Working Memory in Children With Developmental Disorders

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The aim of the present study was to directly compare working memory skills across students with different developmental disorders to investigate whether the uniqueness of their diagnosis would impact memory skills. The authors report findings confirming differential memory profiles on the basis of the following developmental disorders: Specific Language Impairment, Developmental Coordination Disorder (DCD), Attention-Deficit/Hyperactivity Disorder, and Asperger syndrome (AS). Specifically, language impairments were associated with selective deficits in verbal short-term and working memory, whereas motor impairments (DCD) were associated with selective deficits in visuospatial short-term and working memory. Children with attention problems were impaired in working memory in both verbal and visuospatial domains, whereas the children with AS had deficits in verbal short-term memory but not in any other memory component. The implications of these findings are discussed in light of support for learning.

Learning disabilities, which include language impairments, motor impairments, and behavioral problems, are thought to impact almost 8% of children in the United States (Centers for Disease Control, 1999). It is not always clear what causes these difficulties, resulting in different models that account for the nature of the various cognitive profiles. Of interest in the present study is the role of working memory (WM), the ability to store and manipulate information for brief periods, in the following disorders: Specific Language Impairment (SLI), Developmental Coordination Disorder (DCD), Attention-Deficit/Hyperactivity Disorder (ADHD), and Asperger syndrome (AS). We first briefly describe the cognitive profile of children with developmental disorders and then investigate how working memory impacts their cognitive profiles.

Specific Language Impairment

SLI is characterized by an unexpected failure to develop language at the usual rate, despite normal general intellectual abilities, sensory functions, and environmental exposure to language. One clinical marker for SLI is a verbal short-term memory (STM) task, nonword repetition (Bishop, North, & Donlan, 1996), and has led to the suggestion that deficits in this area characterize SLI (Gathercole & Baddeley, 1990). Converging evidence comes from studies demonstrating corresponding deficits on other verbal short-term memory tasks such as digit span and word list recall in this cohort (Hick, Botting, & Conti-Ramsden, 2005). Verbal short-term memory has been specifically linked to learning the phonological forms of new words (Gathercole, Hitch, Service, & Martin, 1997), and it is possible that such difficulties in children with SLI would disrupt language learning. Working memory impairments for SLI groups have also been reported in tasks requiring the

simultaneous storage and processing of verbal information (Ellis Weismer, Evans, & Hesketh, 1999; Hoffman & Gillam, 2004; Montgomery, 2000), although findings in relation to visuospatial information have been mixed (Archibald & Gathercole, 2007; Bavin, Wilson, Maruff, & Sleeman, 2005).

Developmental Coordination Disorder

DCD is a generalized problem that affects movement as well as perception (Visser, 2003). 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. Evidence suggests that they have a specific deficit in visuospatial memory not found in children with general learning difficulties (Alloway & Temple, 2007) or specific language impairments (Archibald & Alloway, 2008). It is worth noting that although those with DCD can have comorbid language impairments (Visser, 2003), their memory profile does not differ greatly compared to children with DCD and typical language skills (Alloway & Archibald, 2008).

Attention-Deficit/Hyperactivity Disorder

ADHD is characterized by difficulties with inhibiting behavior (Barkley, 1997) that trigger secondary effects in various executive functions, including working memory (van Mourik, Oosterlaan, & Sergeant, 2005; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). In particular, visuospatial working memory deficits tend to be more substantial than verbal ones (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). In contrast, children with ADHD typically perform within age-expected levels in short-term memory tasks, such as forward recall of letters, digits, words, and spatial locations (Roodenrys, 2006).

Asperger Syndrome

Research on the memory profile of children with AS is relatively sparse, possibly due to the relative recency of this diagnosis (Belleville, Ménard, Mottron, & Ménard, 2006). AS is a common subgroup of the autistic spectrum, and we can gain some insight into children's memory profile from studies on autistic spectrum disorders. Individuals with autism show typical performance in the immediate serial recall in verbal tasks (Bennetto, Pennington, & Rogers, 1996; Russell, Jarrold, & Henry, 1996) and visuospatial tasks (Ozonoff & Strayer, 2001). Although working memory skills do not seem to be impaired in this population, the pattern of performance appears to depend on their general ability. For example, Russell et al. (1996) reported that low-functioning autistic adolescents performed more poorly than chronological age-matched participants but did not differ from IQ-matched participants on measures of both verbal and visuospatial working memory. In contrast, Belleville, Rouleau, and Caza (1998) found that high-functioning autistic persons performed in a similar manner as age- and IQ-matched controls.

