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Establishing the Link Between Working Memory Function and Learning Disabilities

Elvira V. Masoura[1]
Aristotle University of Thessaloniki

Research findings concerning working memory impairment of children with learning disabilities, poor readers, and individuals with severe learning difficulties are examined within the framework of working memory. Results from developmental and experimental studies indicate a close link between the function of working memory and performance on academic tasks. Converging evidence suggests that a deficit in working memory can affect children's ability to master language. Nevertheless, the causal relationship between working memory and learning disabilities is less well established. Limitations of the current study are discussed and suggestions for future investigations are made.

Key Words: Working Memory, Learning Disabilities.

It is widely recognized that most individuals with learning disabilities (LD) also experience a deficiency in one or more cognitive processes, such as perception, attention, memory, or metacognition (Swanson, 1996). Less is known about the cognitive mechanisms that underlie these deficits. In order to understand the exact nature of learning disabilities, it is important to identify those mechanisms.

Recent research has revealed that a specific memory system, namely, the working memory system, shares close links with language and plays a crucial role in language acquisition (Baddeley, Gathercole, & Papagno, 1998). The term *working memory* is widely used to refer to a limited capacity system responsible for storing and operating temporal information. The working memory model proposed by Baddeley and Hitch (1974) provides a theoretical framework for investigating the contributions of memory systems to cognitive processes. The model describes a mental workspace for the temporary storage and manipulation of information in a range of cognitive tasks. The multi-component model consists of three subsystems: the phonological loop, the visuo-spatial sketchpad, and the central executive.

The phonological loop is responsible for the retention and rehearsal of verbal information (Papagno, Valentine, & Baddeley, 1991), while the visuospatial sketchpad concerns the construction and storage of visual images. The key feature of the working memory model, the central executive, is responsible for higher-order functions, such as the coordination of the other two subsystems, attentional control, and the integration of working memory with long-term memory (Baddeley, 1986). Based on the limitations of the original model of working memory (Baddeley & Hitch, 1974), Baddeley (2000) proposed a fourth subsystem, the "episodic buffer."

1. Please address correspondence to: Elvira Masoura, School of Psychology, Department of Experimental Cognitive Psychology, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece; E-mail: emasoura@psy.auth.gr

The new component is assumed to be responsible for the temporary retention of prose and has the capacity of integrating information from multiple codes used by the other subsystems and long-term memory (Baddeley & Wilson, 2002).

A review of recent empirical evidence suggests that individuals with LD perform poorly on working memory tasks. This pattern is striking and appears in diverse groups of individuals with LD: Children with severe, mild, moderate, borderline or specific learning disabilities seem to be less capable of performing immediate memory tasks when compared with controls. The same picture seems to hold even when children are matched with controls for nonverbal ability, general mental ability, and language level.

Two questions arise from these finding. First, what is the exact nature of the deficit and where is it located? Second, is this deficit of short-term memory the cause of the learning disabilities these individuals experience? An attempt to address these questions is made here. The development of the working memory model with the multicomponent system of immediate memory comprises a useful framework for answering the first question. By looking at the working memory as a system with independent components, we can assess each subsystem separately, which gives us the opportunity to be more precise about the severity and the location of the impairment. By looking closely at studies that assert a causal relation between working memory function and learning disabilities occurrence, we can attempt to answer the second question.

Working Memory and Learning Disabilities

A great deal of evidence suggests that children with LD have considerable impairment of short-term memory. A possible explanation for this observation could be that problems of short-term memory may contribute significantly to the cognitive deficits found in children with LD. Given the role of short-term memory to retain and manipulate temporal information, it is a crucial system for a range of skills, such as comprehending and producing language, reading, arithmetic, and reasoning. However, this causal relationship between deficits of short-term memory and LD is based mainly on correlational evidence. Thus, a causal link between short-term memory impairments and LD has yet to be demonstrated conclusively. We will consider some of the recent evidence suggesting that individuals with LD have deficits of working memory. Even if the causal relationship cannot be demonstrated clearly, the consistency of working memory deficits over a wide range of LD suggests that the assessment of working memory skills offers a valuable method for screening children who are likely to be at risk for poor academic performance.

