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Review

Working Memory and Learning Disabilities: A Review

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ABSTRACT

Working Memory provides a mental work place to support everyday cognitive activities that require both processing and storage. It has been found to be associated with a range of cognitive functions. Recently, a strong link between working memory and learning has been reported. This finding can be implicated in learning disabilities. It is likely that limited working memory functioning of children with learning disabilities hampers their learning skills; possibly because of the crucial role played by working memory in learning process. The current paper reviews working memory functioning in subtypes of learning disabilities (Dyslexia, Dysgraphia and Dyscalculia) and provides a detailed account of pattern of deficit seen in working memory in the three subtypes of LD. Review of literature suggests that working memory functions differently in children with LD than normal achieving children. Children with LD often fail to learn because high working memory demand of the learning task often exceeds their working memory capacity. Some researchers suggest that working memory deficits are not entirely a capacity deficit, rather a strategy deficit. Evidences suggest that learning performance of these children can be improved by teaching appropriate strategy to reduce working memory load of the task, and through remedial training. Failure to identify working memory problems at early stage and rectify resultant learning problems may leave the child struggling with this invisible handicap and can even lead to dropout from school.

Keywords: *Working Memory, Cognitive functions, Learning Disability (LD), Dyslexia, Dysgraphia, Dyscalculia*

Working memory is 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 (Baddeley, 1986). It is an online memory configuration in which certain information is held in awareness or span of attention for use in an ongoing information processing. It's a kind of mental workplace that we use for many aspects in our everyday life including reading, mental arithmetic and planning a series of thought or actions. The primary function of working memory is to facilitate and enhance the capacity of encoding, storage,

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and retrieval functions that are essential for learning and higher level processing of information.

Working memory tasks require one to hold on one important piece of information while processing the other, for example - attempting to solve a mathematical problem (e.g. multiplying two digit number) in mind requires one to remember the two numbers, apply multiplication rules, store intermediate products simultaneously and proceed through next stage of calculation. The task is possible only if we manage to meet both the storage and processing demands of the activity. Carrying out such mental activities is an effortful process. Even a minor distraction or an interruption by someone is likely to result in complete loss of the stored information, and so in a failed calculation attempt. At this stage no amount of effort will allow us to recall the lost information, the only course of action is to start the calculation afresh. Our abilities to carry out such tasks are limited by the amount of information we have to store and process (a working memory ability). We fail to perform such tasks because the storage demands of the tasks exceed our working memory capacity.

The typical classroom learning requires one to meet both storage and processing demand of the task (e.g., listening to teacher’s lecture and taking notes simultaneously). Unfortunately, not all children are able to meet these demands and consequently they fail to learn. Among these are children who are often referred as children with special educational needs and children with learning disabilities.

Learning disability (LD) manifests as persistent difficulties in learning to efficiently read (dyslexia), write (dysgraphia) or perform mathematical operations (dyscalculia) despite normal intelligence, conventional schooling, intact sensory system, adequate motivation and learning opportunity. LD results in academic underachievement that is unexpected based on child’s potential as well as the opportunity to have learned more. Approximately 5-15% school going children suffer from some form of learning disability (Krishnan, 2007; Krishna Kumar, 1999; Mehta, 2003; Karande, S. E. & Kulkarni, M., 2005). The actual number can be estimated to be higher as many children dropout from school at early stage and remain unidentified.

Learning problems has often been seen to arise from subnormal intelligence. Many even confuse a low verbal IQ with learning disability. Because intelligence includes verbal skills it is likely that a child who has subnormal intelligence, will also show learning ability that is somewhat below average. It is worth noticing that learning disabilities are specific, in the sense that they affect specific processing areas (e.g. reading, writing and mathematics) as opposed to global difficulties seen in children with compromised intelligence. Despite having average or above average intellectual functioning, children with learning disabilities fail to learn as quickly as others. This indicates that their problem can not be simply explained by intellectual functioning and there could be more complex phenomena that should be looked upon.