The Present Study

Working memory is our ability to simultaneously store and process information for a brief period. According to the Baddeley (2000) revision of the influential Baddeley and Hitch (1974) model, the processing aspect of the task is controlled by a centralized component known as the central executive (Baddeley, 2000). The short-term storage aspect is supported by domain-specific components for verbal and visuospatial information (see Baddeley & Logie, 1999, for a review). The notion that there is a domain-general component construct that coordinates separate codes for verbal and visuospatial storage has been supported by studies of children (Alloway, Gathercole, & Pickering, 2006; Alloway, Gathercole, Willis, & Adams, 2004; Bayliss, Jarrold, Gunn, & Baddeley, 2003), adult participants (Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004), neuropsychological patients, and neuroimaging research (Jonides, Lacey, & Nee, 2005).

In the present study, memory performance was measured using a computerized and standardized tool, the *Automated Working Memory Assessment* (AWMA; Alloway, 2007a). The development of the AWMA was based on a dominant conceptualization of working memory as a system comprising multiple components whose coordinated activity provides the capacity for the temporary storage and manipulation of information in a variety of domains. The AWMA provides three measures each of verbal and visuospatial aspects of short-term memory and working memory. In line with a substantial body of prior evidence, verbal and visuospatial working memory were measured using tasks involving simultaneous storage and processing of information, whereas tasks involving only the storage of information were used to measure verbal and visuospatial short-term memory. In tests of verbal short-term memory (tapping the phonological loop), the participant is required to recall sequences of verbal material such as digits, words, or nonwords. Visuospatial

short-term memory tests (tapping the visuospatial sketchpad) involve the presentation and recall of material such as sequences of tapped blocks or of filled cells in a visual matrix. More complex memory tasks have been designed to assess the central executive or attentional control aspect of the working memory. In these working memory tasks, the individual is typically required both to process and store increasing amounts of information until the point at which recall errors are made. One example of a verbal working memory task is listening recall, in which the participant verifies a sentence and then recalls the final word. Analogous visuospatial working memory tasks include rotating images and recalling their locations.

To our knowledge, this is the first study that directly compared memory profiles of these four developmental disorders using a common assessment. The advantage of such an approach is that it minimizes discrepancies due to test differences and allows for direct comparisons in performance across developmental disorders. As such, any differences in memory skills could be attributed to a particular disorder. The automated presentation of stimuli also eliminates experimenter differences in presentation rates and vocal inflections, which can impact recall performance.

As all of the developmental disorder groups of interest appear to have working memory deficits, we can investigate two different explanations. The first possibility is that working memory difficulties represent a primary deficit that impacts both verbal and visuospatial memory functioning in these disorder groups. There is substantial evidence for the link between working memory and learning in both reading (Gathercole, Alloway, Willis, & Adams, 2006; Swanson, 2003; Swanson & Beebe-Frankenberger, 2004) and math (Bull & Scerif, 2001; Gersten, Jordan, & Flojo, 2005; see Cowan & Alloway, in press, for a review). Recent evidence from a large-scale study of children identified on the basis of very low working memory scores indicated that these students have a pervasive working memory deficit that extends to both verbal and visuospatial tasks. As a result of these generalized working memory deficits, the majority of these students scored very poorly in standardized learning outcomes (Alloway, Gathercole, Kirkwood, & Elliott, in press). As the developmental disorder groups in the present study perform poorly in learning outcomes as well, their difficulty might stem from a generalized working memory deficit.

An alternate possibility is that working memory problems may not represent damage to a separate cognitive mechanism but rather could be impacted by specific modular deficits that are characteristic of developmental disorders (Frith & Happé, 1998). For example, verbal memory impairments would be greater in children with SLI as these are linked with language skills, children with DCD would show decrements in visuospatial memory as a function of their motor difficulties, those with ADHD would struggle in working memory tasks linked to attentional problems, and students with AS would have difficulty in verbal tasks related to their language difficulties.