Children with learning disabilities are a heterogeneous group showing various academic abilities. A strategy for dealing with this variability is to assess children's cognitive abilities and then subdivide them into subgroups according to their cognitive patterns. For example, it is important to differentiate children with LD from children who are slow readers and identify the distinct cognitive deficits each group exhibits. In the case of short-term memory, a battery of memory tasks should be used to identify which specific function of working memory is impaired.

In a detailed study of children with LD, Swanson and his colleagues (Swanson, Cochran, & Ewers, 1990) found that children with a high performance on short-term memory tasks also demonstrated higher academic performance. The question that arises here is which component of working memory is deficient? In this group of children with LD it seemed that the problem did not result from poor recall or visuospatial abilities or memory span. In other words, the capacity of the peripheral systems of the phonological loop and the visuospatial sketchpad were relatively intact. The disabilities resulted mainly from the function of higher-order processes, such as the central executive. Accordingly, the subgroups of children who had adequate central executive capacity had consistently higher scores across achievement and IQ measures than other children deficient in this memory area. The authors concluded that children with LD could be classified according to patterns of memory performance and that working memory is the cognitive system that underlies individual differences in learning disability (Swanson et al., 1990).

A similar conclusion arises from data on children with special educational needs (Gathercole & Pickering, 2001). Among other working memory tasks (phonological short-term memory, visuospatial short-term memory, and central executive tasks), the backwards digit span task was the one that consistently differentiated between children with and without special educational needs at 7 and 8 years of age. The backwards digit span is a task that particularly loads the central executive, and possibly the extremely effective discriminating capacity of the task arises from its sensitivity to the function of the central executive.

In a further investigation of specific links between working memory systems and LD among children, Swanson (2000) investigated the likelihood that performance on working memory tasks can change if you give cues and probes to readers with LD. He observed that deficits of working memory performance are significantly resistant to changes. The readers with LD showed less change in working memory tasks than chronological age-matched and reading level-matched children. The author suggests a direct explanation for this lack of change: A general system that moderates the changes in the retrieval process of phonological and visual information in working memory is possibly impaired in readers with LD.

The majority of studies investigating short-term memory function among children with LD report low performance on memory tasks in groups with severe, moderate, or mild learning disabilities (Hulme & Mackenzie, 1992; Marcell & Weeks, 1988; Russel, Jarrold, & Henry, 1996). However, there is a disagreement on the exact location of the deficit. In an investigation of the relationship between the severity of LD and the working memory performance in all three components of working memory, Henry (2001) compared three groups of children who had borderline, mild, and moderate LD on their performance on working memory tasks. Overall, the working memory function was significantly lower in children with mild and moderate LD and slightly lower in children with borderline LD. The children with the borderline LD showed no evidence of impairment on visuospatial immediate memory, nor of the central executive function. The only component of working memory that appeared to be impaired in this group was the phonological loop.

This is an interesting finding. A substantial body of evidence suggests a close relationship between the functions of the phonological loop and vocabulary acquisition (Gathercole & Baddeley, 1990; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994). This particular component of working memory plays a crucial role in the learning of new words (Baddeley et al., 1998), not only in one's native language but also in a second language (Masoura & Gathercole, 1999; Service & Kohonen, 1995). All children with LD are expected to have vocabulary deficits and encounter problems on learning new words or acquiring a second language. Nevertheless, children with borderline LD seemed to be advanced in terms of visuo-spatial working memory and be rather impaired as far as phonological-loop capacity is concerned. Considering the importance of vocabulary knowledge in several academic tasks, such as reading, text comprehension, communication, spontaneous speech, and expressive language, the lack of good vocabulary skills may seriously hamper the performance of those borderliners. Whether or not the phonological memory impairment lies at the root of children's LD remains to be examined.

More detailed comparisons between the severity of learning disabilities and specific components of working memory revealed that children with moderate LD were indistinguishable from children with mild LD on visuo-spatial and phonological loop tasks, but performed significantly lower than the mild group on the more demanding, complex span tasks that load the central executive (Henry, 2001).

