Working Memory and Learning in Children With Developmental Coordination Disorder and Specific Language Impairment

Tracy Packiam Alloway
Durham University
Lisa Archibald
University of Western Ontario

The authors compared 6- to 11-year-olds with developmental coordination disorder (DCD) and those with specific language impairment (SLI) on measures of memory (verbal and visuospatial short-term and working memory) and learning (reading and mathematics). Children with DCD with typical language skills were impaired in all four areas of memory function for their age level, and this pattern was also found to be characteristic of a larger DCD group with varied language abilities. SLI-group deficits in standard scores were observed for the verbal versions of the short-term and working memory tasks only. There were also differential links between memory and attainment between the two groups, with visuospatial working memory strongly related to numeracy in the SLI group and all of the memory measures correlated with at least one attainment measure in the DCD group. Reasons for why working memory contributes to learning in these two developmental groups are discussed.

Keywords: working memory; learning; developmental coordination disorder; specific language impairment

The extent to which deficits in specific cognitive mechanisms may underlie developmental disorders is a matter of considerable interest in the fields of cognition and cognitive development. The functioning of the working memory system has been implicated in groups of children with marked learning difficulties, such as learning disabilities (e.g., Alloway et al., 2005; Swanson & Saez, 2003), reading impairments (Gathercole, Alloway, Willis & Adams, 2006), and specific language impairment (SLI; e.g., Archibald & Gathercole, 2006a). To date, however, no studies have provided a comparison of working memory profiles in children with different developmental pathologies, and it was the purpose of the present study to do so. The comparison groups represented children with impairments predominantly affecting either language or motor skills: SLI, an impairment disproportionately affecting language skills, and developmental coordination disorder (DCD; also known as motor dyspraxia), characterized by difficulties with motor coordination. The extent to which deficits in subcomponents of working memory may differentiate these groups was explored by measuring skills systematically across the verbal and visuospatial domains.

SLI in children is an unexpected failure to develop language at the usual rate, despite normal general intellectual abilities, sensory functions, and environmental exposure to language. It is a relatively common developmental condition, estimated to occur in approximately 7% of kindergarten children (Tomblin et al., 1997), and is more prevalent in male than female children (e.g., Choudhury & Benasich, 2003; Flax et al., 2003). Affected children have the greatest problems in learning word forms and the grammatical structure of language, with the acquisition of semantics and pragmatics relatively spared (Leonard, 1998). Although the difficulties disproportionately affect the verbal domain, deficits in more general skills such as processing speed (Miller, Kail, Leonard, & Tomblin, 2001) and hypothesis testing (e.g., Ellis Weismer, 1991; Nelson, Kamhi & Apel, 1987) have been reported. In addition, it is widely acknowledged that individuals with SLI commonly experience learning difficulties of a comparable magnitude across all scholastic domains, including mathematics (Arvedson, 2002; Donlan & Gourlay, 1999; Fazio, 1996) and literacy (Bishop & Adams, 1990; Catts, Fey, Tomblin, & Zhang, 2002; Flax et al., 2003).

Authors’ Note: We would like to thank Susan Gathercole for valuable comments made to an earlier version of this article. We also wish to extend our gratitude to the primary schools and children who participated in this research.
DCD is characterized by marked motor impairment that affects functioning in daily activities in the absence of intellectual or neurological dysfunction (American Psychiatric Association, 1994). Observable behaviors in children with DCD include clumsiness, poor posture, confusion about which hand to use, difficulties throwing or catching a ball, reading and writing difficulties, and an inability to hold a pen or pencil properly. The estimated prevalence of DCD in children aged 5 to 11 years is about 6% (Mandich & Polatajko, 2003), with more male than female children being affected. As with SLI, substantial heterogeneity exists in the cognitive profiles of children with DCD, with some researchers suggesting that comorbidity is so widespread in DCD as to be the norm rather than the exception (Kaplan, Wilson, Dewey, & Crawford, 1998; Piek & Dyck, 2004; Wilson, 2005). The common occurrence of concomitant language impairments with DCD (e.g., Hill, 2001; Visser, 2003) has led to the suggestion that linguistic difficulties may underlie some of the learning problems experienced by children with DCD (Visser, 2003).

Although these developmental disorders are distinguished by the domain of principal deficit, they are both associated with significant learning difficulties. A key contributing factor in learning during development is working memory abilities (e.g., Alloway, Gathercole, Adams, et al., 2005; Gathercole, et al., 2006; Swanson & Sachse-Lee, 2001). Working memory is the capacity to store and manipulate information over brief periods of time (Baddeley & Hitch, 1974; Just & Carpenter, 1992). Extensive research over the past three decades has established that working memory is not a single store but a memory system composed of separable interacting components. Functioning in concert, these components provide a kind of flexible mental workspace that can be used to maintain and transform information in the course of demanding cognitive activities.

