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Cognition and maths in children with Attention-Deficit/ Hyperactivity disorder with and without co-occurring movement difficulties

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ABSTRACT

Background: Movement difficulties are common in ADHD, however, the implications of their co-occurrences on cognitive and maths performance is unknown.
Aims: This study set out to examine whether cognitive and maths performance of children with high ADHD symptoms differs depending on the co-occurrence of movement difficulties given evidence that weaker visuospatial processing, known to be important for maths performance, differentiates ADHD and DCD. We also aimed to examine whether relationships between cognition and maths in ADHD differs depending on co-occurring movement difficulties.
Methods: Participants were 43 drug naïve children between 6 and 12 years old ($M = 101.53$ months $SD = 19.58$). The ADHD-only group ($n = 18$) included children with high ADHD scores, and those in the ADHD+DCD group ($n = 25$) concurrently had high movement difficulty scores. All completed executive function and memory, including 2 visuo-spatial memory tasks from the CANTAB battery and Mathematics Problem Solving, Numeracy, and Maths Fluency tasks from the WIAT-III and specific factual, conceptual, and procedural maths component tasks.
Results: Children in the ADHD+DCD group scored significantly lower on visuospatial working memory (WM) capacity, than those in the ADHD-only group. Both groups were comparable on all other cognitive assessments of executive functions, memory, and processing speed. The groups did not differ in their maths attainment scores, nor on more specific maths skills. Comparison of the correlations between cognitive processes and maths revealed that the association between visuospatial WM updating and procedural skill efficiency was stronger for the ADHD-only group. Moreover, associations between visuospatial WM and maths problem solving attainment were stronger in the ADHD+DCD group.
Conclusions: Despite similarities in maths performance, children with ADHD+DCD could be distinguished by lower visuospatial WM. Differential associations with some of the maths domain implicate recruitment of different cognitive processes for some aspects of maths. This distinction can be particularly useful for conceptualising cognitive characteristics of different clinical groups

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and understanding cognitive pathways of maths difficulties. Implications for interventions are discussed.

1. Introduction

ADHD is diagnosed in 1–2 % of children in the UK, with even more children experiencing difficulties below diagnostic thresholds (Russell et al., 2014; Sayal et al., 2018). Around half of children with ADHD meet criteria for Developmental Coordination Disorder (DCD) (Brossard-Racine et al., 2012). DCD, sometimes referred to as *dyspraxia,* is characterised by persistent difficulties in acquiring and executing fine (e.g., holding a pencil) and gross motor movements (e.g., hopping) to age-expected milestones (APA, 2013). Even children with high DCD symptoms not meeting clinical cut-offs show substantial motor difficulties (Sartori et al., 2020; Schoemaker et al., 2005). Both disorders are linked to lower cognitive and academic performance when compared to neurotypical children, and a co-occurring diagnosis significantly increases risk for poor academic outcomes (Alloway, 2010; Landgren et al., 2021). However, despite evidence for varying performance profiles, little is known about the effects of their co-existence on the cognitive functions these children are known to have difficulties with such as executive functions and memory alongside maths outcomes that rely on these cognitive processes.

There is empirical evidence for varying maths achievement profiles in children with ADHD and heightened risk for developing a maths learning difficulty even after controlling for confounding factors such as IQ and medication (Capano et al., 2008; Tosto et al., 2015). Furthermore, both clinical and subthreshold ADHD symptoms are shown to negatively impact maths performance (Loe & Feldman, 2007; Czamara et al., 2013). Maths underachievement in ADHD has been linked to lower cognitive functioning (Gathercole et al., 2018; Friedman et al., 2018). Specifically, diminished performance on neuropsychological tasks assessing Executive Functions (EFs), memory, and processing speed are documented in ADHD (Coghill et al., 2014; Mayes & Calhoun, 2007; Rhodes et al., 2012; Sonuga-Barke et al., 2010; Willcutt et al., 2005) and are important for maths performance in both ADHD and neurotypical children (Biederman et al., 2004; Bull et al., 2008; Cragg et al., 2017; Gathercole et al., 2018; Friedman et al., 2018; Geary, 2011; Holmes and Adams, 2006).

EFs have received particular attention due to their close affiliations with attentional control and well-documented difficulties in ADHD (Brocki et al., 2010; Gau & Shang, 2010). Conceptualisations of EF during primary school typically comprise inhibitory control, cognitive flexibility/set shifting, working memory (WM) and planning (Diamond, 2013; Miyake et al., 2000). Previous work supports the importance of these EF domains to children's maths attainment (Alloway, 2011; Antonini et al., 2016; Gremilllion & Martel, 2012; Friedman et al., 2018; Gathercole et al., 2018; Holmes & Adams 2014). For example, Antonini and colleagues (2016) found that although inhibitory control performance showed substantial associations with maths achievement in children with ADHD, only n-back (1-back) performance (a paradigm frequently used to assess WM capacity) remained a unique predictor when both were considered together. Notably, maths achievement was mediated by children's n-back performance but not by parent-rated symptoms of inattention. Another study by Gremillion and Martel (2012) found that verbal WM only partially mediated the relationship between 6 and 12-year-olds' ADHD symptoms and mathematics attainment. However, both studies used a community-based sample limiting the generalisability of findings to children who experience clinically debilitating difficulties. Furthermore, other EF domains (e.g., set shifting and planning), were not examined making it difficult to ascertain the relative association of each domain to maths achievement.

In a comprehensive investigation of both EF and memory in children with ADHD and learning difficulties, Gathercole and colleagues (2018) found that maths attainment yielded the strongest associations with visuospatial cognition, including higher order EF tasks of switching, planning, and visuo-spatial WM as well as storage. In addition to this, verbal STM also showed unique associations with children's maths score. However, it is important to note the aforementioned studies relied on reverse span tasks which have been criticised in the literature as reflecting short-term memory (STM) storage and recognition processes, rather than more complex updating requirements linked to higher order EF processing (Jaeggi et al., 2010).

According to the prominent model by Baddeley and Hitch (1974) the capacity-limited central executive of the WM system uses attentional processing for actively regulating, manipulating, and updating information 'online'. Meanwhile, the phonological loop and visuospatial sketchpad are responsible for storing modality-specific information in STM in the absence of concurrent processing (Baddeley & Hitch, 1974; Cowan, 2008). Working memory refers to a more complex cognitive process of actively manipulating and updating information in STM constituting: (1) serial reordering of information, (2) updating information by actively adding and deleting information from memory, and (3) dual processing by working with the information while concurrently storing it (Wager & Smith, 2003; Wells et al., 2018). Although reverse span tasks are frequently used to index WM, it has been argued that sequence reversal is insufficient for tapping into updating and dual processing subdomains of working memory (Conway et al., 2005; Swanson & Kim, 2007; Wells et al., 2018).

Although ADHD is predominantly conceptualised as a single disorder, children present with heterogeneous cognitive profiles (Coghill et al., 2014; Nigg et al., 2005; Willcutt et al., 2005) that can catalogue differential patterns of academic vulnerabilities (Astle et al., 2019; Roberts et al., 2017). Indeed, maths profiles in ADHD are also subject to marked within-group variability (Czamara et al., 2013; Capano et al., 2008; Mayes et al., 2019). Differential patterns of performance in cognitive processes underpinning maths acquisition are proposed to be at the core of this heterogeneity (de Souza Salvador et al., 2019). Some research points to lower-level verbal and visuospatial memory storage difficulties as core characteristics of ADHD (Rapport et al., 2008; Rhodes et al., 2012; Tillman et al., 2011). Modality-specific memory storage components are also implicated in maths achievement (Cragg et al., 2017; Gathercole et al., 2018; Holmes & Adams, 2006). Thus, it is important to address the relative association of WM capacity with and without updating requirements. Research suggests that while executive WM processes are employed by more complex Mathematics Problem Solving tasks such as those found in achievement tests, domain-specific storage of numbers and equations in the phonological loop and visuospatial sketchpad is particularly important for elementary maths skills, such as rehearsal of visuospatial (e.g., $2 + 2 = 4$), and phonological codes (e.g., two plus two equals four) for basic arithmetic facts (Bull et al., 2008; Cragg et al., 2017; Friedman et al., 2018; Holmes & Adams, 2006). Given the foundational role of early arithmetic skills to more advanced maths acquisition, investigating the role of memory in the absence of an active executive function processing component represents an imperative construct for further investigation.

Another cognitive construct without a prominent executive function component identified as vulnerable in ADHD (Nikolas & Nigg, 2013) and associated with maths achievement (Gathercole et al., 2018) is processing speed. More efficient processing enables the processing of more complex, or greater amounts of, information (Clark et al., 2014). Processing speed has previously been linked to children's basic arithmetic fluency, and indirectly to more advanced problem solving (Fuchs et al., 2006, 2008; Rose et al., 2011). Although some studies show that children's processing speed is a viable predictor of maths achievement independent of WM, some of these associations may be exaggerated due to measures of processing speed containing maths-related stimuli such as numbers (e.g., Bull and Johnston, 1997; Geary, 2011; Mayes & Calhoun, 2007; Sturm et al., 2018). Exploring processing speed performance using tasks without maths-related stimuli is therefore more favourable in identifying whether its' associations are domain general or not. A further argument for focusing on processing speed comes from studies that have examined it in relation to maths performance in typical populations (Gordon et al., 2020; Gordon et al., 2022). In these studies, processing speed was extracted from WM tasks (Gordon et al., 2020) and in further work processing speed and STM were measured separately (Gordon et al., 2022). Processing speed was a strong predictor above other measures of WM and related to different maths abilities.

Like those with ADHD, children with DCD show variable performance on cognitive tasks described above (Alloway, 2011; Asonitou et al., 2012; Sartori et al., 2020), even when ADHD symptoms are accounted for (Piek et al., 2007; Leonard et al., 2015). Children with DCD also show heterogeneous neurocognitive profiles (Sumner et al., 2016; Vaivre-Douret et al., 2011). Weaker visuospatial processing has been suggested to be a differentiating characteristic of DCD when compared to ADHD (Alloway, 2011; Loh et al., 2011). Given strong associations between visuospatial processes and children's maths performance (e.g., Allen et al., 2019), diminished visuospatial cognition in DCD could increase children's risk for maths difficulties.

While research in this area is scarce, lower maths performance is documented in DCD on broad achievement tests as well as more specific maths skills such as fact retrieval and calculation procedures (Alloway, 2007; Gomez et al., 2015; Pieters et al., 2012). Alloway (2011) found that children with ADHD and DCD were indistinguishable on maths attainment scores, but both clinical groups scored substantially lower than neurotypical controls. Children with ADHD mainly showed difficulties on measures of verbal and visuospatial working memory (WM), with intact short-term memory (STM) performance. Difficulties in the DCD group manifested more broadly across other memory domains, marked by particularly low scores on visuospatial memory tasks. Thus, different cognitive processes may have contributed to underachievement in each group.