These slight discrepancies in the findings may be attributed to the sample's heterogeneity. That is, children with LD are a heterogeneous group, and often studies include children who are simply at the lower end of the normal distribution of ability. Moreover, some of the tasks used for working memory assessment are always appropriate. For example, a widely used task for verbal memory, the digit span, has been thought to be less sensitive than other less conventional tasks, such as the repetition of nonwords (Gathercole, 1995). Also, the status of the reverse digit span as a central executive-loaded span task has been questioned, and the low performance of on this task can be explained by deficits in verbal rehearsal in the phonological loop (Ellis, 1970). Nevertheless, the exact deficits of working memory that underlie the poor performance of groups with severe LD still remain be determined.

Children with Specific Language Impairment

Recent developmental studies among children with specific language impairment revealed that these individuals have poor performances on verbal working memory tasks (Kirchner & Klatzsky, 1985; Menyuk & Looney, 1976). The term *specific language impairment* refers to a condition where a child fails to develop language at a normal rate for no obvious reason, despite adequate progress in other areas (Bishop, 1992). Often these individuals are labeled as having "an unexpected difficulty to acquire language" or suffering "developmental aphasia," "developmental language impairment," or "language difficulties." The term *specific language impairment* is used here to refer to individuals who perform at least 12 months below their age on language tasks, have typical intelligence, and show no emotional, perceptional, or physical impairment (Stark & Tallal, 1981). In other words, their language development differs significantly from their intelligence—at least one standard deviation (World Health Organization, 1993).

Developmental studies have found that children with specific language impairment (SLI) are impaired in phonological working memory (Kirchner & Kllatzsky, 1985; Menyuk & Looney, 1976). When compared with age-matched controls, these children perform poorly on verbal short-term memory tasks (Locke & Scott, 1979; Raine, Hulme, Chadderton, & Bailey, 1991) and on tasks that assess the phonological loop of working memory (Kamhi & Catts, 1986; Taylor, Lean, & Schwartz, 1989), tasks such as word list recall or nonword list recall. Further, studies of incidental word learning have shown that SLI children are particularly poor at recalling phonologically novel names for new concepts compared with age-matched controls, although the non-phonological aspects of their acquisition of new words are unimpaired (Dollaghan, 1987; Rice, Buhr, & Nemeth, 1990). These findings have been interpreted as evidence suggesting that one specific component of working memory, the phonological loop, is impaired. Poor phonological working memory in children with SLI has been suggested as being the cause of the language impairment.

In a study of SLI children, Gathercole and Baddeley (1990) compared groups of children with disordered language to matched-controls on nonverbal intelligence and found that the former were poor on phonological working memory. Also, they showed that the verbal working memory deficit was more severe than the generalized language delay of these children. This finding is consistent with the hypothesis that memory deficits hold back children's language development. However, we do not know from this study exactly what language impairment participating children had.

In a study with well-defined children with SLI, Montgomery (1995) found that although the phonological encoding abilities of children were intact, they had difficulties processing verbal material and their phonological short-term storage capacity was reduced (Montgomery, 1995). In a similar study with a group of well-defined SLI children matched for language and age with controls, participants performed working memory tasks, such verbal repetition of words and picture pointing (van der Lely & Howard, 1993). Surprisingly, there was no significant difference between the performance of the SLI children and language-age controls. These results seem to contrast with the conclusion of Gathercole and Baddeley (1990) that SLI children have dramatic impairments of immediate phonological memory. While the study designed by van der Lely and Howard (1993) was appropriate as they carefully matched the SLI children with age-language controls, the assessments used for immediate memory were not very sensitive to memory function. Specifically, they asked children to repeat words as a measure of their phonological memory capacity. Such tasks do not only assess short-term memory but also long-term knowledge. Children (and adults) repeat familiar material such as words more easily than unfamiliar material such as nonwords (Gathercole, Frankish, Pickering, & Peaker, 1999; Hulme, Maughan, & Brown, 1991; Roodenrys & Quinlan, 2000). This all suggests that it is difficult to employ measures that merely tap the capacity of short-term memory while avoiding the contributions of long-term memory.