There are several theoretical accounts of working memory. In the present study, we used Baddeley and Hitch’s (1974) model of working memory model (see also Baddeley, 2000), a widely used model in both developmental and adult samples (e.g., Alloway, Gathercole, Willis & Adams, 2004; Baddeley, 1996). According to this model, there are separable components for the temporary storage of verbal and visuospatial information: the phonological loop and the visuospatial sketchpad, respectively. A centralized component is responsible for coordinating the flow of information between these storage systems and the temporary activation of long-term memory. The central executive also functions as a mental workspace involved in the temporary storage and manipulation of information needed in the execution of complex cognitive tasks, such as learning, reasoning, and comprehension.

In recent years, standard methods of assessing both verbal and visuospatial aspects of working memory have been developed and validated. Two tests, the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001) and the Automated Working Memory Assessment (AWMA; Alloway & Gathercole, 2007), provide multiple measures of subcomponents of working memory standardized for children aged 4 to 11 years. Tasks tapping the temporary storage of the phonological loop and visuospatial sketchpad require the serial retention of either phonological information such as digits (e.g., Conrad & Hull, 1964) or visuospatial material such as visual patterns (e.g., Smyth & Scholey, 1996). Working memory is typically assessed using complex memory span paradigms that impose demands for both temporary storage and significant processing activity with selected task components varied across domains. An example of a verbal complex span task is reading span, in which a participant is asked to make a meaning-based judgment about each of a series of sentences and then remember the last word of each sentence in sequence (Daneman & Carpenter, 1980). A corresponding visuospatial task is spatial span, in which a participant is asked to judge the orientation of a set of letters and then remember the sequence of degrees of rotation of the letters (Shah & Miyake, 1996).

Working memory skills can explain individual differences in learning. Poor performance on working memory measures is characteristic of children failing to progress normally in the areas of reading (e.g., De Jong, 1998; Swanson, 1994), mathematics (e.g., Bull & Scerif, 2001; Mayringer & Wimmer, 2000; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989), and language comprehension (e.g., Nation, Adams, Bowyer-Crain, & Snowling, 1999; Seigueruc, Ehrlich, Oakhill, & Yuill, 2000). There are also links between performance on tasks measuring phonological loop capacity of working memory and vocabulary acquisition (for a review, see Baddeley, Gathercole, & Papagno, 1998). Associations have been reported as well between measures of the visuospatial sketchpad component of working memory and mental arithmetic (Lee & Kang, 2002; McLean & Hitch, 1999).

Associations between working memory abilities and learning have also been found in children with special educational needs. In particular, children experiencing learning difficulties that are sufficiently severe to warrant special education provision have been found to perform very poorly on measures of working memory (Alloway, Gathercole, Willis, & Adams, 2005; Gathercole & Pickering, 2001; Pickering & Gathercole, 2004). In a recent study of children with deficits in literacy and numeracy, Gathercole et al. (2006) found that performance on verbal working memory tasks is not mediated
by other associated cognitive skills and that it taps an ability that is uniquely linked with learning abilities. This is consistent with the view that verbal working memory is not just a proxy for IQ and is supported by related research on learning disabilities, verbal working memory, and IQ (e.g., Cain, Oakhill & Bryant, 2004; Siegel & Ryan, 1989).

Working memory functioning has been investigated in some detail in SLI. Deficits in phonological loop capacity in SLI have been widely reported in studies of non-word repetition (e.g., Botting & Conti-Ramsden, 2001; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990), as well as studies using more conventional verbal short-term memory measures, such as serial recall of digits or words (Archibald & Gathercole, 2006a; Graham, 1980; Wiig & Semel, 1976). Age-appropriate performance, on the other hand, has been reported for SLI groups on visuospatial storage tasks (Archibald & Gathercole, 2006a, 2006b). Children with SLI have also been found to be impaired on working memory tasks involving the storage and processing of verbal (e.g., Archibald & Gathercole; 2006a; Ellis Weismer, Evans, & Hesketh, 1999) but not visuospatial information (e.g., Archibald & Gathercole, 2006; Bavin, Wilson, Maruff, & Sleeman, 2005). This dissociation has been explained in light of evidence that performance decrements occur only when the task additionally taps the impaired phonological but not preserved visuospatial storage abilities (Archibald & Gathercole, 2007). However children with SLI are slower than typically developing peers in completing the processing portion of both verbal and visuospatial working memory tasks.

With respect to children with DCD, there is emerging evidence that they have a specific deficit in visuospatial memory (e.g., Alloway, 2006; Alloway & Temple, 2007). This deficit can be understood in light of research indicating that visuospatial skills are linked with movement planning and control (e.g., Quinn, 1994; Smyth, Pearson, & Pendleton, 1988). For example, Smyth et al. (1988) found that participants’ retention of simple movements in sequence was comparable with their retention of verbal information, indicating that visuospatial memory parallels verbal memory. This is consistent with the view that certain aspects of visuospatial working memory overlap with cognitive resources allocated to generating movement (e.g., Duff & Logie, 1999). Visuospatial memory skills in children with DCD have been linked to learning. A recent study comparing DCD children with high and low visuospatial memory skills found that children with low visuospatial memory skills performed significantly worse than children with high visuospatial memory skills in literacy and numeracy, even when IQ was taken into account (Alloway, 2007b). The unique link between visuospatial memory skills and learning suggests that the processing demands of the working memory tasks and the active motor component reflected in the visuospatial memory tasks both play a crucial role in learning in children with DCD.