The nature of working memory impairments in developmental disorders has important implications for learning. If working memory deficits are pervasive impacting both verbal and visuospatial domains across disorder groups, then a common strategy would suffice to support working memory in the classroom. However, if working memory deficits vary across disorder groups, impacted by specific core deficits, then it may be best to tailor intervention to support the strengths and weakness of each group.

Method

Participants

There were 163 children recruited for this study. All were native English speakers, and none had hearing impairments. Parental consent was obtained for each child participating in the study.

The SLI group consisted of 15 children (60% boys; mean age = 9.2 years; *SD* = 20 months) from primary language units and special schools. The children met the criteria consistent with that of Records and Tomblin (1994) for SLI: Each participant scored at least 1.25 standard deviations below the mean on at least two language measures including one receptive measure. The receptive measures were the *British Picture Vocabulary Scales–Second 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* (EVT; K. T. Williams, 1997), and the *Recalling Sentences* subtest of *Clinical Evaluation of Language Fundamental–UK 3* (CELF-UK3; Semel, Wiig, & Secord, 1995). None of the children with SLI had received a clinical diagnosis of behavioral problems or had motor difficulties confirmed by the *Movement Assessment Battery Teacher Checklist* (Henderson & Sugden, 1996). The gender distribution is consistent with published studies on SLI (Leonard, 1998).

The DCD group consisted of 55 children (80% boys, mean age = 8.8 years, *SD* = 19 months) attending mainstream schools. They were referred by an occupational

therapist who had identified them as experiencing motor difficulties using the *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition, Text Revision* (American Psychiatric Association, 2000) criteria and standardized motor assessments such as the *Movement Assessment Battery for Children* (M-ABC; Henderson & Sugden, 1992). None of these children had received a clinical diagnosis of behavioral problems. The gender distribution corresponds with reports of more males than females being affected (Mandich & Polatajko, 2003).

The ADHD group comprised 83 children (85% boys; mean age = 9.10 years, *SD* = 13 months) with a combination of hyperactive-impulsive and inattentive behavior (ADHD-Combined). Diagnosis of ADHD subtype was confirmed by a comprehensive clinical diagnostic assessment by pediatric psychiatrists and community pediatricians based in the United Kingdom. The assessments were based on scores in the deficit range on the *Continuous Performance Test* (Conners, 2004) and clinical assessments during interview sessions using the *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition* criteria (American Psychiatric Association, 1994). The study only included children who score in the normal range on the *Developmental, Diagnostic and Dimensional Interview* (3di), a computerized assessment for autistic spectrum disorders (Skuse et al., 2004). No participants had received a clinical diagnosis of comorbid motor difficulties. All children were receiving stimulants for ADHD (e.g., methylphenidate). To ensure assessments were uninfluenced by medication (Mehta, Goodyear, & Sahakian, 2004), participants ceased taking their medication 24 hours prior to testing. The greater number of boys than girls in the ADHD group reflects the higher rate of clinical diagnosis among boys (Gershon, 2002).

There were 10 AS participants (80% boys; mean age = 8.8 years, *SD* = 18 months) recruited from mainstream schools. They were diagnosed by the senior pediatrician or child psychiatrist, with evaluation of communication, reciprocal social interaction, and repetitive behaviors, using observational assessments including the *Autism Diagnostic Observation Schedule* (Lord, Rutter, DiLavore, & Risi, 1999). No participants had received a clinical diagnosis of comorbid behavioral or motor disorders. The ratio of males to females in the present study corresponds with previous reports (Baird et al., 2006).

Procedure and Materials

All children were administered tests from the AWMA (Alloway, 2007a); the exception was the SLI group, which was tested on verbal memory tests from the *Working Memory Test Battery for Children* (Pickering & Gathercole, 2001), a paper and pencil analogue of the AWMA. All children were also administered a measure of nonverbal general ability. All three tests provide standardized scores with a mean value of 100 and a standard deviation of 15. Test-retest reliability of the AWMA is reported with the description of each test (Alloway, 2007a); test validity is reported in Alloway, Gathercole, Kirkwood, and Elliott (2008).