Previous research points to ADHD and DCD as two separate disorders with distinct risk factors which, when co-existing, represent increased difficulties than either disorder alone (Goulardins et al., 2015, 2017). Loh and colleagues (2011) found substantially lower perceptual IQ in DCD and ADHD+DCD groups, but not in children with ADHD alone, suggesting weaker visuospatial processing is a distinct manifestation of DCD. Another study, using a larger sample, found that children with concurrent ADHD+DCD did not differ from the ADHD-only group on perceptual reasoning and WM indices of the WISC-IV (Parke et al., 2020). Both studies relied on composite IQ scores limiting findings to intellectual functioning and masking other important cognitive processes (e.g., visuospatial storage vs. updating).

The notion of additivity between ADHD and DCD is also found for maths performance. Visser and colleagues (2020) found that although children with DCD showed weaker maths performance than neurotypical controls, their maths scores were higher than the ADHD and combined ADHD+DCD groups. Differences in maths between the ADHD and ADHD+DCD groups did not reach statistical significance, suggesting that maths difficulties are mainly due to ADHD. The authors note further research, focusing on more specific aspects of maths and the contribution of specific cognitive processes, is necessary. Indeed, their study used a total maths score that can mask problems in more specific numerical skills (Dowker, 2005; Furlong et al., 2015). This includes (1) *factual knowledge* – the ability to retrieve arithmetic facts from memory, (2) *conceptual understanding* – the ability to identify and understand conceptually based numerical relationships, and (3) *procedural skill* – applying computational procedures accurately and efficiently (Dowker, 2005; Geary, 2004). Research in neurotypical children shows that these distinct yet highly correlated skills collectively contribute to broad maths attainment (Cragg et al., 2017). Some studies suggest that these domain-specific maths skills are impacted in ADHD and DCD (Benedetto-Nasho & Tannock, 1999; Friedman et al., 2018; Gomez et al., 2017; Pieters et al., 2012). However, these components have yet to be addressed in the context of co-occurring ADHD and DCD.

Up until 2013, the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) did not allow for concurrent diagnoses (Harris et al., 2015). However, ADHD seldom occurs in isolation and co-occurrences with other disorders seems to be the rule rather than the exception (Larson et al., 2011). This means that our understanding of educational difficulties in ADHD is limited to research that either excluded children with co-occurring DCD or failed to screen for DCD symptoms, making it difficult to characterise educational difficulties in a way that reflects real-life diagnostic complexities (Goulardins et al., 2015). Appropriate characterisations of ADHD samples, which inherently co-exist with other disorders, is crucial for guiding choices around appropriate intervention strategies tailored to children's needs.

Despite high rates of co-occurrence, little research exists on the co-existence between ADHD and DCD. The aim of the current study was to compare children with clinically high ADHD symptoms to those with high ADHD+DCD symptoms on a comprehensive set of cognitive assessments implicated in ADHD, in areas such as executive functions and memory identified as important for maths (from here on referred to as ADHD-only and ADHD+DCD groups, respectively) and known to be areas of difficulty for children with ADHD and DCD (Alloway, 2011; Rhodes et al., 2005, 2012). With evidence that visuo-spatial processing may differentiate ADHD and DCD, and its important relationship to maths performance, we included two visuo-spatial memory tasks providing several different indices of visuo-spatial memory. These tasks provide measures of visuospatial STM storage, and visuospatial WM and visuospatial WM with updating, included as these have all been demonstrated as key differential constructs (Hu et al., 2023). We set out to examine whether cognitive and maths performance of children with high ADHD symptoms differs depending on the co-occurrence of movement difficulties. We also aimed to examine whether relationships between cognition and maths in ADHD differs depending on co-occurring movement difficulties. Based on previous findings of diminished visuospatial processing in DCD it was expected that the ADHD+DCD group would show poorer scores on tasks that tap into visuospatial processing than the ADHD-only group. Another exploratory aim was to statistically examine whether there are differences in the associations between maths and executive functions and memory in the ADHD-only and ADHD+DCD groups. Exploring differences in cognitive and maths profile pathways is imperative for identifying the source of difficulties and informing intervention methods to support maths outcomes.

2. Method

2.1. Participants

Forty-three drug naïve children aged 6–12 years participated (*M*=101.53 months *SD* = 19.58). Children were recruited from the ADHD referral list at the Child and Adolescent Mental Health Services (CAMHS) in Lothian, Scotland, UK. The following exclusion criteria were applied: (1) primary language other than English, (2) current/previous stimulant treatment, (3) known chromosomal condition, (4) IQ score ≤ 70, or (5) scores within the typical range (<60) on the Conners 3-Parent (Conners, 2008) DSM-5 Inattention and/or Hyperactivity-Impulsivity subscales. Children with other co-occurring neurodevelopmental disorders were included. One child was excluded as their parent failed to complete the movement difficulties questionnaire. All parents and children provided consent prior to participation.

The ADHD+DCD group included 25 children with high T-scores ≥ 60 on the Conners 3-Parent (Conners, 2008) DSM-5 Inattention and/or Hyperactivity-Impulsivity subscales, and concurrently had a serious movement difficulty with a score ≤ 5th percentile on the Movement ABC-2 Checklist (MABC-2; Schulz et al., 2011). The ADHD-only[5] group included 18 children without significant movement difficulties. Children in this group had a typical movement score (≥5th percentile) on the MABC-2 and a high score on the Conners 3-Parent DSM-5 ADHD symptom scores (see Table 1 for demographic information).

2.2. Measures

2.2.1. ADHD symptoms

The 110 item Conners 3-Parent assessed DSM-5 symptom criteria for ADHD-Inattention, ADHD- Hyperactivity-Impulsivity, Conduct Disorder (CD) and Oppositional Defiant Disorder (ODD). As specified by the manual, a T-score ≥ 60 indicated clinically atypical level of symptoms and is a cut-off for more symptoms of the disorder than is typical for the child's age. The Conners 3 Parent DSM-5 Symptom Scales provide good internal consistency (α = .90), test-retest reliability (r = 0.89) and interrater reliability (r = .84; Kao & Thomas, 2010).

2.2.2. DCD motor difficulties

The MABC-2 obtained parents' views about children's motor difficulties in day-to-day settings. The MABC-2 is appropriate for children aged 5–12 years, with high classification agreement (80%−90%) to the Movement-ABC Test and good internal consistency (α = 0.94; (Schoemaker et al., 2012). Children were scored as having a serious movement difficulty if they scored ≤ 5th percentile.

2.2.3. Behavioural and emotional difficulties

The Strengths and Difficulties Questionnaire (SDQ; Goodman, 2001) was used to screen for behavioural and emotional difficulties. A total score of ≥ 17 reflected high levels of difficulties. The SDQ is a promising tool for identifying ADHD cases in community and clinical samples with good test-retest reliability (r = 0.70) and internal consistency (α = 0.73; Algorta et al., 2016; Goodman & Goodman, 2009; Stone et al., 2010).

2.2.4. IQ

The Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler, 2011) assessed children's intellectual functioning. Together, the Vocabulary and Similarities subtest T-Scores provided the Verbal Comprehension Index (VCI; r = .94) while the Block Design and Matrix Reasoning T-Scores together provided the Perceptual Reasoning Index (PRI; r = .92). Furthermore, a Full-Scale IQ (FSIQ; r = .96) score was generated from all four subtests.

The British Picture Vocabulary Scale (BPVS-III; Dunn & Dunn, 2009) provided an index of receptive vocabulary IQ (r = 0.91 and

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[5] This group is referred to as ADHD-only for ease of interpretation when comparing to ADHD+DCD group, but neither refer to 'pure' ADHD as demonstrated by high rates of co-occurrences in the results section.

Table 1
Sociodemographic, clinical, and IQ characteristics of groups.

	ADHD+DCD (n = 25)	ADHD (n = 18)	$\chi 2$ (or *t*)	*p*
Sociodemographic				
Age in months, Mean (SD)	100.4 (19.54)	103.11 (20.09)	-0.44	.660
Male (%)	15 (60%)	15 (83%)	1.94	.163
Lowest SIMD-Q (%)	12 (44%)	8 (44.4%)	.001	.977
ADHD Symptoms				
Conners Inattention, Mean (SD)	82.80 (9.44)	79.39 (11.92)	1.05	.301
Conners Hyperactive Impulsive, Mean (SD)	83.44 (10.35)	86.06 (6.94)	-0.93	.358
Co-occurring difficulties				
Conners ODD (%)	19 (76%)	15 (83%)	0.35	.712
Conners CD (%)	19 (76%)	13 (72%)	0.78	1.00
SDQ (%)	20 (80%)	15 (83%)	0.08	1.00
Perinatal complications				
Low Birthweight	2 (8%)	0	2.24	.502
Preterm Birth	4 (16%)	0	4.63	.127
IQ				
WASI Verbal Comprehension, Mean (SD)	101.04(10.99)	94.33 (12.65)	1.82	.077
WASI Perceptual Reasoning, Mean (SD)	97.32 (14.55)	97.44 (16.77)	-0.03	.979

SD standard deviation; *SIMD-Q* Scottish Index of Multiple Deprivation Quintile; *ODD* Oppositional Defiant Disorder; *CD* Conduct Disorder; Strengths and Difficulties Questionnaire; *WASI* Wechsler Abbreviated Scaled of Intelligence

validity with the Wechsler Intelligence Scale for Children as r = .76). Children with a BPVS and WASI-II FSIQ score ≤ 70 were deemed as potentially having an intellectual disability and were excluded from the study.

2.2.5. Cognitive tasks

The selection of cognitive tasks was largely informed by identifying domains that are areas of difficulty for children with ADHD including executive functions and memory (Coghill et al., 2014; Kofler et al., 2019; Nigg et al., 2002; Rhodes et al., 2012, 2005; Rhodes et al., 2006; Willcutt et al., 2005) and, concurrently, those which have been shown to be important to children's maths performance (Anonini et al., 2016; Andersson, 2010; Clark et al., 2010; Cowan et al., 2011; Cragg et al., 2017; Gilmore et al., 2015; Gremillion and Martel, 2012). The CANTAB battery has been used extensively to examine neuropsychological functioning in neurotypical children and in children with developmental disorders such as ADHD (e.g., Lawson & Farah, 2017; Rhodes et al., 2016, 2012; Coghill et al., 2018, 2014; Seyedtabaei et al., 2018). It benefits from nonverbal task stimuli and requires minimal linguistic proficiency during administration (Luciana, 2003). This liberty from verbal responses is particularly important as language difficulties have been documented in children with ADHD (Helland et al., 2016; Geurts & Embrechts, 2008). Another advantage of the CANTAB is that administration was identical for every participant and so minimises administration variability (Fried et al., 2015). Children completed seven tasks from the Cambridge Neuropsychological Test Automated Battery (CANTAB®, 2018) on an iPad and one assessment from the Wechsler Intelligence Scale for Children (WISC-V; Wechsler, 2016). Paediatric normative data for the CANTAB version used here was not available at the time of analysis and so raw scores were compared to data from published studies with typically developing children as illustrated in Appendix 1. To adjust for age, all raw scores were transformed into *z*-scores using participants' age (Table 2). Measures of impairment were reverse scored so that higher scores indicated better performance. Internal studies of reliability completed by Cambridge Cognition indicate test-retest reliability coefficients as ranging from 0.4 to 0.87 (Sandberg, 2011).