The current work represents one of the first comparisons of working memory and learning in children with DCD and those with SLI. Because one of the criteria for DCD included in the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) is “significant difficulties with motor coordination, which affects their academic achievement” (American Psychiatric Association, 1994), these children often perform worse than age-matched controls on measures of literacy, such as reading, writing, and spelling (e.g., Dewey, Kaplan, Crawford, & Wilson, 2002; Iversen, Berg, Ellertsen, & Tonnessen, 2005). A longitudinal study confirmed that children who are diagnosed with DCD at 7 years of age are limited in their reading and comprehension levels by the age of 10 (Kadesjo & Gillberg, 1999). As with other atypical populations, such as children with poor reading comprehension (Swanson & Berninger, 1995) and children with persistent learning difficulties (Gathercole et al., 2006), it may be that the learning difficulties of children with DCD are associated with working memory impairments. An alternative possibility is that deficits in comorbid cognitive or language skills account for the performance levels of children with DCD.

In this study, measures of verbal and visuospatial short-term memory and verbal or visuospatial working memory were completed by three groups of children: children with SLI, an age-matched group of children with typically developing language skills and DCD, and an unselected group of children with DCD that also included children with language impairments. Although the selection of a DCD and typical language group provides an interesting contrast to an SLI group, it was unknown whether a DCD and typical language group would perform differently than an unselected DCD group on the memory and learning measures included in the present study. One goal of this study therefore was to compare the working memory profiles of the two DCD groups. A second goal was to compare the SLI and DCD and typical language groups. Similar working memory profiles across groups would favor an account emphasizing the commonalities between these developmental disorders and suggesting that a generalized deficit may underlie both conditions (e.g., Hill, 2001; Visser, 2003). Findings of differential working memory impairments would make an important contribution to understanding the cognitive mechanisms that may give rise to domain-specific deficits.
Method

Participants

Thirty-four children participated in three groups in the present study: 11 children with SLI (7 boys, 4 girls), 11 chronologically age-matched children with DCD and typical language skills (8 boys, 3 girls), and 12 additional, unselected children with DCD (8 boys, 4 girls) participated in the present study. The mean ages of the groups were as follows: SLI: 8 years 10 months (SD = 1.41 years, range = 6 years 9 months to 10 years 10 months); DCD and typical language: 8 years 11 months (SD = 1.43 years, range = 6 years 11 months to 11 years 0 months); unselected DCD: 8 years 6 months (SD = 1.64 years, range = 5 years 0 months to 11 years 8 months). All participants were native English speakers. None of the children were diagnosed with attention-deficit disorder or attention-deficit/hyperactivity disorder, autism spectrum disorder, or hearing impairment.

SLI group. The children in the SLI group were recruited from language units in urban areas of the Northeast of England over a 4-month period. All of the children met SLI criteria consistent with those described by Records and Tomblin (1994). They achieved standard scores of 85 or greater on a test of nonverbal reasoning (Raven’s Coloured Matrices; Raven, Court, & Raven, 1986). In addition, they performed at least 1.25 standard deviations below the mean on two of four language measures, including one receptive measure. The receptive measures were the British Picture Vocabulary Scales, 2nd Edition (BPVS-II; Dunn, Dunn, Whetton, & Burley, 1997) and the Test for Reception of Grammar (TROG; Bishop, 1982). The expressive measures were the Expressive Vocabulary Test (Williams, 1997) and the Recalling Sentences subtest of Clinical Evaluation of Language Fundamentals–UK 3 (CELF-UK3; Semel, Wiig, & Secord, 1995). It is worth noting that although some of the language tests may have minimal working memory demands, these tests are commonly used to identify language impairments and were used for this purpose in the present study. None of the children had motor difficulties as identified by the Movement Assessment Battery Teacher Checklist (Henderson & Sugden, 1996), completed by the participating children.

DCD groups. The children with DCD also attended schools in the Northeast of England and were referred by an occupational therapist who had identified them as experiencing motor difficulties using the DSM-IV criteria for DCD (American Psychiatric Association, 1994) and standardized motor assessments such as the Movement Assessment Battery for Children (Henderson & Sugden, 1992). The Movement Assessment Battery Teacher Checklist (Henderson & Sugden, 1996), completed for each participating child at the time of the present study, confirmed the severity of the child’s movement difficulties.

