Working memory functioning in children with learning disabilities: does intelligence make a difference?

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Abstract

Background Children with learning disabilities are identified by their severe learning problems and their deficient school achievement. On the other hand, children with sub-average school achievement and sub-average intellectual development are thought to suffer from a general intellectual delay rather than from specific learning disabilities. The open question is whether these two groups are characterised by differences in their cognitive functioning. The present study explored several functions of working memory.

Method A working memory battery with tasks for the phonological loop, the visual–spatial sketchpad and central executive skills was presented in individual sessions to 27 children with learning disabilities and normal IQ (ICD-10: mixed disorders of scholastic skills), 27 children with learning disabilities and low IQ (intellectual disabilities), and a control group of 27 typically developing children with regular school achievement levels and normal IQ.

Results The results reveal an overall deficit in working memory of the two groups with learning disabilities compared with the control group. However, unexpectedly, there were no differences between the two groups of children with disabilities (normal vs. low IQ).

Conclusions These findings do not support the notion of different cognitive functioning because of differences in intelligence of these two groups. In the ongoing discussion about the role of intelligence (especially as to the postulated discrepancy between intelligence and school achievement in diagnosis and special education), our findings might lead to rethinking the current practice of treating these two groups as fundamentally different.

Keywords working memory, intellectual disabilities, learning disabilities

Introduction

Working memory deficits are being widely discussed and identified as possible causal factors underlying learning disabilities. Although various models of working memory have been developed, the British model by Baddeley (1986) has proved a particularly useful theoretical tool in numerous studies on learning disabilities. According to this model, working memory comprises three components: the modality-free central executive, which is a kind of supervisory system that serves to control and regulate the occurring cognitive processes, and two slave systems, the phonological loop and the visual–spatial sketchpad.
The functions of the central executive identified by Baddeley (1996) include (1) coordinating the slave systems; (2) focusing and switching attention; and (3) retrieving representations from long-term memory. The two slave systems perform modality-specific operations. Verbal and auditory information is temporarily stored and processed in the phonological loop. Two components of the phonological loop are distinguished: the phonological store and the subvocal rehearsal process. The visual–spatial sketchpad is concerned with remembering and processing visual and spatial information; it comprises a visual cache for static visual information and an inner scribe for dynamic spatial information (Logie 1995; Pickering et al. 2001).

Research has provided numerous indications that specific learning disabilities are associated with working memory impairments (Alloway & Gathercole 2006; Pickering 2006a). There is considerable evidence that children with specific reading disabilities have deficits in phonological processing and storage (Vellutino et al. 2004; Pickering 2006b; Swanson 2006). Further evidence suggests that these children also experience deficits in central executive functioning (Landerl et al. 2004; Pickering 2006b). However, relatively few reports exist with regard to impairments of the visual–spatial working memory of children with reading disabilities (Kibby et al. 2004; Pickering 2006b).

Empirical findings on children with specific arithmetic learning disabilities are also available for all three domains of working memory (Passolunghi 2006). Here, the central executive seems to be particularly impaired (Geary et al. 1999, 2000; Passolunghi & Siegel 2001; Swanson & Sachse-Lee 2001), while findings on the phonological loop are inconsistent (see Swanson & Sachse-Lee 2001 vs. Geary et al. 1999, 2000 or Landerl et al. 2004). Hence, deficits in the phonological loop may not be a defining characteristic for children with arithmetic learning disabilities. Recent studies (Van der Sluis et al. 2005; Passolunghi 2006) have also reported visual–spatial deficits in children with specific arithmetic disabilities (but see also Bull et al. 1999; Geary et al. 2000).

So far, little research has been performed regarding children who show specific developmental disorders in both areas of scholastic skills (arithmetics and reading and/or spelling skills). This is either due to the fact that insufficient information is given about the characteristics of the groups of children with learning disabilities, hence it is not possible to precisely define the children as suffering from a double deficit, or the existing studies were limited to a small number of working memory tasks and therefore could not yield a comprehensive assessment of the working memory system. Van der Sluis et al. (2005) found a deficit only in the central executive subsystem that could be interpreted as combination of the minor deficits of either reading disabled or arithmetically disabled children. In a study performed by our own lab (Schuchardt et al. in press), we used a broad battery of working memory measures to assess phonological, visual–spatial, and central executive functioning in children with specific disorders of arithmetical skills, specific reading disorders, and mixed disorders of scholastic skills, and in a control group of peers with normal achievement levels. Altogether, results confirm the value of using a comprehensive battery of measures to assess the cognitive memory deficits of children with clinically relevant learning disorders. While previous findings have been mixed, a direct comparison of different learning disorders within a single study design provides broad support to distinct patterns of deficits. Children with impairments in just one domain clearly outperformed children with combined arithmetic and reading disorders on almost all the tasks administered in the present study. The results indicate that these children exhibit both deficits, i.e. those found for specific disorders of arithmetic skills and for specific disorders of reading/writing, to a greater extent (see also Pickering & Gathercole 2004).