The Stop Signal Task assessed children's inhibitory control. Participants responded to arrows pointing in either left or right direction by pressing corresponding buttons. Responses had to be withheld when an auditory signal was heard. The key outcome measure was the stop signal reaction time (Stop Signal RT) in milliseconds (ms).

The Intra-Extra Dimensional Set Shift measured attentional set-shifting. Participants selected abstract shapes and were prompted to learn rules regarding their choices via feedback. Once a rule was learned, the stimuli and/or rules changed, and participants shifted attention to previously trivial stimulus attributes. The key outcome was the total number of times that an incorrect stimulus was selected, adjusted for every stage that was not reached (Intra-Extra Dimensional Errors).

The Spatial Working Memory (Spatial WM) task assessed visuospatial WM with updating. Participants were shown square 'boxes' and were asked to find a concealed token by looking in each box, with the caveat that once found, a token would not be hidden in the same box twice. The number of boxes increased from four, six, and eight items. The key outcome measure was the number of times participants incorrectly revisited a box in which a token was previously found (Spatial WM Between Search Errors).

The Stockings of Cambridge task assessed planning. Participants copied a model pattern of three stacked coloured balls using a pre-specified minimum number of moves ranging from two, three, four, and five. The key outcome measure was the total number of problems solved in the minimum number of moves (Stockings of Cambridge Problems Solved).

The Letters Numbers Sequencing task (WISC-V) measured verbal WM updating. Participants listened to letters and numbers and recited the numbers in ascending numerical order and the letters in alphabetical order. The total number of items increased from two to eight. The outcome measure was children's scaled score for the total number of trials (max=30) for which the letters numbers sequence was correctly recited.

The Spatial Span task indexed visuospatial STM storage and visuospatial WM. Participants reproduced the order in which boxes change colour in a forward sequence (Spatial Span Forwards; visuospatial STM) and in reverse sequence (Spatial Span Reverse;

Table 2
Descriptive statistics and group differences in cognition and maths scores.

		ADHD+DCD		ADHD			
	N	Mean (SD)	N	Mean (SD)	*g/r*	*t/U*	*BCa p- value*
Cognition							
Stop Signal Task RT (ms)	24	-0.08 (0.96)	18	0.06 (0.95)	-0.14	-0.45	.635
Intra-Extra Dimensional Set Shift Errors	24	-0.10 (0.88)	18	0.12 (1.04)	0.10	245.50	.453
Spatial WM Between Search Errors	24	-0.09 (0.89)	16	0.14 (1.00)	0.12	214.50	.539
Letters Numbers Sequencing Scaled Score	20	7.60(2.91)	16	7.00 (3.69)	0.18	0.55	.589
Stockings of Cambridge Problems Solved	24	-0.02 (0.85)	17	0.03 (1.07)	-0.05	-0.18	.860
Spatial Span Forwards	24	-0.17 (0.87)	16	0.16 (1.00)	-0.35	-1.15	.242
Spatial Span Reverse	**24**	**-0.30 (0.84)**	**16**	**0.41 (0.95)**	**-0.77**	**-2.48**	**.024**
Delayed Matching to Sample % Correct (12 s delay)	24	-0.01 (0.93)	18	0.02 (0.96)	-0.03	-0.11	.912
Stop Signal Task Median RT Go Trials (processing speed; ms)	24	-0.15 (0.94)	18	0.17 (0.95)	-0.39	-1.10	.269
VRM Immediate	12	-0.19 (0.92)	11	0.19 (0.93)	-0.31	-0.77	.427
VRM Delayed	11	-0.14 (0.98)	11	0.16 (0.89)	-0.33	-0.96	.328
Maths							
WIAT Mathematics Problem Solving	25	92.12(12.03)	18	93.11(13.00)	-0.08	-0.26	.798
WIAT Numeracy	25	92.56(12.25)	18	92.50(10.84)	0.00	0.02	.987
WIAT Maths Fluency	24	88.67(10.16)	18	94.50(15.95)	0.19	265	.212
Factual Knowledge Accuracy	21	-0.02 (0.97)	17	-0.01 (0.96)	-0.01	-0.05	.964
Conceptual Understanding Accuracy	21	0.02 (1.03)	16	-0.07 (0.86)	0.10	0.30	.763
Procedural Skill Accuracy	17	0.16 (0.95)	13	-0.12 (0.88)	0.31	0.84	.409
Procedural Skill Efficiency (RT)	17	-0.04 (1.03)	13	0.11 (0.83)	-0.15	-0.42	.675

RT reaction time; *WIAT* Wechsler Individual Achievement Test; *VRM* Verbal Recognition Memory; BCa Bias corrected and accelerated bootstrap.

visuospatial WM). The number of boxes increased from two to nine items, depending on the child's progress. The outcome measure was the maximum correct span length.

The Delayed Matching to Sample assessed delayed short-term visual recognition memory. Participants selected a previously presented pattern from a choice of four patterns shown either simultaneously or at zero, four, and twelve second (s) delays. The outcome measure was percentage of trials on which participants correctly responded upon first attempt on 12 s delays (Delayed Matching to Sample % Correct 12 s delay).

The Verbal Recognition Memory (VRM) task assessed immediate and delayed memory for verbal information. Children were presented with a list of 18 words and were asked to identify previously presented words from a larger list of words. Outcome measures were the total number of distinct words participants correctly recalled (1) immediately after presentation (VRM Immediate Recognition), and (2) following a 20-minute delay (VRM Delayed).[6] This task required children to be able to read words and was only administered to children aged over eight years.

The median RT (ms) on all Go trials in the Stop Signal Task was used to assess children's processing speed (Stop Signal Task Median RT All Go Trials).

2.2.6. *Maths achievement*

Maths attainment was assessed using standardised scores on the Wechsler Individual Achievement Test (WIAT®-III; Wechsler, 2017) subtests: Mathematics Problem Solving, Numeracy, and Maths Fluency. On the Mathematics Problem Solving, children solved word problems relating to time, money, measurement, geometry, probability or reading graphs. The Numeracy subtest measured written calculation skills. The Maths Fluency subtests measured written maths calculation fluency under timed conditions on addition, subtraction, and multiplication sums.

2.2.7. *Maths components*

Children completed three tasks assessing specific maths skills. To eliminate floor or ceiling effects, items of varying difficulty were presented depending on the child's year at school. Raw scores were transformed into *z*-scores based on children's year group.

The factual knowledge task (Cowan et al., 2011; Simms et al., 2015) assessed knowledge of arithmetic facts. Children were asked to quickly solve single digit addition sums, each presented on the screen for four seconds. The outcome measure was the total number of correct responses provided within the four seconds limit (max = 12).

The conceptual understanding task (Cowan et al., 2011; Simms et al., 2015) assessed children's understanding and application of maths concepts. Participants were presented with double-digit addition and subtraction sums on the screen with its corresponding answer (e.g., 31 +45 = 76). After six seconds, another related sum appeared below it but this time without an answer (e.g., 76–45 =?). Children were asked to use the first sum to help solve the second sum. There were 12 experimental trials, three for each conceptual principle: double plus one (e.g., 42 +42 = 84, 42 +43 =?), related by commutativity (e.g., 48 +21 =69, 21 +48 =?), related by inversion (e.g., 79–17 =62, 62 +17 =?) and identical (e.g., 56–27 = 29, 56–27 =?). Children had six seconds to provide an answer for

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[6] VRM Delayed/Immediate Recognition: = The total number of target words that the child correctly recognises in the delayed/immediate recognition phase, plus the total number of distractor words that the child correctly rejects.

the second sum. The problems were designed so that children were unlikely to solve the sum within this time limit unless they relied on conceptual insight. The outcome measure was the total number of correct responses provided within the time limit (max = 12).

The procedural skills task (Cragg et al., 2017) assessed children's ability to execute maths procedures accurately and efficiently. Children received 10 experimental trials comprising addition and subtraction operations using single and double-digit numbers and were instructed to give an answer as quickly as possible. The outcome measures were the total correct responses (i.e., accuracy max=10) and the mean RT in seconds for correctly answered trials (i.e., efficiency). The mean RT scores were reverse scored so that higher scores indicated better performance.

2.3. Procedure

Testing was conducted across two to three sessions and typically took place either at home (first session) or at school in a quiet room (second and third sessions). The total assessment time was around three hours per child. At the first session children completed the CANTAB tasks on an iPad, while the parent/carer completed the questionnaires (i.e., Conners, MABC-2, and the SDQ). During the other sessions children completed assessments of maths, IQ, and the verbal WM task.

2.4. Statistical analysis

2.4.1. Statistical approach

Analyses were conducted using IBM SPSS Statistics 24. Independent sample *t*-tests and chi squared (x^2) tests were used to compare groups on sociodemographic, clinical, and IQ characteristics, as well as to compare the groups on all cognitive and maths outcome measures. Given the small sample size, we report Bias corrected and accelerated (BCa) bootstrapped confidence intervals (Polansky, 2000). To decrease false-positives due to multiple correlations, correlational analyses between maths and cognition were implemented using Spearman's rho, with the Benjamini-Hochberg correction applied using a false discovery rate of 0.05 (Benjamini and Hochberg (1995) The Fisher's *r*-to-*z* test was used to compare the correlation values between the groups (Raghunathan et al., 1996; Field, 2018).

No univariate outliers were identified for the cognitive and maths variables using *z*-scores > 3.29 (Field, 2018; Tabachnik & Fidell, 2013). Multivariate outliers were also screened for using Mahalanobis distance scores. Chi-square distributions of the Mahalanobis distance scores for the maths ($df = 7$) and cognitive ($df = 11$) variables were all non-significant ($p > .001$). Normality within each group was checked using skewness and kurtosis *z*-scores using a cut-off of 1.96 (alpha level of $p < .05$; Kim, 2013; Tabachnik & Fidell, 2013). Non-parametric variant Mann-Whitney U test for paired comparisons were used as an alternative to compare groups on variables violating the assumption of normality (Field, 2018).

2.4.2. Power considerations

A power analysis using G*Power was conducted to test two-tailed *t*-test using a medium ($d = .50$), and large ($d = .80$) effect size (Faul et al., 2007). To achieve power of 0.8, a total sample of 54 participants would be necessary to detect a large effect size and 132 participants would be necessary to detect a medium effect size. Due to the small sample size, it was possible that the analysis would not be able to detect significant effects. However, small sample sizes are common in this research area (e.g., Bikic et a., 2018; Downs et al.,2016) and we applied bootstrapped confidence intervals as appropriate. Previous researchers challenge reliance on *p*-values and instead suggest using effect size estimates to explore important differences that could otherwise be missed by *p*-values (Field & Wright, 2006). Effect size magnitudes are reported using Hedges *g* (0.2 = small effect, 0.5 = medium effect, 0.8 = large effect) which is less biased than Cohen's *d* in smaller samples (Borenstein et al., 2021; Lakens, 2013). For the non-parametric Mann Whitney U tests effect sizes were calculated using *r* (0.1 = small effect, 0.3 =moderate effect and 0.5 =large effect; Field, 2018).