Memory. The AWMA (Alloway, 2007a) consisted of the following tests. The three verbal short-term memory measures were digit recall, word recall, and nonword recall. In each test, the child hears a sequence of verbal items (digits, one-syllable words, and one-syllable nonwords, respectively) and has to recall each sequence in the correct order. For individuals aged 4.5 and 22.5 years, test-retest reliability is .88, .89, and .69 for digit recall, word recall, and nonword recall, respectively.

The three verbal working memory measures were listening recall, backward digit recall, and counting recall. In the listening recall task, the child is presented with a series of spoken sentences, has to verify the sentence by stating "true" or "false," and recalls the final word for each sentence in sequence. In the backward digit recall task, the child is required to recall a sequence of spoken digits in the reverse order. In the counting recall task, the 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. For individuals aged 4.5 and 22.5 years, test-retest reliability is .88, .83, and .86 for listening recall, counting recall, and backward digit recall, respectively.

Three measures of visuospatial short-term memory were administered. In the dot matrix task, the child is shown the position of a red dot in a series of 4 × 4 matrices and has to recall this position by tapping the squares on the computer screen. In the mazes memory task, the child is shown a maze with a red path drawn through it for 3 seconds. She or he then has to trace in the same path on a blank maze presented on the computer screen. In the block recall task, the child views a video of a series of blocks being tapped and reproduces the sequence in the correct order by tapping on a picture of the blocks. For individuals aged 4.5 and 22.5 years, test-retest reliability is .85, .86, and .90 for dot matrix, mazes memory, and block recall, respectively.

Three measures of visuospatial working memory were administered. In the odd-one-out task, the child views three shapes, each in a box presented in a row, and

Table 1
Descriptive Statistics of Standard Scores for Measures of Working Memory and Nonverbal Ability

	SLI (n = 15)		DCD (n = 55)		ADHD (n = 83)		AS (n = 10)	
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Digit recall	84.33	11.25	82.55	17.82	94.73	15.54	85.70	20.81
Word recall	83.93	7.52	90.24	20.55	98.81	18.20	76.40	14.90
Nonword recall	82.93	13.66	93.62	22.35	103.08	16.54	80.10	18.75
Verbal STM	83.73	7.62	88.78	17.35	98.82	16.81	80.73	16.11
Listening recall	85.67	13.97	89.15	17.87	90.65	17.70	94.10	20.40
Counting recall	73.13	10.98	81.44	16.46	87.48	17.53	101.30	17.78
Backward digit recall	82.20	7.79	85.45	17.44	89.24	14.21	90.70	18.01
Verbal WM	80.33	5.25	85.31	13.49	86.76	17.03	95.37	17.22
Dot matrix	93.07	16.88	80.11	17.53	90.70	17.87	90.00	12.56
Mazes memory	90.07	14.10	88.31	16.51	97.72	18.02	92.90	21.15
Block recall	92.20	14.60	80.20	18.66	87.99	18.68	86.60	15.47
VS STM	91.78	11.24	82.87	13.67	90.60	18.94	89.83	13.33
Odd one out	95.80	15.02	85.84	15.70	88.25	17.14	97.60	17.55
Mr. X	88.27	9.85	83.18	15.87	85.84	14.67	98.10	18.22
Spatial recall	85.87	7.89	77.64	18.53	82.82	16.13	93.10	17.68
VS WM	89.98	8.12	82.20	14.34	82.93	15.53	96.27	15.84
Nonverbal ability	103.47	9.76	76.27	21.48	96.59	14.49	85.10	15.01

Note: ADHD = Attention-Deficit/Hyperactivity Disorder; AS = Asperger syndrome; DCD = Developmental Coordination Disorder; SLI = Specific Language Impairment; STM = short-term memory; VS = visuospatial; WM = working memory.

identifies the odd-one-out shape. At the end of each trial, the child recalls the location of each odd-one-out shape, in the correct order, by tapping the correct box on the screen. In the Mr. X task, the 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 the blue Mr. X's hand in sequence, by pointing to a picture with eight compass points. In the spatial recall task, the child views a picture of two arbitrary shapes where the shape on the right has a red dot on it and 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. For individuals aged 4.5 and 22.5 years, test-retest reliability is .88, .84, and .79 for odd one out, Mr. X, and spatial recall, respectively.