An alternative approach to the language problems of children with SLI has been suggested by Tallal (1976), who argues that language problems arise from a deficit in temporal processing. As such, children with SLI have difficulty identifying speech sounds due to problems in sound discrimination, particularly at the rate of normal speech (Eisenson, 1972; Merzenich et al., 1996; Tallal & Piercy, 1973). Indeed, a study by Bishop et al. (1999) with twins meeting the criteria for SLI contrasted the predictive power of a short-term memory deficit and auditory processing impairment. The authors found that phonological memory assessment was a better predictor of low language performance than auditory processing test. However, they did not find any hereditary influence on auditory processing tests while there was a significant hereditary influence on phonological short-term memory tasks.

Severe limitations of phonological working memory have been found in children with a history of SLI, whose language problems had been resolved (Bishop, North, & Donlan, 1996). This finding is even more consistent with the causality suggestion, because the group with the resolved language problems no longer had impairments on language tests, and their memory failures could have been the cause of their language problems rather than a secondary consequence of generally weak verbal skills. Also, evidence from non-English-speaking populations indicates a similar pattern of impairment in immediate memory. For example, Leonard, Sabbadini, Leonard, and Volterra (1987) found that Italian children with SLI experienced problems with immediate process of phonological information (Leonard et al., 1987).

Poor Readers and Dyslexics

Together with the interest in how children acquire the spoken forms of their language, much importance has been placed on how children become skilled readers. Thus, the reasons why some children experience unexpected difficulties in learning to read have occupied psychologists since the beginning of the last century. The processing ability that has been most closely linked with reading development is phonological awareness, the ability to process the sound structure of spoken language (Goswami & Bryant, 1990). In several tasks assessing phonological awareness children are required either to make judgments about or to manipulate the sound structures of words. Poor readers and dyslexics are impaired in a wide range of those tasks and usually fail to make correct judgments about the phonemic structure of speech stimuli (Snowling, 1981). However, reading ability has also been linked with phonological short-term memory capacity. That is, poor readers generally do not perform well on short-term memory tasks such as digit span, serial recall of unrelated strings of words, and the repetition of nonwords (see Jeffries & Everatt, 2004).

One important issue in the area of reading abilities concerns whether the children who experience difficulties in learning to read and write are one homogeneous population or, alternatively, a cluster of varying groups. For example, dyslexic children seem to be different from poor readers. While poor readers presumably represent the lower end of the normal distribution of reading abilities, dyslexics are distinctive in term of their cognitive profiles and have been characterized as disordered rather than simply lagging in developmental terms. Regardless of the qualitative differences among children with reading disabilities, impairment in phonological memory seems to be a constant finding in a number of investigations (Joanisse, Manis, Keating, & Seidenberg, 2000; Kramer, Knee, & Delis, 2000).

The first studies that revealed links between reading and phonological short-term memory compared the short-term memory characteristics of good and poor readers. The main finding was that good readers performed better than poor readers on all memory tasks (Liberman, Man, Shankweiler, & Werfelman, 1982). Similar results were found in an experiment with poor readers, who were asked to recall sequences of consonants presented auditorily. The phonological memory performance of the children of poorer reading skills was inferior. This finding was interpreted as strong evidence favoring the hypothesis that low performance on memory tasks reflects a specific impairment of the phonological loop of working memory rather than simply being a consequence of problems in reading.

Several studies have compared the phonological memory capacity of poor readers with younger control children matched for reading age. Although there was no difference on serial recall task between dyslexic children and their reading-age-matched group, the overall phonological memory performance of dyslexic children was poorer than that of age-matched controls (Johnston, 1982). The earlier experiments assessing the phonological memory of poor readers or dyslexics mainly used conventional assessments of short-term memory, such as serial recall, a task on which the child is asked to repeat back a series of auditorily or visual verbal material. Recent studies have used an alternative technique to assess phonological short-term memory, which asks children to repeat back unfamiliar items, referred to as "nonwords," immediately after they have been presented. This task has proven to be a useful and sensitive indicator of phonological memory skills (Gathercole et al., 1994).

