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Relationships between cognition and literacy in children with attention-deficit/hyperactivity disorder: A systematic review and meta-analysis

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Evidence suggests that cognitive and literacy difficulties are common for children with Attention-Deficit/Hyperactivity Disorder (ADHD). The current systematic review and meta-analysis investigated the relationship between cognition and literacy in children with ADHD. Ten thousand and thirty-eight articles were screened against the inclusion criteria and six eligible studies were retained for final review. Where two or more studies used comparable measures of cognition and literacy, a meta-analysis of the relationship between these measures was undertaken. A narrative synthesis of all included studies was also completed. There were medium effect sizes between working memory and aspects of reading, and small effect sizes between processing speed and reading. Inhibition and attention had differential relationships with aspects of literacy with varying effect sizes. This systematic review demonstrates differential relationships between aspects of literacy and cognition in children with ADHD. Further examination of these relationships is warranted to support intervention development.

Statement of contribution

What is already known on this subject?

- Children with cognitive difficulties tend to have poorer literacy skills.
- Less is known about how cognition and literacy are related for children with ADHD.

What the present study adds

- The first comprehensive review and meta-analysis of cognition and literacy in ADHD.
- Aspects of cognitive function are differentially related to literacy components.

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Background

Attention Deficit Hyperactivity Disorder (ADHD) is characterized by pervasive inattention, hyperactivity, and impulsivity (DSM-5; APA, 2013) and affects approximately 5% of the population (Russell, Rodgers, Ukoumunne, & Ford, 2014). Children with ADHD often face increased academic challenges compared with their peers (Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2020; DuPaul, Morgan, Farkas, Hillemeier, & Maczuga, 2016; Loe & Feldman, 2007; Mayes, Waschbusch, Calhoun, & Mattison, 2020; Silva et al., 2020). Given that this can lead to difficulties in adulthood, such as increased likelihood of unemployment (Kuriyan et al., 2013), it is vital that the reasons for these challenges are understood in order to facilitate the development of effective educational interventions.

Evidence has accumulated showing many children with ADHD have difficulties in maths and literacy. For example, DuPaul et al. (2016) reported that over a third of children with ADHD (approximately 39%) had consistently poor maths and reading achievement when their performance was measured at four time points between the ages of 5 and 11 years. While maths achievement was shown to be more variable over time, with some children's performance remaining stable and others improving or deteriorating, reading achievement was generally stable over time. Although this is positive for children whose literacy is already very good at age 5 (16.1%; DuPaul et al., 2016), this means that children whose literacy is poorer may struggle to improve without any intervention. Furthermore, the majority of children with ADHD who had the poorest reading achievement (up to 78%) also had the poorest maths achievement, which may be linked to the importance of early reading skills for maths performance (Grimm, 2008). DuPaul et al. reported that 63.1% of children with the poorest reading achievement were also likely to have the lowest interpersonal skills, suggesting that the impact of literacy impairment may be far-reaching, and a strong indicator for broader academic, social, or behavioural difficulties. Taken together, a focus on understanding the potential underlying causes of literacy difficulties is an important first step to understanding outcomes more broadly for individuals with ADHD.

In addition to educational and behavioural symptoms, children with ADHD can face a number of challenges in aspects of cognition. Documented features of the cognitive profile of ADHD include differences in attentional shifting and updating (Elosúa, Del Olmo, & Contreras, 2017), inhibition (Coghill, Seth, & Matthews, 2014), delayed short-term memory (Rhodes, Park, Seth, & Coghill, 2012), timing (Coghill et al., 2014), and working memory (Coghill et al., 2014; Miller et al., 2013; Rhodes et al., 2012). Together, this body of research points towards broad rather than isolated cognitive difficulties in ADHD. We know that children with broad cognitive difficulties also have significantly poorer literacy skills such as reading and spelling than children without these difficulties, or than those with isolated deficits such as in working memory alone (Astle, Bathelt, & Holmes, 2019). These complex profiles have significant implications for understanding literacy performance in ADHD.

A range of aspects of cognition are known to predict literacy performance for typically developing children (Lubin, Regrin, Boulc'h, Pacton, & Lanoë, 2016; Nouwens, Groen, Kleemans, & Verhoeven, 2020), and importantly, different aspects of cognition predict differential components of literacy. For example, in their study of 9-year-olds, Nouwens et al. (2020) reported that while planning was important for reading comprehension, better inhibitory control was related to increased phonetic decoding skills. Furthermore, working memory was broadly relevant for literacy performance. This demonstrates the need to understand how cognitive components may influence aspects of literacy differentially. Less is known about how cognition and literacy are related for children with ADHD, particularly the unique contributions that different aspects of cognition may make to different literacy components such as word reading, decoding, reading comprehension, writing, or spelling. The current systematic review and meta-analysis aimed to synthesize the existing literature focusing on the relationship between cognition and literacy in ADHD, and where possible, examine whether aspects of cognition contribute to literacy components differentially.

