment and interventions for neurodevelopmental disorders, 2nd edn; New York, Springer.

Swanson, H. L. 2000. Are working memory deficits in readers with learning disabilities hard to change?, *J. Learn. Disabil.*, **33**, 551–566.

Swanson, H. L. and Alexander, J. 1997. Cognitive processes as predictors of word recognition and reading comprehension in learning disabled and skilled readers: revisiting the specificity hypothesis. *J. Educ. Psychol.*, **89**, 128–158.

Swanson, H. L. and Beebe-Frankenberger, M. 2004. The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties, *J. Educ. Psychol.*, **96**, 471–491.

Swanson, H. L. and Berninger, V. W. 1996. Individual differences in children working memory and writing skill, *J. Exp. Child Psychol.*, **63**, 358–385.

Swanson, H. L., Cochran, K. F. and Ewers, C. A. 1990. Can learning disabilities be determined from working memory performance?, *J. Learn. Disabil.*, **23**, 59–67.

Swanson, H. L. and Hoskyn, M. 1998. A synthesis of experimental intervention literature for students with learning disabilities: a meta-analysis of treatment outcomes, *Rev. Educ. Res.*, **68**, 277–321.

Swanson, H., L. and Jerman, O. 2006. Math disabilities: a selective meta-analysis of the literature, *Rev. Educ. Res.*, **76**, 249–251.

Swanson, H. L., Kehler, P. and Jerman, O. 2010. Working memory, strategy knowledge, and strategy instruction in children with reading disabilities, *J. Learn. Disabil.*, **43**, (1), 24–47.

Swanson, H. L. and Siegel, L. 2001. Learning disabilities as a working memory deficit, *Issues Educ.*, **7**, 1–48.

Swanson, H., L., Zheng, X. and Jerman, O. 2009. Working memory, short-term memory, and reading disabilities, *J. Learn. Disabil.*, **42**, (3), 260–287.

Takeuchi, H., Sekiguchi, A., Taki, Y., Yokoyama, S., Yomogida, Y., Komuro, N., Yamanouchi, T., Suzuki, S. and Kawashima, R. 2010. Training of working memory impacts structural connectivity, *J. Neurosci.*, **30**, (9), 3297–3303.

Turley-Ames, K. J. and Whitfield, M. M. 2003. Strategy training and working memory task performance, *J. Mem. Lang.*, **49**, 446–468.

US Department of Education, Office of Special Education and Rehabilitative Services. 2006. Twenty-sixth annual report to congress on the implementation of the Individuals with Disabilities Education Act; Washington, DC, US Department of Education.

Van der Sluis, S., de Jong, P. F. and Van der Leij, A. 2005. Working memory in Dutch children with reading- and arithmetic-related LD, *J. Learn. Disabil.*, **38**, 207–221.

Wechsler, D. 1939. The measurement of adult intelligence; Baltimore, MD, Williams & Wilkins.

Wilson, K. M. and Swanson, H. L. 2001. Are mathematics disabilities due to a domain-specific working memory deficit?, *J. Learn. Disabil.*, **34**, 237–248.

Notes on contributors

Correspondence to: M Malekpour, Department of Children with Special Needs, University of Isfahan, Isfahan, Iran. Email: mokhtarmalekpour@ymail.com