2.5. Results

2.5.1. Non-completers

Overall, 9.98% of values were missing on cognitive and maths assessments. Of the included participants, thirteen children did not complete at least one of the maths tasks. Children with missing maths observations were younger $t\,(41) = -4.63$, $p < .001$ and had higher motor difficulty scores than completers $t\,(41) = 2.03$, $p = .048$. Completers and non-completers did not differ on IQ, cognitive scores, nor on parent rated clinical characteristics (all *p*'s > .05). Of the included participants, thirteen children had missing data on at least one of the cognitive assessments. Non-completers were younger $t\,(41) = -3.55$, $p = .001$, and had lower parent reported birthweight $t\,(26.22) = -2.97$, $p = .006$ than those with complete cognitive data. Non-completers on cognitive assessments however had lower (i.e., less difficulties) SDQ scores $t\,(35.29) = -2.64$, $p = .012$ and ODD scores $t\,(16.79) = -2.62$, $p = .018$. Lastly, children with incomplete cognitive data scored lower on procedural efficiency than completers $t\,(28) = -3.20$, $p = .003$. Completers and non-completers did not differ on other measures (all *p*'s > .05). All children were included, regardless of completion status.

2.5.2. Group differences

Groups did not differ from each other in age, gender, nor on the Scottish Index of Multiple Deprivation (SIMD; Table 1). Similar proportions of children in each group scored high on symptoms of ODD and CD, as well as high emotional and behavioural difficulties indexed by the SDQ. Two children in the ADHD+DCD group were of low birthweight (<2500 g) and four children were born preterm (<37 weeks; Anderson et al., 2011; Franz et al., 2018). The groups had comparable verbal and perceptual IQ scores.

Descriptive statistics and results of the group differences for cognition and maths are presented in Table 2.

2.5.2.1. Cognition. Children in ADHD+DCD group had lower Spatial Span Reverse scores, indexing visuospatial WM ($M = -0.30$, $SD = 0.84$) than the ADHD-only group ($M = 0.41$, $SD = 0.95$, t (38) = −2.48, BCa $p = .024$, BCa 95% CI [− 1.25, − 0.20]. Hedge' *g* effect size was − 0.77, indicating a large effect. No other statistically significant differences or large effect sizes were found between these groups (all *p* values > 0.05, Hedge's *g* from −0.03 to 0.39).

2.5.2.2. Maths. Group differences on the standardised achievement scores (*g*'s from 0.00 to 0.19) and maths component assessments (*g*'s from −0.01 to 0.31) were all non-statistically significant (*p*'*s* > 0.05).

2.5.2.3. Correlations. The correlations between maths and cognition scores in the ADHD+DCD and ADHD-only groups are presented in Tables 3 and 4, respectively.

2.5.2.4. IQ. Perceptual IQ scores on the WASI significantly correlated with Mathematics Problem Solving Scores ($r = .638$, $p = .001$) only in the ADHD+DCD group, showing greater perceptual IQ was associated with greater maths problem solving skills. In the ADHD-only group higher comprehension IQ scores were significantly associated with higher conceptual understanding accuracy rates ($r = .618$, $p = .011$). All other associations were non-significant.

2.5.2.5. Cognition. Letters Numbers Sequencing scores, indexing verbal WM, significantly correlated with the WIAT Mathematics Problem Solving scores in both the ADHD+DCD group ($r = .671$, $p = .001$) and ADHD-only group ($r = .738$, $p = .001$), such that greater verbal WM was associated with higher problem-solving. Spatial WM Between Search Errors, assessing visuospatial WM updating, showed significant associations with procedural skill efficiency RTs only in the ADHD-only group ($r = .786$, $p = .001$), such that greater visuospatial WM updating was associated with higher procedural efficiency. All other associations between EF tasks and maths measures were not statistically significant.

In the ADHD+DCD group, higher Spatial Span Revere scores (visuospatial WM) were associated with greater achievement scores on the WIAT Mathematics Problem Solving achievement subtest ($r = .753$, $p < .001$), as well as higher scores on more specific maths knowledge skills including factual knowledge accuracy ($r = .620$, $p = .004$), and procedural skill accuracy ($r = .669$, $p = .003$). Additionally, higher immediate verbal recognition memory scores were associated with greater factual knowledge accuracy ($r = .894$, $p < .001$) and Mathematics Problem Solving scores on the WIAT ($r = .691$, $p = .013$) only in the ADHD+DCD group.

In the ADHD-only group, only the delayed verbal recognition memory scores significantly correlated to accuracy on the conceptual understanding task ($r = .742$, $p = .009$). All other associations failed to reach statistical significance.

2.5.3. Comparing correlations between groups

Fisher's *r*-to-*Z* transformation revealed that correlations between visuospatial WM updating scores and procedural skill efficiency were significantly different for the two groups ($Z = -2.05$, $p = .040$), with stronger associations in the ADHD-only group. Notably, group differences in the correlations between visuospatial WM and WIAT Mathematics Problem Solving scores were on the threshold for statistical significance ($Z = 1.95$, $p = .050$), with more substantial associations for the ADHD+DCD group. All other contrasts of

Table 3
Correlation matrix for ADHD+DCD group.

	Maths problem solving	Numeracy	Maths fluency	Factual knowledge accuracy	Conceptual understanding accuracy	Procedural skill accuracy	Procedural skill RT
WASI Perceptual Reasoning	.638**◊	.451*	.460*	.175	.179	.517*	.066
WASI Verbal Comprehension	.373	.042	.066	.204	.485*	.196	-.189
Stop Signal Task RT (ms)	.068	-.034	-.193	.038	-.114	-.038	-.268
Intra-Extra Dimensional Set Shift Errors	.276	.353	.070	.298	.152	.200	.228
Spatial WM Between Search Errors	.257	.367	.243	.153	-.096	.048	.208
Letters Numbers Sequencing Scaled Score	.671**◊	.409	.441	.168	.508*	.400	-.134
Stockings of Cambridge Problems Solved	-.252	-.182	-.166	-.088	-.128	-.111	.325
Spatial Span Forwards	.437*	.331	.085	.275	.100	.274	-.123
Spatial Span Reverse	.753**◊	.535**	.356	.620** ◊	.493*	.669**◊	.475
Delayed Matching to Sample % Correct (12 s delay)	.383	.428 *	.217	.455*	.116	.348	.115
VRM Immediate	.691*◊	.605 *	.387	.894** ◊	.793**	.576	.491
VRM Delayed	.530	.598	.492	.579	.642*	.486	.492
Stop Signal Task Median RT Go Trials (ms)	.177	.151	.282	.200	-.060	.010	.318

*p < .05, * * p < .01, ◊ significant effect after Benjamini-Hochberg correction
RT reaction time; *WASI* Wechsler Abbreviated Scale of Intelligence; *VRM* Verbal Recognition Memory

Table 4
Correlation matrix for ADHD-only group.

	Maths problem solving	Numeracy	Maths fluency	Factual knowledge accuracy	Conceptual understanding accuracy	Procedural skill accuracy	Procedural skill RT
WASI Perceptual Reasoning	.567*	.494*	.456	.519*	.533*	.538	.265
WASI Verbal Comprehension	.521*	.497*	.461	.379	.618*◊	.390	.036
Stop Signal Task RT (ms)	.277	.155	-.050	-.079	.594*	.209	-.291
Intra-Extra Dimensional Set Shift Errors	.100	.262	.294	.279	-.041	.540	.582*
Spatial WM Between Search Errors	.500*	.539*	.433	.459	.262	.639*	.786**◊
Letters Numbers Sequencing Scaled Score	.738**◊	.564*	.546*	.548*	.761**◊	.320	.272
Stockings of Cambridge Problems Solved	-.127	.087	-.128	-.090	-.146	.256	.364
Spatial Span Forwards	.447	.251	.386	.418	.495	.068	-.036
Spatial Span Reverse	.283	.301	.280	.269	.254	.538	.152
Delayed Matching to Sample % Correct (12 s delay)	.025	-.011	.188	.072	.010	.564*	.388
VRM Immediate	.564	.629*	.582	.571	.593	.516	.709*
VRM Delayed	.638*	.409	.756**	.449	.742**◊	.593	.369
Stop Signal Task Median RT Go Trials (ms)	.263	.263	.328	.226	.075	.424	.324

*$p < .05$, * * $p < .01$, ◊ significant effect after Benjamini-Hochberg correction
RT reaction time*; WASI* Wechsler Abbreviated Scale of Intelligence; *VRM* Verbal Recognition Memory

correlation coefficients between the groups were non-significant.

3. Discussion

This study compared children with high ADHD symptoms to those with ADHD+DCD difficulties on a comprehensive set of cognitive and maths assessments. Although the two ADHD groups could not be differentiated based on maths performance, the ADHD+DCD group showed substantially lower visuospatial WM performance. Comparison of the correlation coefficients between the groups revealed differences in associations between some maths domains and visuospatial memory domains. Specifically, visuospatial WM updating and procedural skill efficiency scores were more strongly correlated in ADHD-only group, while visuospatial WM scores (i.e., w/o updating demands) showed stronger associations with maths problem solving attainment scores in the ADHD+DCD group. Collectively, findings suggest that although children with ADHD with and without movement difficulties are comparable in maths performance, lower visuospatial WM is a distinct characteristic of children with concurrently high DCD symptoms. Furthermore, the results point to differential contribution of visuospatial memory performance with and without updating demands to more complex maths problem solving and procedural calculations in these groups.

3.1. *Group differences*

The hypothesis relating to more diminished visuospatial memory in the ADHD+DCD group was only partially supported. Children in the ADHD+DCD group performed lower on the visuospatial WM task, consistent with previous research pointing to weaker visuospatial memory processing as a hallmark of DCD (Alloway, 2011). However, children in the ADHD+DCD group were comparable to their ADHD-only counterparts on visuospatial WM updating which also taxed visuospatial memory processes. On the Spatial WM task children use a self-directed elimination strategy to remember and update which boxes they already opened to check for tokens and must avoid going back to for duration of the trial, and concurrently remember and update which boxes are still left to check. This emphasises updating requirements of the task as, although participants recall previous token locations, the main focus is on being able to continuously update visuospatial content in WM (Smith et al., 2013). However, on the Spatial Span Reverse task sequences are explicitly displayed, memorised, and reverse ordered, primarily taxing WM storage and manipulation capacity (Jaeggi al., 2010; Wells et al., 2018). Such sequence reversal is insufficient for tapping into the updating domain of WM (Conway et al., 2005; Engle et al., 1999; Wells et al., 2018). The present findings therefore imply that children with ADHD+DCD can be distinguished by marked difficulties on visuospatial WM without updating requirements. Furthermore, it suggests that children with concurrent DCD would benefit from remediation strategies that support manoeuvring of visuospatial information.