The findings from these studies suggest that children with low reading ability are impaired in repeating nonwords. The first demonstration of this impairment was provided by Snowling (1981) in an investigation of how dyslexic children repeat spoken items. Dyslexic children were impaired in the repetition of nonwords task compared with normal controls. More important, they were impaired on this task even when compared with younger controls of matched reading ability. Further studies have confirmed this observation: Children with poor reading ability perform on nonword repetition at a lower level than younger children matched on reading ability (Brady, Shankweiler, & Mann, 1983; Snowling, Goulandris, Bowlby, & Howell, 1986). Although one interpretation of these findings could be that low reading achievement arises as a consequence of impairments in phonological working memory capacity, an alternative interpretation could be that both the low reading achievement and the deficient memory function stem from a third independent component, possibly a domain-general factor that impairs all language-related systems. Regardless of the direction of the causation, phonological short-term memory is deficient in both low-ability readers and dyslexics (see Swanson & Siegel, 2001).

The most convincing evidence that the low performance of poor readers on phonological short-term memory tasks is attributable to a pure memory deficit, rather than a secondary characteristic of their poor performance on language-related tasks, comes from longitudinal studies (Ellis, 1989; Gatehrcole & Baddeley, 1989; Mann & Liberman, 1984). A series of studies has shown that assessment of phonological memory can predict later performance on reading tasks (see Jorm, 1983, for a review). The finding that children with reading disabilities perform at significantly lower levels than those with normal reading skills has also been confirmed by studies using convergent age groups; that is, older populations and preschoolers both show this specific impairment on short-term memory. Poor phonological memory even among university students with dyslexia, who have age-appropriate performance on standardized reading and spelling measures, shows that the deficit is still evident in adult life and is rather persistent in nature (Wilson & Lesaux, 2001). Moreover, it appears that dyslexics with different native languages experience the same impairment in memory function. Such evidence comes form Greek (Porpodas, 1999), Chinese (Ho & Lai, 1999), and Italian dyslexic children (Paulesu et al., 2001).

So far, the investigations reviewed here have focused on the operation of the phonological loop component of working memory, which has been linked to language-related activities. However, there is evidence that other components of working memory might also be impaired in children with reading disabilities. While few studies have investigated the processing of visual and spatial information in working memory, it has been found that individuals with reading disabilities are poorer than controls on recalling visual-spatial information (Swanson et al., 1993). Moreover, Baddeley (1986) has argued that central executive component of working memory is involved in reading.

Children with Arithmetic Disabilities

A similar impairment in the working memory system appears to emerge also in children with arithmetic disabilities. Children with arithmetic learning difficulty differ from other children with LD in terms of their patterns of cognitive deficits. For example, children whose arithmetical LD were accompanied by reading problems were impaired on both listening-span and counting-span tasks, while children whose learning disabilities were specific to arithmetic were impaired only on counting-span and show no deficit on listening-span tasks (Siegel & Ryan, 1989).

Nevertheless, there are fewer children with LD in arithmetic only than children who have delays in both reading and arithmetic (Gibbs & Cooper, 1989). Although these children are specifically impaired in arithmetic, despite having normal intelligence, relatively little is known about them. It is possible that within schools greater importance is attached to reading than arithmetic. In a study of children with specific arithmetical learning disabilities, Hitch (1991) found that children were impaired on counting span and that this deficit holds independently of the visuospatial or auditory-verbal characteristics of the task. Hitch (1991) concluded that although there is no a clear reduction in the capacity of the working memory per se, the poor performance on concurrent span tasks has implications for children's ability to perform several arithmetical tasks.

It is still open to speculation as to which component of working memory, if any, is responsible for arithmetical learning disabilities. Unfortunately, the answers to this question are rather confusing. On the one hand, some authors argue that the component responsible for arithmetic calculations is the phonological loop (Dark & Benbow, 1994); others suggest that the visuospatial sketchpad is primarily responsible (Fletcher, 1985; Siegel & Ryan, 1989). Indeed, some have even argued that *both* a verbal and a visual-spatial working memory deficit may strongly influence mathematical performance (Clark & Campbel, 1991). However, the important fact to note here is that they all agree that a deficit within working memory is important in understanding the mechanisms involved in children with arithmetic disabilities.