Nonverbal IQ. This was indexed using the *Block Design* subtest from the *Wechsler Intelligence Scale for Children* (WISC-III; Wechsler, 1992). The SLI group completed the *Raven's Colored Matrices* (Raven, Court, & Raven, 1986) instead, a measure of nonverbal reasoning.

Results

Descriptive statistics for memory and IQ as a function of group are shown in Table 1. The following patterns emerge: Children with SLI exhibited weakness in both verbal short-term and working memory tasks; children with DCD had a depressed performance in all areas, with particularly low scores in visuospatial memory tasks; children with ADHD performed within age-expected levels in short-term memory but had a pervasive working memory deficit that impacted both verbal and visuospatial domains; and children with AS had a selective verbal short-term memory deficit.

To determine the prevalence of working memory deficits across groups, the proportions of children obtaining composite scores below and above particular cutoff values were calculated (< 86 and > 95; see Table 2). As there is no discrete point at which typical and atypical performance can be unequivocally distinguished, cumulative proportions over a range of values that represent different degrees of severity of low performance are presented. For the present purposes, values below one standard deviation from the mean (standard scores < 86) are viewed as indicative of mild deficit, with lower scores representing greater degrees of severity (see Alloway et al., in press). About two thirds of the children with SLI achieved scores of less than 86 in the verbal memory

Table 2
Proportions of Children Obtaining Scores in Each Band as a Function of Developmental Disorder and Cognitive Test

	SLI		DCD		ADHD		AS		MANOVA			MANCOVA		
Measure	< 86	> 95	< 86	> 95	< 86	> 95	< 86	> 95	*F*	η_p^2	Pairwise Comparisons	*F*	η_p^2	Pairwise Comparisons
Verbal STM	.67	.07	.42	.27	.18	.55	.70	.10	8.19	.13	ADHD > SLI, DCD, AS	7.05	.12	ADHD > SLI, AS DCD > SLI
Verbal WM	.80	.00	.49	.22	.51	.35	.30	.60	2.06	.04	*ns*	6.77	.11	AS > SLI, ADHD DCD > SLI
Visuospatial STM	.20	.40	.56	.13	.37	.47	.40	.30	2.79	.05	ADHD > DCD	< 1	—	*ns*
Visuospatial WM	.33	.20	.60	.20	.61	.20	.20	.50	3.60	.06	AS > DCD, ADHD	6.16	.11	AS > ADHD
Nonverbal ability	.00	.73	.67	.20	.25	.48	.50	.30						

Note: ADHD = Attention-Deficit/Hyperactivity Disorder; AS = Asperger syndrome; DCD = Developmental Coordination Disorder; MANCOVA = multivariate analysis of covariance; MANOVA = multivariate analysis of variance; *ns* = not significant; SLI = Specific Language Impairment; STM = short-term memory; WM = working memory.

measures (67% and 80%, for verbal short-term memory and working memory, respectively). More than half of the children with DCD had deficits (< 86) in the visuospatial memory measures (56% and 60%, for visuospatial short-term memory and working memory, respectively). More than half of the children with ADHD had deficits (< 86) in the working memory measures (51% and 61%, for verbal and visuospatial working memory, respectively). The majority of children with AS scored less than 86 on the verbal short-term memory measure (70%).

To compare the specificity of deficits between the groups, a multivariate analysis of variance was performed on the memory composite standard scores. The probability value associated with Hotelling's *t* test is reported. The overall group term was significant, ($F = 6.56$, $p < .001$, $\eta_p^2 = .15$). Significant deficits were found in the following memory components ($p < .05$; F values and effects sizes are reported in Table 2): verbal STM, visuospatial STM, and visuospatial WM but not verbal WM. Post hoc pairwise comparisons found significant differences between the following groups ($p < .05$, Bonferroni adjustment for multiple comparisons; see Table 2). In verbal STM, the ADHD group performed better than the SLI, DCD, and AS groups; in verbal WM, there was no difference between groups; in visuospatial STM, the ADHD group performed better than those with DCD; and in visuospatial WM, the AS group performed better than those with DCD and ADHD.