The lack of statistically significant findings or large effect sizes in relation to visuospatial STM storage (Spatial Span Forwards) implies that children with concurrent DCD struggle more with the manipulation subdomain of visuospatial WM, than retention of visuospatial information. To illustrate how this translates in the context of maths, we can take a sum such as $15 + 7 = ?$. One way to solve this would be to decompose the problem into subproblems: (1) $5 + 7 = 12$, and (2) $10 + 12 = 22$. Visuospatial storage would be involved in storing the interim solution 12 in memory, while manipulation would help visualise and restructure the problem into the easier format. Carrying and borrowing procedures in more complex calculations (e.g., 70–19 =?) are also heavily reliant on the child's ability to re-organise and manipulate content, for example in 70–19 = ? the 70 is manipulated to first become a 10 where 10–9 = 1, thereafter the 70 transforms into a 60 where 60–10 = 50. While the child may have no difficulty in storing a particular solution (i.e., 10–9 = 1), it is the transformation into variable formats that could be problematic. Thus, intervention strategies for children with ADHD+DCD may benefit by specifically supporting children's skill in manipulating digits in visuospatial formats.

The finding that groups did not differ on any EF assessments suggests that children with ADHD and co-occurring DCD are generally indistinguishable from their ADHD-only peers when higher order executive processes are involved. This is in line with previous arguments that EF difficulties are a feature of ADHD (Piek et al., 2004). Nonetheless, research by Leonard and colleagues (2015) found that children with DCD also struggle with EF performance, even where ADHD symptoms are accounted for. Based on the current study, it cannot be ruled out that both groups struggle with EF when compared to neurotypical children. Future research would benefit from incorporating normative data and including a DCD-only group to establish whether EF difficulties are a specific manifestation of DCD.

Unlike Loh and colleagues (2011), this study did not find evidence for better perceptual IQ in the ADHD-only group. This could be the product of their recruitment of children from schools, as opposed to the clinically referred sample used here. Another study, which also recruited a clinical group of children, found that perceptual reasoning IQ scores in the ADHD and ADHD+DCD groups were comparable (Parke et al., 2020). This highlights the effects that different recruitment contexts can have on emerging results and the generalisability of their implications. Similar to the current findings, Parke and colleagues (2020) also found that children in the ADHD and ADHD+DCD groups did not differ in their verbal IQ scores. However, they also identified a group of children with ADHD + co-occurring reading/written expression disorder – this group scored substantially lower on verbal IQ than the ADHD-only and ADHD+DCD groups. Literacy difficulties are common in ADHD (Mayes & Calhoun, 2006). In the present study, children in the ADHD+DCD group had higher verbal IQ scores, although this failed to reach statistical significance when they were compared to the ADHD-only group. Given that children's literacy abilities were not included here, it is possible that children in the ADHD-only group had varying reading/writing abilities, which could explain the lack of significant findings in verbal IQ scores.

The finding that children in the ADHD and ADHD+DCD groups did not differ from one another on any of the broader maths scores is consistent with previous research (Alloway, 2011; Visser et al., 2020). Importantly, the current study extends this to more specific maths components of the factual, conceptual, and procedural subdomains. Visser and colleagues (2020) found that their DCD group scored higher on maths than the ADHD and combined ADHD+DCD groups, suggesting that maths difficulties are mainly due to ADHD difficulties. However, other research shows that maths achievement profiles of children with ADHD are indistinguishable from those with DCD (Alloway, 2011), autism (Bullen et al., 2020), low WM (Holmes et al., 2014), and learning difficulties (Gathercole et al., 2018) implying that lower maths attainment is not exclusive to ADHD. More recent research shows that children's cognitive profiles are more informative for identifying struggling learners than traditional diagnostic groupings (Astle al., 2019). It would be interesting for future research to further explore whether data-driven cognitive subgroups that cut across diagnoses are more informative for domain-specific maths skills than the categorical approach used here.

At first glance the lack of difference between the groups in maths may be interpreted as visuospatial WM as not being important for maths performance. However, visuospatial WM shows substantial associations with range of maths skills. A more plausible explanation is that grouping children using diagnostic categories (i.e., ADHD vs ADHD + co-occurring motor difficulties) exaggerated homogeneity of maths performance. This parallels recent advances in the literature which show that diagnostic categories are not informative to academic outcomes (Astle et al., 2019; Gathercole et al., 2018). This is further supported by the finding that cognitive correlates of maths performance in ADHD with and without concurrent DCD were generally comparable (see below).

3.2. *Comparing correlations between groups*

Statistical comparison of the correlations revealed that associations between maths and cognition in both groups were generally similar, however, some notable exceptions were evident. Specifically, visuospatial WM updating showed stronger associations with procedural skill efficiency in the ADHD-only group. It could be that children in the ADHD-only group relied more heavily on procedural strategies that tax WM updating, such as decomposition strategies (e.g., in 15 + 7 =? (1) 15 + 7 = 12, and (2) 10 + 12 = 22, then updating old solution *12* with new answer *22*). By contrast, it is possible that children in the ADHD+DCD did not capitalise on updating-based strategies as much and instead used less mature and more time-consuming manual counting strategies (e.g., finger counting and counting on). In theory these latter strategies are more prone to errors but, despite taking longer to compute, the ADHD+DCD group were more accurate in their calculations than their ADHD-only counterparts (moderate effect size differences). Similarly, it is unlikely that children in the ADHD+DCD opted for faster visuospatial retrieval-based strategies as this should have resulted in higher efficiency rates. Notably, WM updating is shown to be important to virtually all arithmetic strategies including decomposition, retrieval, and counting on (Cragg al., 2017). Thus, whichever strategy children opted for should have resulted in some level of WM mobilisation. These findings also can't be explained by greater updating difficulties in the ADHD-only group, as the groups showed similar performance on this domain. Further research is therefore necessary to explore this further.

Visuospatial WM (i.e., w/o updating requirements) performance was more strongly associated with WIAT Mathematics Problem Solving attainment scores in the ADHD+DCD group than the ADHD-only group. This implies that for the ADHD+DCD group visuospatial WM was particularly important for successful navigation of maths problem solving. This subtest required children to encode, store and manipulate visuospatial stimuli such as coloured pictures, shapes, and graphs to accommodate problem solving (Fung & Swanson, 2017). Plausibly, more pronounced difficulties with visuospatial WM in the ADHD+DCD group resulted in greater difficulties with maths problem solving. However, it is important to note that this difference in the correlations fell on the threshold of significance (p = .050) and so further research is necessary before conclusive remarks can be made.

Verbal WM performance significantly related to Mathematics Problem Solving attainment scores in both groups. This subtest required children to listen to orally presented problems, identify, and hold the most relevant phonological information 'online', whilst concurrently trying to solve the problem – updating previously held information with newly identified solutions (Bull & Lee, 2014; Cragg et al., 2017). This suggest that children's ability to solve word problems is closely linked to retrieval and storage of relevant phonological information in memory and its' active processing during problem solving. Children with low verbal WM capacity may therefore benefit from intervention strategies that support cyclic rehearsal and reduce demands on active updating of phonological information.

Previous evidence interprets comparable cognitive correlates of maths performance in diagnostic subgroups (e.g., Alloway, 2011; Mayes et al., 2020). However, these correlations were not statistically compared, and research mainly focused on standardised attainment scores. The statistical comparison of the correlation coefficients in the current study showed that the majority of the correlations between a wide range of cognitive domains (i.e., EFs, memory and processing speed) were statistically comparable across the two groups and extends this finding to domain-specific maths skills. It is therefore possible that diagnostic subgroups are simply not informative to children's maths difficulties from a practical perspective.

3.3. Limitations

The small sample size in the present study suggests that findings should be interpreted with caution. We applied Bootstrapped confidence intervals and focused on examination of effect sizes, rather than overreliance on p-values, in order to avoid any over interpretation though. Bootstrapping has been recommended instead of bonferroni corrections for multiple comparisons (Beaumont & Bocci, 2009) and indeed there are some suggestions in the literature that adjustments are not needed for multiple comparisons (Rothman, 1990). Small sample sizes are common in research with neurodivergent populations but the exploratory nature of this work and focus on effect sizes suggests we can have confidence in the findings as presented. Future research with larger samples would be useful.

The current study used a more conservative (≤ 5th percentile) cut-off for identifying children with DCD. Some studies use a score of ≤ 15th percentile to identify children with DCD (e.g., Gomez et al., 2015; Pieters et al., 2012). However, these studies rely on the MABC-2 Performance Test, typically administered by a trained professional to objectively assess children's ability to complete motor tasks. The current study utilised the MABC-2 Checklist, which is more open to parents' subjective interpretation of their child's abilities. Furthermore, whilst scores ≤ 5th percentile indicate 'significant' motor impairment, scores between 6th and 15th percentile are interpreted as 'at risk' of developing a movement difficulty requiring continued monitoring.[7] To minimise ambiguity the more definitive cut-off of the 5th percentile was selected. This cut-off was also selected in line with other studies and suggestions that scores below 2 SDs are more diagnostically accurate for differentiating between children with typical motor functioning (Barnett & Wiggs, 2012; Griffiths et al., 2017; Zoia et al., 2002).

Furthermore, to receive a DCD diagnosis, motor impairment cannot be attributed to underlying ADHD symptoms (Goulardins et al., 2015). Children in the ADHD-only and ADHD+DCD groups did not differ in their parent rated ADHD symptoms of inattention and hyperactivity-impulsivity. This suggests that lower motor abilities in the ADHD+DCD sample were unlikely due to ADHD symptoms and is consistent with previous findings showing that motor difficulties are not part of an ADHD phenotype (Farran et al., 2020).

Another factor which could be considered a limitation is the lack of control group as this may challenge the internal validity of the findings. Karalunas and Nigg (2020) argue that although comparisons of ADHD with control groups can be informative for identifying ADHD-specific characteristics, it is more favourable to move away from such approaches and instead focus on identifying features and mechanisms for clinical subgroups, as observable characteristics are likely to cluster together in informative ways even without such comparisons. An abundance of research over the years demonstrated behavioural, cognitive, and educational difficulties in children with ADHD when compared to their neurotypical peers. Yet, after decades of such research we are still far from understanding the aetiological mechanisms behind academic difficulties in ADHD and developing suitable intervention methods that have long-lasting benefits (Kofler et al., 2017; Luo et al., 2019). In the current study, the focus was on examination of the additional contribution of co-occurring movement difficulties on cognitive and educational attainment profiles in children with high ADHD symptoms rather than documentation of differential patterns of performance and variable associations in comparison to typically developing children. Nonetheless future research could add to the current focus on co-occurrences by including a typically developing control group to determine the generalisability of the current results.