In an attempt to disentangle the distinctive contributions of different working memory components to arithmetic ability, Wilson and Swanson (2001) showed that both verbal and the visual-spatial working memory composite scores can predict mathematical performance among children with arithmetic disabilities. Most important, this finding holds even when more general factors like reading ability and gender are partialed out. Because the central executive system of working memory interacts with the two passive systems, these results are in line with the hypothesis that the central executive of working memory plays an important role in predicting arithmetical performance. 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 information from the two passive systems of working memory (the phonological loop or the visuospatial sketchpad). In line with these results, more general investigations onto the links between working memory and academic achievement have shown that children with poor performance on arithmetic also score very poorly on tests that asses the central executive capacity (Gathercole & Pickering, 2000).

Related to the first question addressed here, on which component of working memory the deficit is located, results are rather conflicting. Some studies have concluded that the central executive is the system of working memory that is most hampered, whereas others have identified a deficit in one of the slave systems of working memory. Fewer studies have identified a deficit in all components of working memory. Obviously this issue merits further research. Also, the connection between the severity of the learning disabilities and the location of the deficit has gained the interest of some researchers. The few findings in this area seem to suggest that there is a differentiation and that the borderliners of learning disabilities are impaired only in the general system of working memory, the central executive.

With regard to the second question addressed here, whether the impairment in working memory can account for learning disabilities, again the results seem to be conflicting. Some authors have concluded that the memory deficits are the cause of learning disabilities whereas others have suggested that the learning disabilities result in poor performance on memory tasks. Yet others argue for a general developmental deficit that affects both systems, language and memory. To date, most evidence is correlational, and it is difficult to prove the causality of the relationship. Few investigations and longitudinal studies have attempted to rule out the possibility that language delay affects memory performance, but these findings are implications rather than proof of a causal direction. Nevertheless, the etiology of LD has produced several other suggestions of causality, due to the lack of a common agreement on this issue.

In conclusion, it seems that even if impairments in working memory are not the cause of learning difficulties among individuals with LD, the function of this system contributes significantly to their overall performance on cognitive and educational tasks. The involvement of working memory in several cognitive and educational tasks is apparent. Children rely on their working memory when they learn new words (Gathercole & Baddeley, 1990), acquire a second language (Service, 1992), read (Snowling et al., 1986), comprehend texts (Yuill, Oakhill, & Parkin, 1989), solve arithmetic problems (Siegel & Ryan, 1989), produce sentences (Adams & Gathercole, 1996), and make reasoning judgments (Baddeley & Hitch, 1974). Individuals who have good working memory function are also good at all those tasks, whereas individuals with poor working memory capacity experience difficulty in reading, arithmetic, comprehending language, and learning new words. The working memory system seems to be limited in capacity but important for several cognitive tasks. A deficit in such a system can dramatically affect individuals' performance on a range of academically related tasks.

A cognitive system that for several years has been thought to be responsible merely for remembering telephone numbers until we have dialed them seems to play an important role in several cognitive tasks such as reading, arithmetic, reasoning, text comprehension, and word learning. Thus, with the development of the working memory model it has become apparent that this is a multicomponent system that functions as a workplace where information is temporarily stored and manipulated in order to support ongoing complex cognitive activities. Evidence from developmental, experimental, and neuropsychological studies has made it clear that deficits in working memory can result in poor performance on several tasks acquired at school. Although an impairment of working memory seems to be present in children with learning disabilities, arithmetic disabilities, and specific language impairment, the causal link between working memory function and learning disabilities has not been established. At the rate with which short-term memory models are developing, it is simply a matter of time before we will have a full account of the exact function of short-term memory and its involvement in cognitive tasks. The investigation of specific memory impairments in individuals with learning disabilities is of great educational and theoretical value: Assessment of cognitive mechanisms such as working memory can offer a method for screening children who are at risk of encountering learning disabilities at school and can contribute to a better understanding of the nature of learning disabilities.

Elvira Masoura *is a lecturer in the Deparment of Psychology at Aristotle University of Thessaloniki. Her research interests involve the functioning of memory across different cultures and populations.*

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