Working Memory and Learning process: How working memory is linked with learning

Since ages, intelligence is believed to determine one's learning ability, academic achievement and success in life. Recent researches have reported a strong link between working memory and learning. Some researchers (e.g., Alloway, T. P. 2009b) on the basis of their research findings suggest that working memory is even more important for learning than IQ (a measure of intelligence). Findings of the study indicated that working memory was a better predictor of learning than IQ even after two years. Some researchers have suggested that the key factor underlying the relationship between working memory and learning is IQ (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Stothard & Hulme, 1992). However, contrasting evidences suggest that working memory shares unique links with learning after statistically accounting for IQ (e.g., Cain, Oakhill, & Bryant, 2004; Gathercole, Alloway, et al., 2006). IQ is a measure of what a child has already learned whereas working memory measures one's ability to learn (the actual learning potential). Thus working memory seems to be a true measure of one's learning potential.

Academic learning requires children to meet both storage and processing demand of the learning task (e.g., listening to teacher's lecture and taking notes simultaneously, following a set of instructions etc.). The process of reading sentences, holding them in mind, and integrating the information to uncover the meaning relies heavily on one's ability to simultaneously process and store information over the short term. Similarly following a set of complex instruction relies on the ability to remember the different parts of the instruction while carrying out various steps to complete the action successfully. Working Memory provides a mental workspace for tasks requiring both processing and storage. A successful learning requires one to control attention to focus on relevant information while ignoring irrelevant information. This function too is governed by working memory. Working memory is required whenever anything must be learned because learning requires manipulation of information, interaction with long-term memory, simultaneous processing and storage of information. Nearly all of what must be learnt and remembered must pass through working memory. Thus working memory seems to play a crucial role in learning.

Our working memory capacities are limited. For any person there is a limit to what can be held in this mental workspace; if this limit is exceeded, information is lost. However, this working memory capacity varies greatly between the individuals. Individual differences in working memory are primarily determined by central executive processes. The typical problem seen in working memory is difficulty to hold on to the first part of information while processing the second. Working memory demand increases with task complexity. When working memory demand of a given task exceeds children's working memory capacity they forget some important piece of information which leads to a failed learning attempt. Hence, the capacity and effective functioning of working memory determines the rate and extent of learning.

Learning Disabilities as a Working Memory deficit

Learning new material requires manipulation of information, interaction with long-term memory, and simultaneous storage and processing of information. It also integrates new knowledge with prior existing information in long term memory (LTM). Individuals with learning disabilities are likely to have a deficiency in one or more cognitive processes (Masoura, 2006), including phonological processing, long term retrieval, attention, short term memory, and working memory. Out of several cognitive processes working memory has been found to be strongly related to academic skills. Numerous studies have reported a strong relationship between working memory performance, reading skills (Smith-Spark & Fisk, 2007; Swanson & Jerman, 2007), written expression (Kellogg, Olive, & Piolat 2007), and mathematics performance (Hutton & Towse, 2001).

The typical learning environment requires one to simultaneously focus on instruction, processing and storage of information in the presence of distracting stimuli making high demand on working memory. Children who are capable of meeting those demands on working memory learn the material easily but some children who have poor working memory often fail to learn because they fail to meet high working memory demand of the task. In their study Swanson & Berninger (1996) found that children with all types of learning disabilities and difficulties display poor working memory performance, especially in verbal and executive working memory. Executive working memory tasks require simultaneous processing and storage of information. Children with learning disabilities often fail to meet those demands and consequently fail to learn. The working memory load of learning task often exceeds their working memory capacity.

Studies have indicated that deficits in working memory are a common feature of a wide range of developmental disorders and specific learning difficulties, including ADHD, Dyslexia, Specific language impairment and, reading and arithmetic difficulties (Arichbald & Gathercole, 2007; Geary, Hoard, Byrd-Craven, Nugent & Numtee, 2007; Holmes, Hilton, Place, Alloway, Elliot & Gathercole, 2014; Jeffries & Everatt, 2004; Swanson, Howard & Sáez Lee, 2007).