Lastly, the finding in relation to verbal WM updating should be interpreted with caution. The verbal WM task required processing of numbers which may have confounded its associations with children's numerical performance. Future research would benefit from exploring verbal WM performance in tasks without digit processing to rule out the confounding effects of numerical abilities.

4. Conclusions

This is the first study to comprehensively investigate cognitive and maths profiles in a well characterised and drug naïve sample of children with high ADHD symptoms with and without co-occurring motor difficulties. Findings showed that whilst children with ADHD and ADHD+DCD show similar maths performance, those with ADHD+DCD can be distinguished by weaker visuospatial WM

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[7] Only three children scored between the 6th and 15th percentile: running the *t*-test analysis with these three participants in the ADHD+DCD group did not change the pattern of results in the group comparisons

performance. This can be particularly informative for clinical distinctions between different types of diagnoses, as well as for informing interventions tailored to children's needs. Few notable differences were identified between the two groups in terms of the pattern of associations between cognition and maths. Most of the statistical comparisons of the correlations revealed comparable associations. Although further research is necessary before conclusions can be made, the current findings point to the notion that similar cognitive processes contribute to maths performance in both groups. Therefore, future research would benefit from using cognitive dimensions, rather than diagnosis or symptoms, for exploring pathways of maths difficulties.

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CRediT authorship contribution statement

MK, JB, SR: Ideas; formulation or evolution of overarching research goals and aims: Conceptualization. **MK, JB, SR, TS**: Development or design of methodology; creation of models: Methodology. MK: Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components: Software. **MK**: Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs: Validation. **MK**: Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesise study data: Formal analysis. **MK, TS**: Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection: Investigation. **MK**: Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools: Resources. **MK**: Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse: Data Curation. **MK, JB, SR, TS**: Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation): Writing - Original Draft. **MK, JB, SR, TS**: Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or postpublication stages: Writing - Review & Editing. **MK**: Preparation, creation and/or presentation of the published work, specifically visualisation/ data presentation: Visualisation. SR JB: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team: Supervision. **MK, JB, SR, TS**: Management and coordination responsibility for the research activity planning and execution: Project administration. **MK, JB, SR**: Acquisition of the financial support for the project leading to this publication: Funding acquisition.

Declaration of Competing Interest

None.

Data availability

The authors do not have permission to share data.

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What this paper adds?

This study contributes to the growing literature on the effects of co-occurrences in ADHD. This study compared cognitive and maths profiles of children with ADHD (ADHD-only) with and without movement difficulties (ADHD+DCD). This is the first study to compare the effects of co-occurring ADHD+DCD symptoms on a comprehensive battery of cognitive and maths tasks. The findings demonstrated that the cognitive and maths profiles of the ADHD+DCD and ADHD-only groups were generally similar. However, children with ADHD+DCD could be distinguished from their ADHD-only counterparts by lower performance on a task tapping into visuospatial WM. This suggests that co-occurring DCD symptoms in ADHD infer added risk for diminished visuospatial WM performance. Furthermore, differential correlations between certain cognitive domains and maths tasks implicate recruitment of different cognitive processes for certain aspects of maths. This highlighted diminished visuospatial WM performance as a distinguishing feature of children with concurrently high DCD symptoms, which can be especially informative for clinical practice and intervention.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ridd.2023.104471.

References

Algorta, G. P., Dodd, A. L., Stringaris, A., & Youngstrom, E. A. (2016). Diagnostic efficiency of the SDQ for parents to identify ADHD in the UK: A ROC analysis. *European Child & Adolescent Psychiatry, 25*(9), 949–957. https://doi.org/10.1007/s00787-015-0815-0

Allen, K., Higgins, S., & Adams, J. (2019). The relationship between visuospatial working memory and mathematical performance in school-aged children: A systematic review. *Educational Psychology Review, 31*(3), 509–531. https://doi.org/10.1007/s10648-019-09470-8

Alloway, T. P. (2007). Working memory, reading, and mathematical skills in children with developmental coordination disorder. *Journal of Experimental Child Psychology, 96*(1), 20–36. https://doi.org/10.1016/j.jecp.2006.07.002

Alloway, T. P. (2011). A comparison of working memory profiles in children with ADHD and DCD. *Child Neuropsychology, 17*(5), 483–494. https://doi.org/10.1080/09297049.2011.553590

Anderson, P. J., De Luca, C. R., Hutchinson, E., Spencer-Smith, M. M., Roberts, G., & Doyle, L. W. (2011). Attention problems in a representative sample of extremely preterm/extremely low birth weight children. *Developmental Neuropsychology, 36*(1), 57–73. https://doi.org/10.1080/87565641.2011.540538 (Victorian Infant Collaborative Study Group, L. W.).

Andersson, U. (2010). Skill development in different components of arithmetic and basic cognitive functions: Findings from a 3-year longitudinal study of children with different types of learning difficulties. *Journal of Educational Psychology, 102*(1), 115–134. https://doi.org/10.1037/a0016838

Antonini, T. N., Kingery, K. M., Narad, M. E., Langberg, J. M., Tamm, L., & Epstein, J. N. (2016). Neurocognitive and behavioral predictors of math performance in children with and without ADHD. *Journal of Attention Disorders, 20*(2), 108–118. https://doi.org/10.1177/1087054713504620

Association, A.P. , (2013). Diagnostic and statistical manual of mental disorders (DSM-5®): American Psychiatric Pub. https://doi.org/10.1007/springerreference_179660.

Astle, D. E., Bathelt, J., & Holmes, J. (2019). Remapping the cognitive and neural profiles of children who struggle at school. *Developmental Science, 22*(1), 1–18. https://doi.org/10.1111/desc.12747

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation, 8*, 47–89. https://doi.org/10.1016/s0079-7421(08)60452-1

Barnett, A., & Wiggs, L. (2012). Sleep behaviour in children with developmental co-ordination disorder. *Child: Care, Health and Development, 38*(3), 403–411. https://doi.org/10.1111/j.1365-2214.2011.01260.x

Beaumont, J.-F., & Bocci, Cynthia (2009). A practical bootstrap method for testing hypotheses from survey data. *Survey Methodology, 35*, 25–35.

Benedetto-Nasho, E., & Tannock, R. (1999). Math computation, error patterns and stimulant effects in children with attention deficit hyperactivity disorder. *Journal of Attention Disorders, 3*(3), 121–134. https://doi.org/10.1177/108705479900300301

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society, 57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Biederman, J., Monuteaux, M. C., Doyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., & Faraone, S. V. (2004). Impact of executive function deficits and attention-deficit/hyperactivity disorder (ADHD) on academic outcomes in children. *Journal of Consulting and Clinical Psychology, 72*(5), 757–766. https://doi.org/10.1037/0022-006x.72.5.757

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). *Introduction to meta-analysis*. John Wiley & Sons. https://doi.org/10.1002/9781119558378

Brocki, K. C., Eninger, L., Thorell, L. B., & Bohlin, G. (2010). Interrelations between executive function and symptoms of hyperactivity/impulsivity and inattention in preschoolers: A two-year longitudinal study. *Journal of Abnormal Child Psychology, 38*(2), 163–171. https://doi.org/10.1007/s10802-009-9354-9

Brossard-Racine, M., Shevell, M., Snider, L., Bélanger, S. A., & Majnemer, A. (2012). Motor skills of children newly diagnosed with attention deficit hyperactivity disorder prior to and following treatment with stimulant medication. *Research in Developmental Disabilities, 33*(6), 2080–2087. https://doi.org/10.1016/j.ridd.2012.06.003

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*(3), 205–228. https://doi.org/10.1080/87565640801982312

Bull, R., & Johnston, R. S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology, 65*(1), 1–24. https://doi.org/10.1006/jecp.1996.2358

Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives, 8*(1), 36–41. https://doi.org/10.1111/cdep.12059

Bullen, J. C., Lerro, L. S., Zajic, M., McIntyre, N., & Mundy, P. (2020). A developmental study of mathematics in children with autism spectrum disorder, symptoms of attention deficit hyperactivity disorder, or typical development. *Journal of Autism and Developmental Disorders, 50*(12), 4463–4476. https://doi.org/10.1007/s10803-020-04500-9

Capano, L., Minden, D., Chen, S. X., Schachar, R. J., & Ickowicz, A. (2008). Mathematical learning disorder in school-age children with attention-deficit hyperactivity disorder. *The Canadian Journal of Psychiatry, 53*(6), 392–399. https://doi.org/10.1177/070674370805300609

Clark, C. A., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology, 46*(5), 1176. https://doi.org/10.1037/a0019672

Clark, C. A. C., Nelson, J. M., Garza, J., Sheffield, T. D., Wiebe, S. A., & Espy, K. A. (2014). Gaining control: Changing relations between executive control and processing speed and their relevance for mathematics achievement over course of the preschool period. *Frontiers in Psychology, 5*, 107. https://doi.org/10.3389/fpsyg.2014.00107

Coghill, D. R., Banaschewski, T., Bliss, C., Robertson, B., & Zuddas, A. (2018). Cognitive function of children and adolescents with attention-deficit/hyperactivity disorder in a 2-year open-label study of lisdexamfetamine dimesylate. *CNS Drugs, 32*(1), 85–95. https://doi.org/10.1007/s40263-017-0487-z

Coghill, D. R., Seth, S., & Matthews, K. (2014). A comprehensive assessment of memory, delay aversion, timing, inhibition, decision making and variability in attention deficit hyperactivity disorder: advancing beyond the three-pathway models. *Psychological Medicine, 44*(9), 1989–2001. https://doi.org/10.1017/s0033291713002547

Conners, C. K. (2008). *Conners third edition (Conners 3)*. Los Angeles, CA: Western Psychological Services.

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. https://doi.org/10.3758/bf03196772

Cowan, R., Donlan, C., Shepherd, D.-L., Cole-Fletcher, R., Saxton, M., & Hurry, J. (2011). Basic calculation proficiency and mathematics achievement in elementary school children. *Journal of Educational Psychology, 103*(4), 786–803. https://doi.org/10.1037/a0024556

Cragg, L., Richardson, S., Hubber, P. J., Keeble, S., & Gilmore, C. (2017). When is working memory important for arithmetic? The impact of strategy and age. *PLOS One, 12*(12). https://doi.org/10.1371/journal.pone.0188693

Czamara, D., Tiesler, C. M., Kohlbock, G., Berdel, D., Hoffmann, B., Bauer, C. P., & Heinrich, J. (2013). Children with ADHD symptoms have a higher risk for reading, spelling and math difficulties in the GINIplus and LISAplus cohort studies. *PLOS ONE, 8*(5). https://doi.org/10.1371/journal.pone.0063859

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dowker, A. (2005). Early identification and intervention for students with mathematics difficulties. *Journal of Learning Disabilities, 38*(4), 324–332. https://doi.org/10.1177/00222194050380040801

Dunn, L. M., & Dunn, D. M. (2009). *The British picture vocabulary scale*. GL Assessment Limited. https://doi.org/10.1037/t15145-000

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128*(3), 309–331. https://doi.org/10.1037/0096-3445.128.3.309

Farran, E. K., Bowler, A., D'Souza, H., Mayall, L., Karmiloff-Smith, A., Sumner, E., & Hill, E. L. (2020). Is the motor impairment in attention deficit hyperactivity disorder (ADHD) a co-occurring deficit or a phenotypic characteristic? *Advances in Neurodevelopmental Disorders, 4*, 253–270. https://doi.org/10.31234/osf.io/hzme7

Field, A. (2018). *Discovering statistics using IBM SPSS statistics*. Sage.