All 23 participants with DCD completed the BPVS-II (Dunn et al., 1997) and the Recalling Sentences subtest of the CELF-3UK (Semel et al., 1995), and 19 completed Raven’s Coloured Matrices (Raven et al., 1986) and the TROG (Bishop, 1982). None of the children experienced difficulty in performing these tasks as a function of their motor impairments. From these, a group of 11 children with DCD individually age matched with participants in the SLI group who had achieved standard scores of 85 or greater on Raven’s Coloured Matrices and the BPVS-II were selected to form the DCD and typical language group.

Procedure

The measures reported her were completed in three or four individual half-hour sessions in a quiet room in the children’s schools. Because the aim of the present study was to compare the performance of two groups, SLI and DCD, standardized measures were used in all instances. In addition to the language screening measures and nonverbal ability test listed above, each child was also tested first on a working memory assessment battery, followed by attainment measures. The SLI group completed the WMTB-C (Pickering & Gathercole, 2001), as well as the visuospatial working memory measures of the AWMA (Alloway, & Gathercole, 2007), and the DCD groups completed the AWMA. Additionally, both groups completed measures of attainment in reading and mathematics. No more than two standardized tests were completed in one session. The subtest order recommended by the standardized test was followed within each test.

The AWMA (Alloway & Gathercole, 2007) was designed as an automated equivalent of the WMTB-C (Pickering & Gathercole, 2001) (see Note 1). Both tests provide multiple assessments of each of the three components of Baddeley and Hitch’s (1974) working memory model, using tasks that have been validated as measures of each component. The batteries include three measures of verbal short-term memory (digit recall, word recall, and nonword recall), three measures of visuospatial short-term memory (block recall, mazes memory, and dot matrix), and three verbal working memory measures (backward digit recall, listening recall, and counting recall), and the AWMA includes three visuospatial working memory measures (odd one out, Mr. X, and spatial span). Both tests provide standardized scores, with a mean value of 100 and a standard deviation of 15, for 4- to

**Verbal short-term memory.** The digit recall, word recall, and nonword recall tests involve the presentation of a sequence of digits, words, or nonwords that a child is required to recall in correct serial order. Digit lists are random constructions without replacement from the digits ranging from 1 to 9, spoken at a rate of one digit per second. The word lists are monosyllabic words with a consonant-vowel-consonant structure, and no stimuli are repeated. The nonwords have the same structure and were created using the same pool of phonemes as the words used in the word recall subtest. The words and nonwords, which are spoken at a rate of one syllable per second, must be recalled with full accuracy (i.e., with all three phonemes correct) and in the correct serial position. Credit was given for phoneme substitutions when the substitution constituted the child’s habitual articulation pattern for that phoneme.

**Verbal working memory.** In the backward digit recall test, a child is required to recall a sequence of spoken digits in reverse order. Test trials begin with two numbers and increase by one number in each block until the child is unable to recall four correct trials at a particular block. In the listening recall task, a child is presented with a series of spoken sentences (e.g., “Lions have four legs,” “Pineapples play football”) and has to verify the sentence by stating “true” or “false” and recall the final word for each sentence in sequence. Test trials begin with one sentence and continue with additional sentences in each block until the child is unable to recall three correct trials at a block. In the counting recall test, a child is presented with a visual array of red circles and blue triangles. He or she is required to count the number of circles in an array and then recall the tallies of circles in the arrays that were presented. The test trial begins with one visual array and increases by an additional visual array in each block until the child is unable to correctly recall four trials. Each visual array stayed on the computer screen until the child indicated that he or she had completed counting all the circles. The number of correct trials was scored for each child.

**Visuospatial short-term memory.** In the block recall test, the presenter taps a sequence of cubes with a finger on a specifically designed board that has nine randomly located cubes. The child’s task is to repeat the sequence in the same order. Testing begins with a single block tap and increases by one additional block. In the mazes memory test, the child views a two-dimensional line maze with a path drawn through the maze. The same maze is then shown to the child without the path, and the child is asked to recall the path by drawing it on the maze. Each maze is presented for 3 seconds. Maze complexity is increased by adding additional walls to the maze. In the dot matrix task, a sequence of red dots is presented on a 4 × 4 grid, and the child is required to point to the positions of each dot that had appeared in the sequence in the same order. Each dot appears for 2 seconds. The sequences were random, with no location being highlighted more than once within a trial.

**Visuospatial working memory.** In the odd one out task, a child is presented with a horizontal row of three boxes in which three complex shapes are presented. The child points to the shape that does not match its others and remembers its location. At the end of the trial, a blank set of three boxes appears on the screen. The child points to the boxes in which the odd shapes had appeared in the correct order. The boxes always appear centered horizontally on the screen, but at different positions along the vertical axis to eliminate visual traces.