Some investigators (e.g., Swanson & Siegel, 2001) believe that intrinsic working memory limitations are the primary cause of learning disabilities. However, because most of the research on working memory and learning disabilities is correlational, we cannot attribute causality. It has also been argued that whether working memory deficit seen in children with learning disabilities are a capacity deficit or strategy deficit. Some researchers (e.g., Swanson, 2000) theorize that a working memory deficit is not entirely a capacity deficit. Rather, for some children with learning disabilities, a working memory problem is primarily a strategy deficit. That is, children with a learning disability often possess sufficient working memory resources but fail to apply effective strategies spontaneously or consistently, resulting in learning failure. If working memory deficit is purely a strategy deficit, children with learning disabilities can be helped by teaching them appropriate strategy to deal with their working memory limitations. Once these children are able to overcome their working memory limitations they would be able to learn as effectively as others.

Working memory has also been used as a measure to discriminate between children with special educational needs and normal performing children with 81% accuracy (Gathercole and Pickering, 2001). In their study Swanson et al., (1990) tested the assumption that children of various academic abilities may be characterized by different patterns of working memory function. To test this assumption, subgroups of children were identified through a hierarchical cluster analysis based upon a test battery of sentence span, preload, and concurrent memory demand tasks. One subtype presented a profile of children with learning disabilities showing severe memory performance deficits, while another subgroup yielded high memory and high academic performance. Results of study provided partial validation for the classification of children with learning disabilities on psychometric measures according to patterns of working memory performance. Findings of these studies indicate that working memory can be used prospectively to identify children with learning disabilities. The empirical evidence also indicate 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).

In recent years, researchers have even identified specific components of working memory associated with learning disabilities, for example – deficit in central executive functioning has been found to be a characteristic feature of children with learning disabilities and children with special educational needs (e.g., Gathercole and Pickering, 2001). Similarly, pattern of deficit in different subtypes of learning disability have also been identified. To gain an understanding of pattern of deficit in working memory in subtypes of learning disability, studies have been presented separately.

Working Memory and Reading Disability (Dyslexia)

Reading skills are typically divided into two main categories—reading decoding, also known as basic reading skills, and reading comprehension. Reading decoding is primarily dependent on phonological processing—the ability to detect and manipulate the sound units (phonemes) of oral language. Reading comprehension is more complex and involves several higher level cognitive processes. Reading decoding is primarily related to phonological working memory and verbal working memory, whereas reading comprehension is primarily related to verbal working memory, executive working memory, and long-term memory (Swanson et al., 2006).

Studies have indicated that children with reading disability (dyslexia) have deficit in "phonological awareness" which is dependent on phonological loop capacity. Phonological loop plays an important role in language processing, literacy, and learning. Individuals with longer phonological spans are better at vocabulary and language learning than those with shorter spans (Baddeley, 2003a). Higher level processing of the verbal information, such as putting the words together to form an idea, involves complex working memory functions that are conducted by the central executive component of working memory.

Information encoded from verbal stimuli are also processed and stored in visuo-spatial sketchpad (Baddeley, 1999; Salway & Logie, 1995), thus visuo-spatial sketchpad may serve an important function in reading. Visuo-spatial sketchpad visually encodes printed letters and words while maintaining a visuo-spatial frame of reference that allows the reader to backtrack and keep his/her place in the text (Baddeley, 1986). Though visuospatial sketchpad is also considered to play role in reading, major deficit in reading disability (dyslexia) has been seen in phonological loop and central executive component only. For example, Pickering and Gathercole (2001) studied working memory function in 15 dyslexic children aged 7-14 years. Dyslexic children were compared with individually matched chronological age (CA) and reading age (RA) control participants. Working Memory Test Battery for Children (WMTB-C) was used to assess their working memory functions. Results showed that dyslexic children performed significantly worse than non-dyslexic children of the same age on a range of measures including; Word List Matching, Matrices static and Backward Digit Recall. In many cases, the dyslexic children's performance was similar to, if not worse than that of the younger children of the same reading age. Interestingly however, with the exception of Matrix Static Task, dyslexic children's visuo-spatial working memory performance was as good as non-dyslexic children of the same age. Findings suggest that the visuo-spatial working memory skills of dyslexic children are largely intact, in contrast to relatively poor phonological loop and central executive skills.