Fried, R., Hirshfeld-Becker, D., Petty, C., Batchelder, H., & Biederman, J. (2015). How informative is the CANTAB to assess executive functioning in children with ADHD? A controlled study. *Journal of Attention Disorders, 19*(6), 468–475. https://doi.org/10.1177/1087054712457038

Friedman, L. M., Rapport, M. D., Orban, S. A., Eckrich, S. J., & Calub, C. A. (2018). Applied problem solving in children with ADHD: The mediating roles of working memory and mathematical calculation. *Journal of Abnormal Child Psychology, 46*(3), 491–504. https://doi.org/10.1007/s10802-017-0312-7

Fuchs, L. S., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., & Fletcher, J. M. (2006). The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *Journal of Educational Psychology, 98*(1), 29. https://doi.org/10.1037/0022-0663.98.1.29

Fuchs, L. S., Fuchs, D., Stuebing, K., Fletcher, J. M., Hamlett, C. L., & Lambert, W. (2008). Problem solving and computational skill: Are they shared or distinct aspects of mathematical cognition? *Journal of Educational Psychology, 100*(1), 30. https://doi.org/10.1037/0022-0663.100.1.30

Fuchs, L. S., Geary, D. C., Compton, D. L., Fuchs, D., Hamlett, C. L., Seethaler, P. M., & Schatschneider, C. (2010). Do different types of school mathematics development depend on different constellations of numerical versus general cognitive abilities? *Developmental Psychology, 46*(6), 1731–1746. https://doi.org/10.1037/a0020662

Furlong, M., McLoughlin, F., McGilloway, S., Geary, D., & Butterworth, B. (2015). Interventions to improve mathematical performance for children with mathematical learning difficulties (MLD. *Cochrane Database of Systematic Reviews, 4*. https://doi.org/10.1002/14651858.cd012130

Gathercole, S. E., Astle, D. A., Manly, T., Holmes, J., & Team, C. (2018). Cognition and behaviour in learning difficulties and ADHD: A dimensional approach. *bioRxiv*, 260–265. https://doi.org/10.1101/260265

Gau, S. S.-F., & Shang, C.-Y. (2010). Executive functions as endophenotypes in ADHD: Evidence from the Cambridge neuropsychological test battery (CANTAB). *Journal of Child Psychology and Psychiatry, 51*(7), 838–849. https://doi.org/10.1111/j.1469-7610.2010.02215.x

Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37*(1), 4–15. https://doi.org/10.1177/00222194040370010201

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: a 5-year longitudinal study. *Developmental Psychology, 47*(6), 1539–1552. https://doi.org/10.1037/a0025510

Geurts, H. M., & Embrechts, M. (2008). Language profiles in ASD, SLI, and ADHD. *Journal of Autism and Developmental Disorders, 38*(10), 1931. https://doi.org/10.1007/s10803-008-0587-1

Gilmore, C., Keeble, S., Richardson, S., & Cragg, L. (2015). The role of cognitive inhibition in different components of arithmetic. *ZDM: The International Journal on Mathematics Education, 47*(5), 771–782. https://doi.org/10.1007/s11858-014-0659-y

Gomez, A., Piazza, M., Jobert, A., Dehaene-Lambertz, G., Dehaene, S., & Huron, C. (2015). Mathematical difficulties in developmental coordination disorder: Symbolic and nonsymbolic number processing. *Research in Developmental Disabilities, 43*, 167–178. https://doi.org/10.1016/j.ridd.2015.06.011

Gomez, A., Piazza, M., Jobert, A., Dehaene-Lambertz, G., & Huron, C. (2017). Numerical abilities of school-age children with developmental coordination disorder (DCD): A behavioral and eye-tracking study. *Human Movement Science, 55*, 315–326. https://doi.org/10.1016/j.humov.2016.08.008

Goodman, A., & Goodman, R. (2009). Strengths and difficulties questionnaire as a dimensional measure of child mental health. *Journal of the American Academy of Child & Adolescent Psychiatry, 48*(4), 400–403. https://doi.org/10.1097/chi.0b013e3181985068

Goodman, R. (2001). Psychometric properties of the strengths and difficulties questionnaire. *Journal of the American Academy of Child & Adolescent Psychiatry, 40*(11), 1337–1345. https://doi.org/10.1097/00004583-200111000-00015

Goulardins, J. B., Marques, J. C. B., & De Oliveira, J. A. (2017). Attention deficit hyperactivity disorder and motor impairment: A critical review. *Perceptual and Motor Skills, 124*(2), 425–440. https://doi.org/10.1177/0031512517690607

Goulardins, J. B., Rigoli, D., Licari, M., Piek, J. P., Hasue, R. H., Oosterlaan, J., & Oliveira, J. A. (2015). Attention deficit hyperactivity disorder and developmental coordination disorder: Two separate disorders or do they share a common etiology. *Behavioural Brain Research, 292*, 484–492. https://doi.org/10.1016/j.bbr.2015.07.009

Gremillion, M. L., & Martel, M. M. (2012). Semantic language as a mechanism explaining the association between ADHD symptoms and reading and mathematics underachievement. *Journal of Abnormal Child Psychology, 40*(8), 1339–1349. https://doi.org/10.1007/s10802-012-9650-7

Griffiths, A., Morgan, P., Anderson, P. J., Doyle, L. W., Lee, K. J., & Spittle, A. J. (2017). Predictive value of the movement assessment battery for children-second edition at 4 years, for motor impairment at 8 years in children born preterm. *Developmental Medicine & Child Neurology, 59*(5), 490–496. https://doi.org/10.1111/dmcn.13367

Harris, S. R., Mickelson, E. C., & Zwicker, J. G. (2015). Diagnosis and management of developmental coordination disorder. *Cmaj, 187*(9), 659–665. https://doi.org/10.1503/cmaj.140994

Helland, W. A., Posserud, M.-B., Helland, T., Heimann, M., & Lundervold, A. J. (2016). Language impairments in children with ADHD and in children with reading disorder. *Journal of Attention Disorders, 20*(7), 581–589. https://doi.org/10.1177/1087054712461530

Holmes, J., & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology, 26*(3), 339–366. https://doi.org/10.1080/01443410500341056

Holmes, J., Hilton, K. A., Place, M., Alloway, T. P., Elliott, J. G., & Gathercole, S. E. (2014). Children with low working memory and children with ADHD: Same or different? *Frontiers in Human Neuroscience, 8*(976), 1–13. https://doi.org/10.3389/fnhum.2014.00976

Hu, Q., Liang, Z., Zhou, Y., Feng, S., & Zhang, Q. (2023). The role of working memory updating and capacity in children's mathematical abilities: A developmental cascade model. *British Journal of Educational Psychology, 00*, 1–20. https://doi.org/10.1111/bjep.12585

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory, 18*(4), 394–412. https://doi.org/10.1080/09658211003702171

Kao, G. S., & Thomas, H. M. (2010). Test review: C. Keith Conners Conners 3rd edition Toronto, Ontario, Canada: Multi-Health systems, 2008. *Journal of Psychoeducational Assessment, 28*(6), 598–602. https://doi.org/10.1177/0734282909360011

Kofler, M. J., Irwin, L. N., Soto, E. F., Groves, N. B., Harmon, S. L., & Sarver, D. E. (2019). Executive functioning heterogeneity in pediatric ADHD. *Journal of Abnormal Child Psychology, 47*(2), 273–286. https://doi.org/10.1007/s10802-018-0438-2

Kofler, M. J., Sarver, D. E., Spiegel, J. A., Day, T. N., Harmon, S. L., & Wells, E. L. (2017). Heterogeneity in ADHD: Neurocognitive predictors of peer, family, and academic functioning. *Child Neuropsychology, 23*(6), 733–759. https://doi.org/10.1080/09297049.2016.1205010

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Landgren, V., Fernell, E., Gillberg, C., Landgren, M., & Johnson, M. (2021). Attention-deficit/hyperactivity disorder with developmental coordination disorder: 24-year follow-up of a population-based sample. *BMC Psychiatry, 21*(1), 1–12.

Larson, K., Russ, S. A., Kahn, R. S., & Halfon, N. (2011). Patterns of comorbidity, functioning, and service use for US children with ADHD, 2007. *Pediatrics, 127*(3), 462–470. https://doi.org/10.1542/peds.2010-0165

Lawson, G. M., & Farah, M. J. (2017). Executive function as a mediator between SES and academic achievement throughout childhood. *International Journal of Behavioral Development, 41*(1), 94–104. https://doi.org/10.1177/0165025415603489

Leonard, H. C., Bernardi, M., Hill, E. L., & Henry, L. A. (2015). Executive functioning, motor difficulties, and developmental coordination disorder. *Developmental Neuropsychology, 40*(4), 201–215. https://doi.org/10.1080/87565641.2014.997933

Loe, I. M., & Feldman, H. M. (2007). Academic and educational outcomes of children with ADHD. *Journal of Pediatric Psychology, 32*(6), 643–654. https://doi.org/10.1093/jpepsy/jsl054

Loh, P. R., Piek, J. P., & Barrett, N. C. (2011). Comorbid ADHD and DCD: Examining cognitive functions using the WISC-IV. *Research in Developmental Disabilities, 32*(4), 1260–1269. https://doi.org/10.1016/j.ridd.2011.02.008

Luo, Y., Weibman, D., Halperin, J., & Li, X. (2019). A review of heterogeneity in attention deficit/hyperactivity disorder (ADHD). *Frontiers in Human Neuroscience, 13*, 42. https://doi.org/10.3389/fnhum.2019.00042

Mayes, S. D., & Calhoun, S. L. (2007). Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychology, 13*(6), 469–493. https://doi.org/10.1080/09297040601112773

Mayes, S. D., Waschbusch, D. A., Calhoun, S. L., & Mattison, R. E. (2019). How common are academic overachievement and underachievement in children with autism or ADHD? *Journal of Developmental and Physical Disabilities*, 1–9. https://doi.org/10.1007/s10882-019-09719-8

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Nigg, J. T., Blaskey, L. G., Huang-Pollock, C. L., & Rappley, M. D. (2002). Neuropsychological executive functions and DSM-IV ADHD subtypes. *Journal of the American Academy of Child & Adolescent Psychiatry, 41*(1), 59–66. https://doi.org/10.1097/00004583-200201000-00012