With regard to general intellectual disabilities (ID, low intelligence) working memory performance seems to depend strongly on the severity of ID (Henry 2001). While children at borderline of ID only showed deficits in phonological working memory, children with mild or moderate ID were characterised by overall deficits in the different subsystems of working memory. Accordingly, working memory functioning seems to be strongly related to mental age and is consistent with a developmental delay theory of mild ID (Henry 2002; Van der Molen et al. 2007). We have recently obtained similar results (overall deficit) from a study with children of subnormal intelligence (IQ 55–85), the
severest deficit being located in phonological working memory (Hasselhorn & Mähler 2007; Mähler 2007).

The diagnosis ‘mixed disorder of scholastic skills’ (ICD-10 F81.3) is given for a category of disorders where both arithmetical and reading or spelling skills are significantly impaired, but the disorder cannot be explained in terms of general ID or inadequate schooling. The essential criterion is the discrepancy explained in terms of general ID or inadequate development are thought to suffer from a general intellectual delay rather than from learning disabilities and therefore do not receive this diagnosis. The open question is whether these two groups are characterised by different cognitive functioning, especially by distinct patterns of working memory functioning.

Therefore, we addressed two questions:
1. Are there specific working memory deficits underlying learning disabilities?
2. Does intelligence make a difference, i.e. are there differences in working memory between children with learning disabilities showing normal vs. subnormal levels of intelligence?

Methods

Participants

Three groups of children participated in the study. Twenty-seven children received the diagnosis ‘mixed disorder of scholastic skills’ (MDSS-group, ICD-10 F81.3, discrepancy between normal intelligence and sub-average scholastic skills). Another 27 children with comparable learning disabilities did not meet the diagnostic criteria because of the lack of discrepancy between scholastic skills and intelligence (ID group, i.e. ID-group, IQ 55–85). These two groups of children with learning disabilities were compared with a control group (C-group) of 27 children without any specific developmental disorders of scholastic skills. Children from grades two, three or four with German as a native language were included. The two groups of children with learning disabilities were recruited from our counselling centre; all of them attended regular primary schools but did not reach the required levels of achievement.

All children were screened with standardised tests of intellectual ability, spelling, reading and arithmetic. We administered the full IQ scale from the German version of the Kaufman Assessment Battery for Children (Melchers & Preuß 2001) to assess general intelligence, and the score for nonverbal holistic thinking was used for matching the groups. Spelling abilities were assessed by using the Weingartener spelling tests for children from second and third grades (WRT 2+, Birkel 1994a; WRT 3+, Birkel 1994b) and the Westermann spelling test was applied to children in the fourth grade (WRT 4/5, Rathenow 1979). In both of these standardised German tests, children insert dictated words into given sentences. Reading was tested by using the Salzburg Reading and Spelling Test (Landerl et al. 1997). Mathematical skills were assessed by using standardised German mathematics tests for the second, third and fourth graders (DEMAT 2+, Krajewski et al. 2004; DEMAT 3+, Roick et al. 2004; DEMAT 4, Göltz et al. 2006). These multi-component tests include computation problems, word problems and geometry problems.

Table 1 summarises the data describing the three subgroups.

The control group showed an average level of performance in all these measures. ID- and MDSS-groups displayed the typical pattern of deficits in spelling, reading and mathematics, ID children performing better but still on a sub-average level (T < 40) in spelling and reading. The ID group is defined by the lower IQ-score. There is a significant difference in intelligence between the two groups of children with learning disabilities [t (44) = 10.17, P = 0.00] and between the ID- and the control group [t (46) = 8.53, P = 0.00], whereas the MDSS-group is not different from the control group [t (44) = 0.33, n. s.].

Tasks

Working memory was assessed by a battery of 14 tasks: five phonological tasks (memory span for digits, one-syllable and three-syllable words, one-syllable non-words, non-word repetition), five visual–spatial tasks (memory span for locations, matrix span simple and complex, corsi-block simple and complex), four central executive tasks (double span, backward spans for one-syllable words and
digits, counting span). Tasks were presented in a fixed order: location span, double span, one- and three-syllable word span, corsi-block simple and complex, non-word repetition, backward word span, backward digit span, counting span, matrix span simple and complex, digit span, one-syllable non-word span. A detailed description of all tasks follows below.