In the Mr. X task, a child is presented with a picture of two Mr. X figures. The child identifies whether the Mr. X with the blue hat is holding the ball in the same hand as the Mr. X with the yellow hat. The Mr. X with the blue hat may also be rotated. At the end of each trial, the child has to recall the location of each ball in Mr. X’s hand in sequence, by pointing to a picture with eight compass points. Both the Mr. X figures and the compass points stayed on the computer screen until the child provided a response.

In the spatial span task, a child views a picture of two identical shapes in which the shape on the right has a red dot on it. The child identifies whether the shape on the right is the same or opposite of the shape on the left. The shape with the red dot may also be rotated. At the end of each trial, the child has to recall the location of each red dot on the shape in sequence, by pointing to a picture with three compass points. Both the shapes and the compass points stayed on the computer screen until the child provided a response.

**Attainment measures.** Abilities in the areas of literacy and numeracy were also tested. All participants completed the basic reading and spelling subtests of the *Wechsler Objective Reading Dimensions* (Wechsler, 1993), and the numerical operations subtest of the *Wechsler Objective Numerical Dimensions* (Wechsler, 1996).

**Results**

**DCD Groups**

Descriptive statistics for the DCD and typical language and unselected DCD groups on the screening, attainment,
and memory measures are shown in Table 1. Group mean standard scores were within 1 standard deviation of the mean for both groups on Raven’s Coloured Matrices, the BPVS-II, and the TROG, and for the DCD and typical language group on all of the attainment measures, and the mazes memory subtest. Performance on the majority of the memory measures was more than 1.25 standard deviations below the standardized mean for both DCD groups.

Group means were remarkably similar across measures, with the greatest group differences occurring on the receptive language measures (BPVS-II and TROG) and visuospatial short-term and working memory measures (mazes memory, Mr. X, and spatial span). Consider first the screening and attainment measures. In independent t tests, the only significant group effect was found for the BPVS-II, t(21) = 2.58, p = .02, as expected given the selection criteria. The remaining comparisons were nonsignificant: Raven’s Coloured Matrices, t(17) < 1; TROG, t(21) = 1.79, p = .09; recalling sentences, t(21) < 1; numerical operations, t(21) < 1; reading, t(21) < 1; and spelling, t(21) = 1.11, p = .28. It is clear from these results that although the DCD and typical language group had superior receptive vocabulary skills, their performance on a variety of cognitive, language, and attainment measures was indistinguishable from that of other children with DCD.

To minimize the number of group comparisons on the memory measures, a multivariate analysis of variance was performed on the overall Hotelling’s T was significant, F(4, 17) = 3.86, p = .02, η² = .48. Two of the univariate group comparisons were significant: visuospatial short-term memory, F(1, 20) = 4.992, p = .035, η² = .20, and visuospatial working memory, F(1, 20) = 11.91, p = .003, η² = .37. The remaining comparisons were nonsignificant (p > .25 in both cases). Thus, the SLI group performed at superior levels on the visuospatial memory measures but at a similar level to the DCD and typical language group on the verbal memory measures.

To confirm that language skills were not mediating performance on memory measures between the two groups, a multivariate analysis of covariance was performed on the four composite memory measures, with the receptive language measure (BPVS-II raw scores) as a covariate. The overall group term was no longer significant, F = 1.52, p = .24, η² = .28), although the DCD group still performed significantly worse compared with the SLI children in visuospatial working memory, F(1, 19) = 4.20, p = .05, η² = .18. These findings indicate that even when the contribution of receptive language skills was accounted for, the DCD group performed significantly worse on the visuospatial working memory measures compared with the SLI group.