Nigg, J. T., Willcutt, E. G., Doyle, A. E., & Sonuga-Barke, E. J. (2005). Causal heterogeneity in attention-deficit/hyperactivity disorder: Do we need neuropsychologically impaired subtypes? *Biological Psychiatry, 57*(11), 1224–1230. https://doi.org/10.1016/j.biopsych.2004.08.025

Nikolas, M. A., & Nigg, J. T. (2013). Neuropsychological performance and attention-deficit hyperactivity disorder subtypes and symptom dimensions. *Neuropsychology, 27*(1), 107. https://doi.org/10.1037/a0030685

Parke, E. M., Thaler, N. S., Etcoff, L. M., & Allen, D. N. (2020). Intellectual profiles in children with ADHD and comorbid learning and motor disorders. *Journal of Attention Disorders, 24*(9), 1227–1236. https://doi.org/10.1177/1087054715576343

Piek, J. P., Dyck, M. J., Francis, M., & Conwell, A. (2007). Working memory, processing speed, and set-shifting in children with developmental coordination disorder and attention-deficit–hyperactivity disorder. *Developmental Medicine & Child Neurology, 49*(9), 678–683. https://doi.org/10.1111/j.1469-8749.2007.00678.x

Piek, J. P., Dyck, M. J., Nieman, A., Anderson, M., Hay, D., Smith, L. M., & Hallmayer, J. (2004). The relationship between motor coordination, executive functioning and attention in school aged children. *Archives of Clinical Neuropsychology, 19*(8), 1063–1076. https://doi.org/10.1016/j.acn.2003.12.007

Pieters, S., Desoete, A., Van Waelvelde, H., Vanderswalmen, R., & Roeyers, H. (2012). Mathematical problems in children with developmental coordination disorder. *Research in Developmental Disabilities, 33*(4), 1128–1135. https://doi.org/10.1016/j.ridd.2012.02.007

Polansky, A. M. (2000). Stabilizing bootstrap-t confidence intervals for small samples. *Canadian Journal of Statistics, 28*, 501–516. https://doi.org/10.2307/3315961

Raghunathan, T. E., Rosenthal, R., & Rubin, D. B. (1996). Comparing correlated but nonoverlapping correlations. *Psychological Methods, 1*(2), 178–183. https://doi.org/10.1037/0033-2909.111.1.172

Rapport, M. D., Alderson, R. M., Kofler, M. J., Sarver, D. E., Bolden, J., & Sims, V. (2008). Working memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of central executive and subsystem processes. *Journal of Abnormal Child Psychology, 36*(6), 825–837. https://doi.org/10.1007/s10802-008-9215-y

Rhodes, S. M., Booth, J. N., Palmer, L. E., Blythe, R. A., Delibegovic, M., & Wheate, N. J. (2016). Executive functions predict conceptual learning of science. *British Journal of Developmental Psychology, 34*(2), 261–275. https://doi.org/10.1111/bjdp.12129

Rhodes, S. M., Coghill, D. R., & Matthews, K. (2005). Neuropsychological functioning in stimulant-naive boys with hyperkinetic disorder. *Psychological Medicine, 35*(8), 1109–1120. https://doi.org/10.1017/s0033291705004599

Rhodes, S. M., Park, J., Seth, S., & Coghill, D. R. (2012). A comprehensive investigation of memory impairment in attention deficit hyperactivity disorder and oppositional defiant disorder. *Journal of Child Psychology and Psychiatry, 53*(2), 128–137. https://doi.org/10.1111/j.1469-7610.2011.02436.x

Roberts, B. A., Martel, M. M., & Nigg, J. T. (2017). Are there executive dysfunction subtypes within ADHD? *Journal of Attention Disorders, 21*(4), 284–293. https://doi.org/10.1177/1087054713510349

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental Science, 14*(5), 1161–1175. https://doi.org/10.1111/j.1467-7687.2011.01068.x

Rothman, K. J. (1990). No adjustments are needed for multiple comparisons. *Epidemiology, 1*(1), 43–46.

Russell, G., Rodgers, L. R., Ukoumunne, O. C., & Ford, T. (2014). Prevalence of parent-reported ASD and ADHD in the UK: Findings from the Millennium Cohort Study. *Journal of Autism and Developmental Disorders, 44*(1), 31–40. https://doi.org/10.1007/s10803-013-1849-0

Sandberg, M. A. (2011). Cambridge neuropsychological testing automated battery. In J. S. Kreutzer, J. DeLuca, & B. Caplan (Eds.), *Encyclopedia of clinical neuropsychology*. New York, NY: Springer. https://doi.org/10.1007/978-0-387-79948-3_169.

Sartori, R. F., Valentini, N. C., & Fonseca, R. P. (2020). Executive function in children with and without developmental coordination disorder: A comparative study. *Child: Care, Health and Development, 46*(3), 294–302. https://doi.org/10.1111/cch.12734

Sayal, K., Prasad, V., Daley, D., Ford, T., & Coghill, D. (2018). ADHD in children and young people: Prevalence, care pathways, and service provision. *The Lancet Psychiatry, 5*(2), 175–186. https://doi.org/10.1016/s2215-0366(17)30167-0

Schoemaker, M. M., Ketelaars, C. E., Van Zonneveld, M., Minderaa, R. B., & PhD, T. M. (2005). Deficits in motor control processes involved in production of graphic movements of children with attention-deficit-hyperactivity disorder. *Developmental Medicine & Child Neurology, 47*(6), 390–395. https://doi.org/10.1017/s0012162205000769

Schulz, J., Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2011). Structural validity of the movement ABC-2 test: Factor structure comparisons across three age groups. *Research in Developmental Disabilities, 32*(4), 1361–1369. https://doi.org/10.1016/j.ridd.2011.01.032

Seyedtabaei, R., Seyedtabaei, R., Mohammadi, S. D., & Tehranidust, M. (2018). Impact of long-term use of methylphenidate on visual memory of drug-naïve children with attention deficit disorder. *Iranian Journal of Psychiatry and Behavioral Sciences, 12*(4). https://doi.org/10.5812/ijpbs.7899

Simms, V., Gilmore, C., Cragg, L., Clayton, S., Marlow, N., & Johnson, S. (2015). Nature and origins of mathematics difficulties in very preterm children: A different etiology than developmental dyscalculia. *Pediatric Research, 77*(2), 389–395. https://doi.org/10.1038/pr.2014.184

Smith, P. J., Need, A. C., Cirulli, E. T., Chiba-Falek, O., & Attix, D. K. (2013). A comparison of the Cambridge automated neuropsychological test battery (CANTAB) with "traditional" neuropsychological testing instruments. *Journal of Clinical and Experimental Neuropsychology, 35*(3), 319–328. https://doi.org/10.1080/13803395.2013.771618

Sonuga-Barke, E., Bitsakou, P., & Thompson, M. (2010). Beyond the dual pathway model: evidence for the dissociation of timing, inhibitory, and delay-related impairments in attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 49*(4), 345–355. https://doi.org/10.1097/00004583-201004000-00009

de Souza Salvador, L., Moura, R., Wood, G., & Haase, V. G. (2019). Cognitive heterogeneity of math difficulties: A bottom-up classification approach. *Journal of Numerical Cognition, 5*(1), 55–85. https://doi.org/10.5964/jnc.v5i1.60

Stone, L. L., Otten, R., Engels, R. C., Vermulst, A. A., & Janssens, J. M. (2010). Psychometric properties of the parent and teacher versions of the strengths and difficulties questionnaire for 4-to 12-year-olds: A review. *Clinical Child and Family Psychology Review, 13*(3), 254–274. https://doi.org/10.1007/s10567-010-0071-2

Sturm, A., Rozenman, M., Piacentini, J. C., McGough, J. J., Loo, S. K., & McCracken, J. T. (2018). The effect of neurocognitive function on math computation in pediatric ADHD: Moderating influences of anxious perfectionism and gender. *Child Psychiatry & Human Development, 49*(5), 822–832. https://doi.org/10.1007/s10578-018-0798-4

Sumner, E., Pratt, M. L., & Hill, E. L. (2016). Examining the cognitive profile of children with developmental coordination disorder. *Research in Developmental Disabilities, 56*, 10–17. https://doi.org/10.1016/j.ridd.2016.05.012

Swanson, L., & Kim, K. (2007). Working memory, short-term memory, and naming speed as predictors of children's mathematical performance. *Intelligence, 35*(2), 151–168. https://doi.org/10.1016/j.intell.2006.07.001

Tillman, C., Eninger, L., Forssman, L., & Bohlin, G. (2011). The relation between working memory components and ADHD symptoms from a developmental perspective. *Developmental Neuropsychology, 36*(2), 181–198. https://doi.org/10.1080/87565641.2010.549981

Tosto, M. G., Momi, S., Asherson, P., & Malki, K. (2015). A systematic review of attention deficit hyperactivity disorder (ADHD) and mathematical ability: Current findings and future implications. *BMC Medicine, 13*(1). https://doi.org/10.1186/s12916-015-0414-4

Vaivre-Douret, L., Lalanne, C., Ingster-Moati, I., Boddaert, N., Cabrol, D., Dufier, J.-L., & Falissard, B. (2011). Subtypes of developmental coordination disorder: Research on their nature and etiology. *Developmental Neuropsychology, 36*(5), 614–643. https://doi.org/10.1080/87565641.2011.560696

Visser, L., Röschinger, J., Barck, K., Büttner, G., & Hasselhorn, M. (2020). Learning difficulties in children with symptoms of DCD And/or ADHD: Analyses from a categorical and a continuous approach. *International Journal of Disability, Development and Education*, 1–17. https://doi.org/10.1080/1034912x.2020.1786023

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory. *Cognitive, Affective, & Behavioral Neuroscience, 3*(4), 255–274. https://doi.org/10.3758/cabn.3.4.255

Wechsler, D. (2011). *Wechsler abbreviated scale of intelligence–second edition.* San Antonio, TX: NCS Pearson.

Wechsler, D. (2016). *Wechsler Intelligence Scale for Children–Fifth UK Edition.* London, UK: Harcourt Assessment.

Wechsler, D. (2017). *Wechsler individual achievement test—third UK edition (WIAT-III UK)*. London: Pearson.

Wells, E. L., Kofler, M. J., Soto, E. F., Schaefer, H. S., & Sarver, D. E. (2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. *Research in Developmental Disabilities, 72*, 166–178. https://doi.org/10.1016/j.ridd.2017.10.024

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*(11), 1336–1346. https://doi.org/10.1016/j.biopsych.2005.02.006

Zoia, S., Pelamatti, G., Cuttini, M., Casotto, V., & Scabar, A. (2002). Performance of gesture in children with and without DCD: effects of sensory input modalities. *Developmental Medicine & Child Neurology, 44*(10), 699–705. https://doi.org/10.1111/j.1469-8749.2002.tb00273.x