Phonological loop

The digit span is the conventional measure used to assess the short-term phonological capacity. A series of digits (1–9) was presented acoustically at a rate of one digit per second, starting with two and continuing up to a maximum of eight digits per sequence. Participants had to repeat the digits immediately in the given order. The one-syllable (e.g. Stern = star, Fisch = fish) and three-syllable word span tasks (e.g. Erdbeere = strawberry, Briefkasten = letterbox) and the one-syllable non-word span tasks (e.g. fen, sim) were presented in the same manner as in the digit span measure. In the non-word repetition task children had to repeat 24 word-like non-words of two, three or four syllables (e.g. vorluch, karflumen, sulibritzen) immediately after their presentation. Non-words of different lengths were presented acoustically in random order. The number of correctly repeated non-words was taken as the score for this task.

Visual–spatial sketchpad

In the location span task, children were shown a series of green dots at different locations on a 3 × 3 matrix and asked to recall these locations in the correct order. Corsi-block tasks were used to assess the dynamic spatial component of visual–spatial working memory. The experimenter taps a sequence of red blocks on a grey board at the rate of one per second. The child then attempts to reproduce the sequence of taps in the correct order. We used two variations of the Corsi-block task: simple sequences involving short distances between blocks without path crossings, and complex sequences involving long distances between blocks with path crossings. A matrix span task was used to measure the static component of visual–spatial memory. Patterns of white and black squares in a 4 × 4 matrix were presented on the computer, beginning with two black squares and continuing up to a maximum of eight black squares. Immediately after presentation, children were asked to reproduce the pattern in an empty matrix. Two variations of this task were also implemented: a simple matrix span with the black squares arranged in simple patterns, and a complex matrix span with the black squares located at some distance from one another.

Central executive

The same items and procedures were used for the backward digit and word span tasks as for the forward spans, the only difference being that participants were required to recall the sequences of items in reverse order. Additionally, a double span task was implemented to assess the children’s ability to coordinate the functioning of the phonological loop and the visual–spatial sketchpad (see also Towse & Houston-Price 2001 for justification of such a task). Pictures of well-known objects were

<table>
<thead>
<tr>
<th></th>
<th>ID (n = 27)</th>
<th>MDSS (n = 27)</th>
<th>C (n = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (m/f)</td>
<td>11/16</td>
<td>13/14</td>
<td>13/14</td>
</tr>
<tr>
<td>Age (months)</td>
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<td>107.63 (12.35)</td>
<td>107.59 (10.58)</td>
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<td>K-ABC IQ</td>
<td>75.44 (7.49)</td>
<td>100.08 (8.25)</td>
<td>101.04 (11.44)</td>
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<tr>
<td>Spelling</td>
<td>36.74 (8.22)</td>
<td>32.22 (5.54)</td>
<td>48.33 (6.91)</td>
</tr>
<tr>
<td>Text reading</td>
<td>37.64 (9.60)</td>
<td>33.80 (8.11)</td>
<td>49.15 (8.68)</td>
</tr>
<tr>
<td>Mathematics</td>
<td>34.00 (10.12)</td>
<td>32.33 (6.20)</td>
<td>50.11 (8.15)</td>
</tr>
</tbody>
</table>

ID, children with intellectual disabilities; MDSS, children with and mixed disorders of scholastic skills; C, normally achieving control children matched for chronological age; K-ABC, Assessment Battery for Children; WRT Weingarten Spelling Test; SLT, Salzburg Reading and Spelling Test; DEMAT, German Mathematics Test.
presented in different locations on a $3 \times 3$ matrix. Children had to recall the pictures and their location in the order of presentation. The complex counting span task (cf. Case et al. 1982) was administered to assess storage and processing efficiency. Increasing series of maps (maximum eight maps) with yellow circles (target items) and squares (distractor items) were presented in a random, computer-generated pattern. Children were instructed to always count the number of circles. Finally, the experimenter asked the child to recall the number of circles counted on each map.