**Group Membership**

As a test of the extent to which memory scores uniquely differentiated the two atypical groups, discriminant function analyses were conducted for the two memory measures that produced significant group differences and
<table>
<thead>
<tr>
<th>Measure</th>
<th>DCD and Typical Language ((n = 11))</th>
<th>Unselected DCD ((n = 12))</th>
<th>SLI ((n = 11))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Screening measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive grammar ((TROG))</td>
<td>86–114</td>
<td>57–103, 87.00–15.70</td>
<td>63–91, 77.36–8.31</td>
</tr>
<tr>
<td>Recalling Sentences subtest of the CELF-UK3(^a)</td>
<td>3–10</td>
<td>3–10, 5.92–2.19</td>
<td>3–5, 3.27–0.65</td>
</tr>
<tr>
<td>Word recall</td>
<td>52–110</td>
<td>55–99, 81.25–15.15</td>
<td>74–97, 84.82–7.81</td>
</tr>
<tr>
<td>Listening recall</td>
<td>43–127</td>
<td>55–113, 83.92–15.74</td>
<td>58–103, 86.82–12.85</td>
</tr>
<tr>
<td>Counting recall</td>
<td>59–91</td>
<td>60–114, 75.17–14.38</td>
<td>60–95, 74.27–12.02</td>
</tr>
<tr>
<td>Backward digit recall</td>
<td>53–109</td>
<td>50–116, 80.42–19.48</td>
<td>72–88, 80.91–6.28</td>
</tr>
<tr>
<td><strong>Visuospatial STM: composite score</strong></td>
<td>56–95</td>
<td>63–100, 77.64–11.40</td>
<td>69–113, 93.09–12.55</td>
</tr>
<tr>
<td>Dot matrix</td>
<td>32–113</td>
<td>55–103, 76.08–12.70</td>
<td>64–126, 93.09–18.37</td>
</tr>
<tr>
<td>Block recall</td>
<td>45–97</td>
<td>57–116, 79.17–18.59</td>
<td>70–124, 93.73–16.27</td>
</tr>
<tr>
<td><strong>Visuospatial WM: composite score</strong></td>
<td>59–106</td>
<td>54–88, 69.83–10.91</td>
<td>79–108, 92.30–8.05</td>
</tr>
<tr>
<td>Odd one out</td>
<td>47–118</td>
<td>68–96, 76.97–9.88</td>
<td>76–130, 98.55–16.19</td>
</tr>
<tr>
<td>Mr. X</td>
<td>61–93</td>
<td>48–90, 68.75–13.02</td>
<td>68–102, 90.18–10.25</td>
</tr>
<tr>
<td>Spatial span</td>
<td>54–111</td>
<td>40–81, 61.08–16.27</td>
<td>79–96, 88.18–6.18</td>
</tr>
<tr>
<td><strong>Attainment measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading ((WORD))</td>
<td>71–118</td>
<td>65–102, 81.00–11.93</td>
<td>71–119, 89.91–15.17</td>
</tr>
<tr>
<td>Spelling ((WORD))</td>
<td>72–118</td>
<td>66–105, 80.00–11.82</td>
<td>72–119, 90.36–14.49</td>
</tr>
</tbody>
</table>

Note: BPVS-II = British Picture Vocabulary Scales, 2nd Edition; CELF-UK3 = Clinical Evaluation of Language Fundamentals–UK 3; DCD = developmental coordination disorder; SLI = specific language impairment; STM = short-term memory; TROG = Test for Reception of Grammar; WM = working memory; WOND = Wechsler Objective Numerical Dimensions; WORD = Wechsler Objective Reading Dimensions.

\(^a\) Scaled scores \((M = 10, SD = 3)\)
BPVS-II standard scores for comparison. Table 2 presents the results of separate analyses for visuospatial short-term memory, visuospatial working memory, and BPVS-II standard score and an analysis with both visuospatial composite memory measures entered. Wilks’s lambda was significant for each of these functions: visuospatial short-term memory, \( \lambda = .800, p = .037 \); visuospatial working memory, \( \lambda = .627, p = .003 \); BPVS-II, \( \lambda = .354, p < .001 \); visuospatial short-term and working memory, \( \lambda = .604, p = .008 \). BPVS-II was the best discriminator, as expected given that the groups were selected on the basis of this measure. Performance on the visuospatial working memory task was sufficient to correctly assign group membership for 82% of both the SLI and DCD and typical language groups. This figure rose to 91% for the DCD and typical language group when the visuospatial short-term memory measure was included. This outcome establishes that visuospatial memory scores were effective at discriminating children in the two atypical groups, with lower scores typically characterizing the children with DCD.

To evaluate the extent to which the memory measures differentiated the SLI group from an unmatched DCD group, a set of discriminant function analyses was conducted comparing the SLI group with the unmatched DCD group, with the results presented in Table 2. In a stepwise discriminant function analysis with all of the composite memory measures entered, there were two significant functions: visuospatial working memory entered alone, \( \lambda(1, 1, 21) = .403, p < .001 \), and visuospatial and verbal working memory entered, \( \lambda(2, 1, 21) = .329, p < .001 \). With both working memory measures entered, 100% of the SLI group and 83% of the DCD group were correctly classified. This proved more accurate than the BPVS-II alone, which correctly differentiated 82% of the SLI group and 83% of the DCD group. It should be noted that in a corresponding discriminant function analysis comparing the SLI with the combined DCD groups (\( n = 23 \)), visuospatial working memory was the only significant variable, with 91% of SLI children and 83% of DCD children correctly assigned.

### Working Memory Profiles and Learning

The two clinical groups in the present study were characterized by different working memory profiles: SLI deficits were found for verbal but not visuospatial measures of short-term and working memory, whereas the DCD groups had across-the-board deficits in both verbal and visuospatial short-term and working memory. The relationship between these working memory profiles and measures of learning was evaluated in a series of correlations. These analyses must be considered exploratory and be interpreted with caution because of the small number of participants and reduced score range typical of clinical groups. Table 3 presents correlation coefficients between the composite memory scores and attainment measures for the SLI, DCD and typical language, and full DCD (combined typical language and unselected, \( n = 23 \)) groups. There was a striking difference between groups:

**Table 2**

<table>
<thead>
<tr>
<th>Variable Entered</th>
<th>SLI Correctly Classified</th>
<th>DCD Correctly Classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLI (n = 11) vs. DCD and typical language (n = 11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visuospatial STM</td>
<td>7 (63.6%)</td>
<td>8 (72.7%)</td>
</tr>
<tr>
<td>Visuospatial WM</td>
<td>9 (81.8%)</td>
<td>9 (81.8%)</td>
</tr>
<tr>
<td>Visuospatial STM and WM</td>
<td>9 (81.8%)</td>
<td>10 (90.9%)</td>
</tr>
<tr>
<td>BPVS-II standard score</td>
<td>9 (81.8%)</td>
<td>10 (90.9%)</td>
</tr>
<tr>
<td>SLI (n = 11) vs. unselected DCD (n = 12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visuospatial WM</td>
<td>10 (83.8%)</td>
<td>10 (90.9%)</td>
</tr>
<tr>
<td>Visuospatial and verbal WM</td>
<td>11 (100%)</td>
<td>10 (83.3%)</td>
</tr>
<tr>
<td>BPVS-II standard score</td>
<td>9 (81.8%)</td>
<td>10 (83.8%)</td>
</tr>
</tbody>
</table>

**Note:** BPVS-II = *British Picture Vocabulary Scales, 2nd Edition*; DCD = developmental coordination disorder; SLI = specific language impairment; STM = short-term memory; WM = working memory.

**Table 3**

**Pearson Correlations Between Composite Memory and Attainment Measures for the SLI, DCD and Typical Language, and Full DCD Groups**

<table>
<thead>
<tr>
<th>Composite Memory Measures</th>
<th>SLI (n = 11)</th>
<th>DCD (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attainment Measure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numeracy</td>
<td>.47</td>
<td>.60**</td>
</tr>
<tr>
<td>Reading</td>
<td>.38</td>
<td>.54**</td>
</tr>
<tr>
<td>Spelling</td>
<td>.38</td>
<td>.48*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visuospatial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numeracy</td>
<td>.73**</td>
<td>.62*</td>
</tr>
<tr>
<td>Reading</td>
<td>.52</td>
<td>.54**</td>
</tr>
<tr>
<td>Spelling</td>
<td>.51</td>
<td>.48*</td>
</tr>
</tbody>
</table>

**Note:** DCD = developmental coordination disorder; SLI = specific language impairment; STM = short-term memory; WM = working memory.

\* \( p < .05 \), \** \( p < .01 \).

The two clinical groups in the present study were characterized by different working memory profiles: SLI deficits were found for verbal but not visuospatial measures of short-term and working memory, whereas the DCD groups had across-the-board deficits in both verbal and visuospatial short-term and working memory. The relationship between these working memory profiles and measures of learning was evaluated in a series of correlations. These analyses must be considered exploratory and be interpreted with caution because of the small number of participants and reduced score range typical of clinical groups. Table 3 presents correlation coefficients between the composite memory scores and attainment measures for the SLI, DCD and typical language, and full DCD (combined typical language and unselected, \( n = 23 \)) groups. There was a striking difference between groups:
Correlations were generally higher and significant for the DCD groups than the SLI group, although this difference was most notable between the DCD and typical language and SLI groups. In addition, all of the memory measures were significantly correlated with at least one attainment measure for the DCD groups, whereas only the correlation between visuospatial working memory composite and numeracy reached significance for the SLI group. Consistent with their uniformly low working memory profile, correlations for the DCD groups were similar across the cognitive measures, ranging from approximately 0.5 to 0.7 for the DCD and typical language group and from 0.3 to 0.6 for the full DCD groups for both the verbal and visuospatial domains, short-term and working memory, and literacy and numeracy. There were indications of a domain difference for the SLI group, but the relationship appeared to be driven by areas of deficit rather than strength: Low but uniform correlations were found between verbal memory and attainment measures (0.35–0.47), whereas visuospatial memory was unrelated to two of the attainment measures (reading and spelling, \( r = 0.01–0.09 \)) and slightly (visuospatial short-term memory) or strongly (visuospatial working memory) correlated with numeracy (\( r = 0.31 \) and 0.74, respectively). It appears that the SLI group did not depend on their stronger visuospatial memory skills in literacy learning.

**Discussion**

In this study, we compared the performance on short-term and working memory measures of children with two different developmental pathologies, SLI and DCD. Children with SLI showed marked impairments on verbal but not visuospatial measures of short-term and working memory, whereas children with DCD had general deficits across verbal and visuospatial short-term and working memory. Performance on the visuospatial and verbal working memory measures successfully discriminated 100% of SLI and 83% of an unselected DCD group, a classification rate higher than a standard language measure. Visuospatial working memory alone was sufficient to classify at least 82% of a matched sample of DCD and SLI groups. The pattern of correlations between the memory and learning measures also differed between groups. Consistent with their uniformly low working memory profile, all of the memory measures were correlated with at least one test of attainment for the DCD group. The relationship between the memory and learning measures was less clear for the SLI group, with low correlations between the attainment measures and verbal memory and a high correlation between numeracy and visuospatial working memory. One explanation for the absence of stronger relationships between memory performance and attainment measures could be that the range of scores for these atypical groups was restricted. Their depressed scores, coupled with the small sample sizes, could account for the absence of correlations found by other authors. This possibility should be tested in future studies.