To investigate whether nonverbal IQ was mediating performance on memory measures between the groups, a MANCOVA was performed on the four composite memory measures, with the nonverbal IQ measure as a covariate. Although the overall group term was significant, ($F = 6.45$, $p < .001$, $\eta_p^2 = .14$), the pattern was slightly different. Significant deficits were found in the following memory components ($p < .05$; F values and effects sizes are reported in Table 2): verbal STM, verbal WM, and visuospatial WM but not visuospatial STM. Post hoc pairwise comparisons found significant differences in the following groups ($p < .05$, Bonferroni adjustment for multiple comparisons; see Table 2). In verbal STM, the ADHD group performed better than the SLI and AS groups, and those with DCD performed better than those with SLI; in verbal WM, those with AS and DCD performed better than the SLI group, and the AS group also did better than those with ADHD; in visuospatial STM, there was no difference between groups; and in visuospatial WM, the AS group performed better than those with ADHD. The findings indicate that although the general pattern of findings remained similar, nonverbal IQ appeared to mediate the memory performance of those with DCD.

Discussion

The aim of this study was to investigate the nature of working memory deficits in prevalent developmental disorders found in mainstream education. The data indicate that the four cohorts had unique working memory profiles, rather than a pervasive working memory deficit that impacted both verbal and visuospatial functioning equally across groups. Rather, working memory appears to be a secondary deficit, possibly driven by core deficits in language, motor, behavior, or social difficulties. This corresponds with the view that a core impairment associated with particular developmental disorders can have a cascading effect on other cognitive skills (Frith & Happé, 1998). This view provides some insight to why the memory profiles reflected the core impairments of the disorder groups in the present study.

We now discuss the implications of the unique working memory patterns in the different developmental disorders. The SLI group had selective deficits in verbal short-term and working memory. These children performed worse in verbal short-term memory compared to those with ADHD and DCD once nonverbal ability was statistically accounted. Their verbal working memory skills were also poorer than those with DCD and AS. In contrast, their visuospatial short-term and working memory scores were within age-expected levels, with only a small proportion falling below average levels. It is likely that children with SLI struggle with storing and processing verbal information, rather storing verbal information only. These deficits may reflect the multiplicity of cognitive skills that contribute to this task, including vocabulary and language skills (Archibald & Gathercole, 2006).

The children with DCD had noticeable visuospatial memory deficits, performing worse than those with ADHD in visuospatial short-term memory and those with AS in visuospatial working memory tests. One explanation for the visuospatial memory deficits in the group with DCD can in part be explained by the motor component of the tests (see Alloway, 2007b, for further discussion). Both the short-term memory and working memory tests required participants to touch the screen, mentally rotate objects, or hold visual information in mind. Studies using nonverbal IQ tests that included a motor component, such as *Block Design*, have also reported depressed IQ scores (Coleman, Piek, & Livesey, 2001). In contrast, IQ scores were higher when the test did not involve motor skills (Bonifacci, 2004). In the

present study, a similar pattern was observed as the children with DCD no longer performed significantly worse than the other disorder groups in the visuospatial memory tests once the shared motor component with the IQ test (*Block Design*) was statistically accounted for.

The children with DCD also appeared to have a separate problem processing and storing information that likely underpins learning difficulties. Related research has found that visuospatial memory was uniquely linked to learning outcomes, even when nonverbal IQ was taken into account (Alloway, 2007b). In a recent intervention study, children with DCD and comorbid learning difficulties participated in a 13-week program of task-specific motor exercises. The findings indicated that motor skills improved; however, this effect did not transfer to reading and math scores (Alloway & Warner, 2008). This suggests that although there is a link between motor skills and working memory, it is the latter skill that affects learning outcomes.