Gathercole, S. E. & Alloway, T. P. (2006) investigated associations between working memory and both reading and mathematics abilities. Sample consisted of 46 children (13 females, 33 boys) aged between 6 and 11 years with reading disabilities. Participants were assessed on a range of measures. Their reading and mathematical skills were assessed using Wechsler Objective Reading Dimension (WORD) and Wechsler Objective Numerical Dimensions (WOND). Working Memory Test Battery for Children (WMTB-C) was administered to assess phonological short term memory, visuo-spatial memory and complex memory (central executive component). Phonological processing skill was measured using three subtests from the Phonological Assessment Battery. The sample was characterized by deficits in complex memory (central executive functioning), visuo-spatial memory and by low IQ scores, whereas language, phonological short-term memory and phonological processing abilities fell in the low average range. Results indicated that the severity of reading difficulties was significantly associated with working memory, language and phonological processing abilities, whereas poor mathematics abilities were associated with complex memory score, phonological short-term memory and phonological processing scores. These findings suggest that working memory skills indexed by complex memory (central executive component) represent an important constraint on the development of skill and knowledge in the key domains of reading and mathematics in children with reading and mathematics disability.

On the basis of above findings and available evidences it can be concluded that reading disability (dyslexia) is associated with deficit in phonological working memory and central executive functioning.

Working Memory and Writing Disability (Dysgraphia)

Similar to reading skills writing skill also comprises of a set of skills – transcription, word and text generation, vocabulary, and text coherence. Working memory functioning in writing disability is less researched. The available evidence indicate that cognitive processes involved in written language are- working memory, executive processing, processing speed, and planning.

In a study Swanson, H. L. & Berninger, V. W. (1996) studied individual differences in children's working memory and writing skill. The sample consisted of 300 participants (100 fourth graders, 100 fifth graders and 100 sixth graders). They were measured on phonological working memory, verbal WM span, executive processing, and visuo–spatial working memory. Findings indicated that WM measures contributed unique variance to writing that was independent of reading skill, and STM measures best predicted transcription processes and reading recognition, whereas WM measures best predicted text generation and reading comprehension. Both verbal and visual–spatial working memory measures predicted reading comprehension; whereas only WM measures that reflect executive processing significantly predicted writing.

Another study conducted by Bourke, L. & Adams, M. (2003) investigated the role of working memory in young children's written language performance at word, sentence and text levels. Sample consisted of 60 children aged between 6 and 7 years attending local schools. Their non-verbal intellectual ability was assessed using Block Design Test of WISC-R. Phonological working memory was assessed using Non-Word Repetition Test, Word Span Test and Digit Span Test. Visuo-spatial working memory was assessed using Corsi Blocks tapping test and Visual Pattern Test. Central executive component of working memory was assessed by Verbal Fluency and Complex Span Test. Children's written texts were analyzed in terms of diversity of vocabulary, mean length of the sentences in morphemes, and overall coherence. Children were also assigned an attainment level according to Key Stage 1 (KS1) guidelines. Hierarchical regressions revealed that individual differences in central executive functioning predicted vocabulary diversity, text coherence and KS1 attainment level. Individual differences in working memory capacity were associated with poorer quality texts.

Findings of these studies indicate that simple writing skill (transcription process) is associated with short term memory whereas text generation (a more complex process) is governed by working memory capacity. Especially, central executive component of working memory predicts vocabulary diversity, text coherence and quality of texts.

Working Memory and Mathematics Disability (Dyscalculia)

Mathematical tasks demand both storage and processing abilities. That is, one must remember some piece of information in mind and while processing it further simultaneously. The central executive is involved whenever an individual must simultaneously store and process information (Tronsky, 2005). Mathematical skills have been found to be dependent on working memory especially executive processing, fluid reasoning, visual processing,

processing speed, and planning. Here we present some studies for a better understanding of the role of working memory in dyscalculia.

In a study Kyttälä et al. (2003) studied the relationship between visuo-spatial working memory and early numeracy in preschoolers. A total of 46 preschoolers (26 girls and 20 boys) aged between 5 yr 3 months to 6 yr 10 months were selected for this study. Their Intelligence was measured with two subtests (vocabulary and block design) of Wechsler intelligence scale for children, third edition (WISC-III). Visuo-spatial working memory was measured by a visuo-spatial test battery comprising two VSWM storage tasks (static visuo-spatial working memory and dynamic visuo spatial working memory) and one mental rotation task as a processing task. The early numeracy test for toddlers (ENT) was used to assess mathematical pre-skills. The results suggested that score on early numeracy test and counting tasks correlated with VSWM capacity as well as with intelligence (Block design test) whereas relational tasks correlated only with general intelligence. The study suggests that visuo-spatial working memory plays role in mathematical pre-skills (e.g. counting).