In addition to the language and motor differences that characterize children with DCD and SLI, the present findings indicate that differences exist also in their immediate memory profiles. The flat profile of DCD deficits in short-term and working memory across domains contrasted with the relatively domain-specific SLI impairments in verbal short-term and working memory. Although the groups achieved similar performance levels on measures of literacy and numeracy, they exhibited different associations between the memory and attainment measures. Perhaps because of the uniformly low memory skills, short-term and working memory were moderately associated with attainment measures across domains in the DCD group. The more interesting case was provided by the SLI group. Despite strengths in visuospatial memory, measures of visuospatial memory were not associated with any of the attainment measures except numeracy. In fact, short-term and working memory in the SLI group showed little relationship to reading and literacy, and the most consistent associations were with the poor verbal memory skills. It may be that verbal working memory measures are more closely associated with scholastic attainment than the visuospatial working memory measures included in the present study.

The verbal short-term and working memory tasks in the present study did not, however, act as additional language measures, as has been suggested by some researchers (MacDonald & Christiansen, 2002; Snowling, Chiat, & Hulme, 1991). All of the groups performed at similarly low levels on these tasks, even though the groups differed widely in language status: the DCD and typical language group had average language skills, the unselected DCD group had low-normal language skills, and the SLI group had impaired language skills. These findings point to a commonality in deficits in these clinical groups, which may account for their similar learning profiles to some extent. Certainly, it is unclear from the present findings if the strengths in visuospatial memory in the SLI group place them at any noticeable advantage.

It is commonly held that there is considerable heterogeneity among children who present with either DCD or SLI. In the present study, the children in the DCD group exhibited the widest score range on all of the screening measures, with minimum scores on the language measures
falling below those of the SLI group. The SLI group, on the other hand, had no concomitant motor impairments. Thus, the DCD group represented a more heterogeneous group than the children with SLI in the present study. Nevertheless, the substantial heterogeneity among the DCD groups did not drastically alter performance on a variety of cognitive, memory, and attainment measures. A subset of children with DCD and typical language skills and an unselected DCD group were found to perform at comparably low levels on verbal short-term and working memory, visuospatial short-term and working memory, and reading, spelling and numeracy tasks (see also Alloway 2007; Alloway & Temple, 2007). These findings suggest that the current focus on heterogeneity with respect to memory skills and learning in developmental pathologies may be misplaced. It may be possible to relax selection criteria to include larger sample groups without introducing excessive variability.

Given the average language profile of the DCD and typical language group, one possibility is that these children may also be classified as having a nonverbal learning disability (see Rourke & Tsatsanis, 1996). The profile of this disability includes average verbal IQ but substantially poorer nonverbal IQ skills. Children with this disability also struggle in tasks involving nonverbal problem solving and visual-spatial-organizational skills. On the surface, they appear to have a certain level of linguistic competence, as evidenced by their use of various sentence structures, strong memorization skills, and above-average abilities in single-word reading and spelling. However, their competence in language is superficial, and they struggle most in tasks requiring the use of contextual information or sophisticated social competence. Closer inspection of the performance of children in the DCD and typical language group in the present study revealed striking contrasts between the two profiles. Specifically, they did not appear to have a deficit in nonverbal IQ skills (as measured by Raven’s Coloured Matrices); rather, they had marked impairments in single-word reading and spelling (as measured by the Reading and Spelling subtests of the Wechsler Objective Reading Dimensions, respectively) and memory (in both sentence memory and working memory, assessed by the Recalling Sentences subtest of the CELF-UK3 and the AWMA, respectively). This suggests that although the DCD and typical language group had relatively poor nonverbal skills compared with the SLI group, they exhibited distinctive skills from a nonverbal learning disability cohort.

SLI and DCD differ in their principal domains of impairment, language and motor coordination, respectively. The present results indicate that in addition, these groups differ in their working memory profiles. Measures of verbal and visuospatial working memory, taken together, are excellent group discriminators. Children with DCD performed at low levels on both verbal and visuospatial measures of short-term and working memory, whereas children with SLI exhibited deficits in verbal memory only. Despite different associations between working memory and measures of attainment for the children with DCD and those with SLI, the groups performed similarly in numeracy, reading, and spelling. It appeared that verbal memory measures were more closely related to learning outcomes for both atypical groups, although visuospatial working memory was strongly related to numeracy as well.

Note

1. The pattern of performance growth as a function of age, which plots the z scores for each year group from 4 to 11 years in the AWMA sample, was compared with the WMTB-C sample. The tests indicate broadly similar developmental functions, with performance increasing across each year group.

References