The students with ADHD had working memory impairments across both verbal and visuospatial domains. They struggled with processing information irrespective of the modality of the material to be remembered or mentally manipulated. It is possible that these children had difficulty regulating their behavior and so struggled to attend to the information in the first instance. As a result, their poor working memory scores were a reflection of lack of behavioral inhibition rather than a working memory deficit per se. Research on the improved working memory scores as a result of medication to regulate behavior and maintain focus provides some support for this notion (Mehta et al., 2004). Correspondingly, data comparing behavioral profiles of children with ADHD and those with low working memory indicate that those with ADHD were associated with oppositional and hyperactive behavior compared to those with working memory deficits (Alloway, Gathercole, Holmes, Place, & Elliott, 2008).

In children with AS, poor performance was restricted to verbal short-term memory, with scores in the typical range for the other memory tasks. The verbal short-term memory deficits evidenced in the present study could be the result of a computerized presentation of verbal stimuli as this group was not able to benefit from phono-articulatory features available in spoken presentation. It is possible that these deficits are linked with problems of language and communication in this disorder as they are required to engage in social reciprocity, which includes remembering conversations in order to participate. Further research is needed to identify whether communication difficulties in those with AS lead to verbal short-term memory difficulties or if the memory problems underpin language problems.

The relatively strong performance in verbal working memory and visuospatial memory tasks suggests that these students do not struggle with the simultaneous task of processing and storing information. The additional requirement of manipulating information may provide individuals with AS more opportunity to link arbitrary verbal information with knowledge from their long-term memory, thus strengthening their skills. Other researchers who have found similarly good verbal working memory profiles in these populations propose that these skills do not drive impairments in associated executive function tasks such as planning and problem solving (e.g., D. L. Williams, Goldstein, Carpenter, & Minshew, 2005). This dissociation in performance supports the view that such deficits are likely to be intrinsic to skills underlying planning and problem-solving tasks specifically, rather than a generalized working memory impairment.

There are some limitations to the present study that would be useful to consider in future considerations. The study would benefit from a prior matching of groups with age. Although standardized tests with age-appropriate norms were used in this study, it is possible that diagnostic changes occur with time and matching the groups by age would address this issue. The sample size was admittedly uneven. Although reported effect sizes indicate a modest difference across groups, replication with a larger sample would provide a better test of potential differences in working memory profiles. The gender bias in the present study is in line with reported higher male-to-female ratios in the various disorders. However, a larger sample size would also provide the opportunity to explore such biases in working memory in these disorder groups. It would also be useful to include standardized measures of learning outcomes as a covariate given the co-occurrence of reading difficulties in those with SLI (Flax, Realpe-Bonilla, Hirsch, Brzustowicz, Bartlett, & Tallal, 2003) and ADHD (Rucklidge & Tannock, 2002).

These limitations notwithstanding, there are clear implications for learning. First, the use of the *Automated Working Memory Assessment* (Alloway, 2007a) as a means of distinguishing between children on the basis of their working memory profiles may be valuable in assisting clinicians and educational psychologists in identifying what lies at the root of the problems faced by a particular child. Next, appropriate support and intervention can be offered on the basis of the student's working memory profile. For example, verbal short-term memory deficits could be compensated by areas of strength in visuospatial short-term memory through the use of visual

aids such as look-up tables. Conversely, weaknesses in visuospatial short-term memory can be boosted by relying on verbal strategies like rehearsal. Where working memory deficits are present, the child will struggle to hold in mind and manipulate relevant material in the course of ongoing mental activities. Support to prevent working memory overload and consequent task failure includes breaking down tasks into smaller components, simplifying the nature of the information to be remembered, and using long-term memory to assist recall (Gathercole & Alloway, 2008). Such strategies have been found to improve working memory, sentence recall and comprehension, and long-term memory in those with language problems (Francis, Clark, & Humphreys, 2003). There is also evidence that cognitive training improves language skills in children with SLI (Bishop, Adams, Lehtonen, & Rosen, 2005) and working memory in those with ADHD (Klingberg et al., 2005).

In summary, the present study investigated the strengths and weaknesses of working memory in different developmental disorders. We find that the distinct memory profiles associated with each disorder reflect the nature of the deficit to some degree. The uniqueness of the diagnosis indicated by the AWMA identifies not only areas of deficit but also areas of strength on which compensatory strategies can be effectively built.

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