Another study conducted by Meyer, M. L. et al. (2010) investigated the relation between specific WM components and mathematics achievement in 2nd grade (n=20) and 3rd grade (50) children. Their IQ was assessed using Wechsler abbreviated Scale of Intelligence. Children with full-scale IQ between 80 and 120 were selected in the sample. Participant's mathematical ability was assessed using WIAT-II and working memory was assessed using four subtests of WMTB-C namely- Counting recall, Backward digit recall, Digit recall and Block recall. Results of the study indicated that for 2nd graders, the central executive and phonological components predicted Mathematical Reasoning skills; whereas the visuo-spatial component predicted both Mathematical Reasoning and Numerical Operations skills in 3rd graders. This pattern suggests that the central executive and phonological loop facilitate performance during early stages of mathematical learning whereas visuo-spatial representations play an increasingly important role during later stages.

A large sample study conducted by McLean, J. F. & Hitch, J. G. (1999) investigated working memory functioning in children with specific arithmetic learning difficulties. Sample consisted of 122 children aged 9-year (64 females and 58 males) with difficulties specific to arithmetic (as indicated by normal reading). They were compared with both age-matched and ability-matched controls. All children were administered the Graded Arithmetic–Mathematics Test, the Primary Reading Test and written tests of speeded calculation. A battery of 10 tasks was used to assess different aspects of working memory, including subtypes of executive function. Findings indicated that relative to age-matched controls, children with poor arithmetic had normal phonological working memory but were impaired on spatial working memory and some aspects of executive processing. Compared to ability-matched controls, they were impaired only on one task designed to assess executive processes for holding and manipulating information in long-term memory. Deficits in executive and spatial aspects of working memory seemed likely to be important factors in poor arithmetical attainment.

Findings of these studies indicate that visuo-spatial working memory plays role in acquisition of mathematical pre-skills (e.g. counting) in early childhood while central executive and phonological components facilitate mathematical reasoning skills. In later stages, mathematical reasoning and numerical operations skills seem to be governed by visuo-spatial working memory. In children with mathematics disability (dyscalculia) deficit in visuo-spatial working memory and central executive functioning has been observed while phonological working memory remains preserved.

Some studies have also investigated working memory in mixed/multiple learning disabilities and have reported that children with multiple learning disabilities (literacy and mathematics) perform poorly in all aspects of working memory. In contrast, children with only one specific learning disability demonstrate fairly distinctive working memory profiles, with deficits limited to one or two components. For example, children with a specific reading disability frequently have impairments in phonological short-term memory and verbal working memory (Pickering & Gathercole, 2004), whereas children with a specific mathematics disability tend to have deficits in visuo-spatial and executive working memory.

CONCLUSION

The role of working memory in academic learning and learning disabilities are discussed. Pattern of deficit in working memory differs in subtypes of learning disabilities. Reading disabilities (dyslexia) are characterized by deficit in phonological working memory and central executive functioning. Simple writing skills (e.g., transcription) are dependent on short term memory whereas as complex writing skills (e.g., vocabulary and text generation) are governed by central executive component of working memory. Thus major deficit in writing disabilities (dysgraphia) are seen in central executive functioning. Mathematical tasks demand simultaneous processing and storage and so rely heavily on central executive functioning. Thus deficit in central executive functioning seem to be a characteristic feature of mathematics disability (dyscalculia). It is believed by some researchers that working memory deficit in children with learning disabilities are not entirely a capacity deficit, rather for some children it is a strategy deficit. That is, children with learning disabilities fail to apply appropriate strategies which limit their working memory functioning and leads to learning failure. This view creates hope for these children as they can be taught appropriate strategies to overcome working memory limitations (e.g., simplifying instructions and presenting information sequentially to reduce working memory load) and learn effectively.

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