**Stop criterion**

We used the same stop criterion for all span tasks. The length of the sequences presented was gradually increased, beginning with a minimum of two, and increasing to a maximum of eight items. There were four trials at each sequence length. If a child succeeded on two successive trials of the same length, the task continued with the next span length. If a child failed on two successive trials of the same length, he or she was not presented with any further sequences of the same length, but with a sequence one item shorter. The dependent measure for all span tasks was the longest sequence of items repeated in correct order. Children were credited an extra 0.25 point if they repeated a further sequence of the same length correctly (e.g. a score of 5.25 was awarded if two of four five-item sequences were recalled correctly, 5.5 if three of four sequences, and 5.75 if all four sequences were recalled correctly).

**Results**

Performance on the different memory span tasks was measured for the three groups of participants (ID, MDSS, C), and group comparisons were carried out separately for the three subsystems of working memory. The significance level of all analyses was set at alpha = 0.05.

Table 2 informs about the performance of the children on the different tasks, sorted by subsystems of working memory (phonological loop, visual–spatial sketchpad and central executive).

The first question of the study was what kind of deficits children with learning disabilities show compared with unimpaired control peers. To answer this question, we compared MDSS-children with controls (both groups with normal IQ) for each subsystem separately. The scores of the six tasks assessing phonological loop functioning were entered

| Table 2 Means (Standard Deviations) for working memory measures by subgroups |
|---------------------------------|-----------------|-----------------|
| ID ($n = 27$) | MDSS ($n = 27$) | C ($n = 27$) |
| **Phonological loop** | | | |
| Digit span | 4.23 (0.80) | 4.20 (0.44) | 5.08 (0.74) |
| One-syllable word span | 3.95 (0.67) | 3.86 (0.54) | 4.51 (0.66) |
| Three-syllable word span | 3.34 (0.41) | 3.35 (0.48) | 3.73 (0.49) |
| One-syllable non-word span | 3.54 (0.52) | 3.38 (0.89) | 4.14 (0.58) |
| Non-word repetition | 18.67 (3.61) | 18.26 (4.29) | 20.81 (1.52) |
| **Visual–spatial sketchpad** | | | |
| Location span | 4.20 (0.70) | 4.61 (0.79) | 5.18 (0.84) |
| Corsi-block simple | 4.57 (1.59) | 5.30 (1.20) | 5.85 (1.21) |
| Corsi-block complex | 3.77 (1.16) | 4.20 (1.24) | 4.91 (0.84) |
| Matrix span simple | 5.12 (1.73) | 5.86 (1.34) | 6.78 (1.33) |
| Matrix span complex | 3.11 (0.91) | 3.50 (1.39) | 4.79 (1.56) |
| **Central executive** | | | |
| Backward digit span | 3.01 (0.71) | 3.34 (0.44) | 3.81 (0.64) |
| Backward word span | 3.15 (0.46) | 3.26 (0.37) | 3.65 (0.54) |
| Double span | 3.07 (0.80) | 3.53 (0.66) | 4.04 (0.69) |
| Counting span | 3.31 (0.73) | 3.23 (0.61) | 4.29 (0.87) |

ID, children with intellectual disabilities; MDSS, children with mixed disorders of scholastic skills; C, normally achieving control children matched for chronological age.

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into a MANOVA. The multivariate main effect, $F_{5,41} = 5.83$, $P < 0.001$, proved to be significant. The univariate tests showed significant differences between groups for all phonological tasks (digit span: $F_{1,52} = 27.85$, $MSE = 0.38$, $P < 0.001$; one-syllable word span: $F_{1,52} = 15.75$, $MSE = 0.36$, $P < 0.001$; three-syllable word span: $F_{1,52} = 8.24$, $MSE = 0.24$, $P < 0.01$; one-syllable non-word span: $F_{1,52} = 13.85$, $MSE = 0.36$, $P < 0.001$; non-word repetition: $F_{1,52} = 8.50$, $MSE = 10.37$, $P < 0.01$).

In the same way, the scores of the five tasks assessing visual–spatial sketchpad were entered into a second MANOVA: again, the multivariate group effect, $F_{5,41} = 2.48$, $P < 0.05$, proved to be significant. The univariate tests of visual–spatial sketchpad revealed significant differences between groups for all visual–spatial memory tasks (location span: $F_{1,52} = 6.44$, $MSE = 0.67$, $P < 0.05$; corsi-block complex: $F_{1,52} = 5.95$, $MSE = 1.12$, $P < 0.05$; matrix span simple: $F_{1,52} = 6.38$, $MSE = 1.78$, $P < 0.05$; matrix span complex: $F_{1,52} = 10.42$, $MSE = 2.18$, $P < 0.01$), with the exception of the corsi-block simple task, $F_{1,52} = 2.76$, $MSE = 1.46$, $P > 0.05$.

Third, the scores of the four tasks assessing central executive were entered into a MANOVA: here, the multivariate group effect, $F_{4,40} = 7.52$, $P < 0.001$, proved to be significant. Univariate tests showed significant differences between groups on all central executive memory tasks (digit backward span: $F_{1,52} = 9.96$, $MSE = 0.30$, $P < 0.01$; word backward span: $F_{1,52} = 9.68$, $MSE = 0.21$, $P < 0.01$; double span: $F_{1,52} = 7.37$, $MSE = 0.46$, $P < 0.01$; counting span: $F_{1,52} = 26.44$, $MSE = 0.57$, $P < 0.001$). In general, the results reveal an overall deficit in working memory of children with learning disabilities (MDSS-group).

The second and more interesting question of the study was whether normal vs. subnormal levels of intelligence constitute a crucial factor to the working memory performance shown by children with learning difficulties. As can easily be figured out from Table 2, unexpectedly, there were no obvious differences between the two groups of children with disabilities. The statistical analysis (comparison between ID- and MDSS-group) was performed once again for each working memory subsystem separately by MANOVA, but none of the multivariate group effects were significant (phonological loop: $F_{6,47} < 1$; visual–spatial sketchpad: $F_{5,49} < 1$; central executive: $F_{4,40} = 2.44$, $P > 0.05$).

Thus, the different levels of intelligence held by the two groups of children with learning disabilities (ID vs. MDSS) did not correspond with differences in working memory performance.

Discussion

Children with general learning disabilities (impairment of arithmetic and reading/spelling scholastic skills) show deficits in all measured aspects of working memory functions. This result is in line with other studies (Pickering & Gathercole 2004) and may lead to the conclusion that these children are more severely impared with respect to their working memory than children with either dyslexia or dyscalculia, a fact that might explain the broader learning disorder.

However, unexpectedly, there were no significant differences between the two groups of children with disabilities: their working memory functioning did not differ despite an IQ difference of 23 points, which is equivalent to more than 1.5 standard deviations. This result corroborates the notion that working memory is associated with learning disabilities irrespective of the intelligence level.

Support for this finding comes from other studies which conclude that working memory skills (especially the performance in complex memory tasks similar to our central executive tasks) place an important constraint on the acquisition of skill and knowledge in reading and mathematics. The impact of this constraint seems to be independent from intelligence (Gathercole et al. 2006).

Following this argument we agree with Dyck et al. (2004), who doubt the validity of the discrepancy criterion for defining developmental disorders. According to their study, the severity of underachievement, as measured in a standardised test that defines the relation to normal development, is the most important criterion, possibly combined with concurrent deficits in functionally related abilities. Consequently, learning disorders can be understood as a substantial scholastic underachievement that is associated with working memory deficits explaining the learning disorder. Currently there is an ongoing discussion on the appropriateness and justification of the criterion of discrepancy for diagnosing learning disorders, particularly regarding ‘mixed disorders of
Working memory in children with learning disabilities

C. Machler & K. Schuchardt

scholastic skills’ (Fletcher et al. 2003; Kavale & Forness 2003; Francis et al. 2005). Performance profiles of children with specific learning disabilities and children with more general ID seem to differ in some ways whereas they are very similar in other aspects (as, for example, working memory in this study). Hence, they do not provide a reason for relying on the criterion of discrepancy. Furthermore, intervention studies did not yield specific outcomes that could be attributed to differences in intelligence (Weber et al. 2002). Taken together, little support is rendered to the clinical practice of treating learning disabled children with or without normal levels of intelligence as fundamentally different (i.e. by sending them to different schools, offering more support to children with learning disabilities who show a higher intelligence level).

Nevertheless, our results cannot support the notion that working memory and intelligence are independent from one another. Comprehensive evidence suggests a strong relation between the two constructs, and even that working memory is a strong predictor of general fluid intelligence (Oberauer et al. 2005). Different levels of intelligence come along with different working memory profiles (Henry 2001). But our current data are at odds with these existing findings. However, the aim of our study was not, to predict intelligence or to explain working memory but to predict learning disabilities. Perhaps our data reveal a special link between working memory and intelligence in children with learning disabilities: Working memory deficits might be so dominant in causing learning disorders that intelligence does no longer make a difference when working memory functioning falls below a certain threshold. Nevertheless, we do not intend to suggest that similar deficits in working memory in our two groups of children with disabilities will predict similar development and similar coping with the learning disorders. Instead, the question concerning the predictive validity of working memory deficits for scholastic achievement is still open to future research.

References


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