Method

The systematic review was conducted in accordance with a protocol pre-registered online on the International Prospective Register of Systematic Reviews (PROSPERO; available from: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020183565).

Search terms and strategy

Six electronic databases were searched up to June 2020: EMBASE, ERIC, PsychINFO, PubMed, SCOPUS, and Web of Science. Medical subject headings (MeSH) and key terms were identified from the research question and relevant literature, and further developed into a full list of key words and combinations (see Table 1).

Inclusion and exclusion criteria

Searches of the above databases were restricted to empirical papers in peer-reviewed journals or academic dissertations, published in English between 1992 and 2020. This signifies inclusion only of studies conceptualizing ADHD in the context of DSM-IV, DSM-5 (American Psychiatric Association, 1994, 2013), ICD-10, or ICD-11 (World Health Organisation, 1992, 2018), published in 1994 and 1992, respectively. The publication of these diagnostic manuals marked the reconceptualization of ADHD (see Lange, Reichl, Lange, Tucha, & Tucha, 2010; Mahone & Denckla, 2017) and the inclusion of studies prior to this would introduce a high risk of bias to the synthesis of studies.

The full inclusion and exclusion criteria is available within the registered PROSPERO Protocol (available from: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020183565), but the core criteria are provided below.

Inclusion criteria were: (1) children aged 6–16 years, (2) a clinical diagnosis of ADHD or hyperkinetic disorder as per DSM-IV, DSM-5, ICD-10, or ICD-11 confirmed by a clinical professional, diagnostic interview (e.g., K-SADS) or identified using a validated parent rating scale (e.g., Conners 3-Parent; Conners, 2008) and corroborated by a validated teacher rating scale (e.g., Conners 3-Teacher; Conners, 2008), (3) drug-naïve samples, samples where participants abstained from taking medication during the study, or where the authors statistically accounted/controlled for drug effects, (4) studies reporting co-occurring diagnoses or learning difficulties alongside ADHD (e.g., ASD, dyslexia), (5) children without conditions that impact neurocognition (i.e., brain injury, chromosomal conditions, epilepsy, Down syndrome), (6) children without intellectual disability (i.e., IQ > 70). Studies not meeting these criteria were excluded.

Outcomes were: (1) studies that report administering a literacy assessment, including standardized tests (e.g., Wide Range Achievement Test, WRAT; Woodcock-Johnson Test of Achievement, WJTA; Wechsler Individual Attainment Test, WIAT) and national school

Table 1. Search strategy keywords and combinations

S1	'Attention deficit disorder with hyperactivity [MeSH]' OR 'Attention deficit hyperactivity disorder' OR 'attention deficit disorder' OR ADHD OR ADD OR 'hyperkinetic disorder' OR 'hyperkinetic syndrome' OR 'attention deficit' OR 'attentional disorder' OR hyper* OR HKD
S2	Literacy OR reading OR 'reading comprehension' OR 'passage comprehension' OR 'reading achievement' OR 'word reading' OR 'reading fluency' OR decoding OR 'pseudoword decoding' OR writing OR 'written expression' OR 'sentence comprehension' OR 'essay composition' OR spelling
S3	Cogniti* OR attention* 'executive function' OR EF OR 'self regulation' OR 'self-regulation' OR 'selective attention' OR 'executive control' OR 'inhibitory control' OR inhibition OR 'interference control' OR 'cognitive flexibility' OR 'set shifting' OR shifting OR switch* OR 'working memory' OR WM OR planning OR 'problem solving' OR organization OR memory OR 'information processing' OR 'processing speed' OR state-regulation OR 'temporal processing' OR 'time perception'
S4	S1 AND S2 AND S3

based standardized tests, or non-standardized literacy assessments such as timed reading tasks, (2) studies reporting assessment of cognitive ability in children, including both direct measures (i.e., children complete cognitive task) and indirect measures (i.e., parent or teacher questionnaire), (3) studies reporting a relationship between literacy and cognition (e.g., Pearson's r). Studies were excluded if they did not meet the above criteria.

Cross-sectional, experimental, and longitudinal studies were eligible for inclusion. Qualitative studies, literature reviews, meta-analyses, and case studies were excluded. Unpublished theses were eligible for inclusion. Studies published in any language other than English were excluded.

Screening and selection

Screening took place in a series of steps in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines (Shamseer et al., 2015) and is presented in Figure 1. Once searches of all six databases had been completed, yielding a total of 10,038 articles, 7,305 titles and abstracts were screened against the inclusion and exclusion criteria after the removal of duplicates. At this step, 20% of the articles were double screened by two researchers (E.M. and H.G.) to ensure fidelity and consistency of screening. Percentage of agreement between independent screeners (98.25%) and Cohen's Kappa (κ = .75) were both at an acceptable level (McHugh, 2012). Disagreements were discussed until consensus was reached. At the second step, the full text of 281 studies were screened for inclusion. As before, 20% of articles were independently double screened by authors E.M. and H.G. and acceptable levels of agreement were reached (98.21% agreement, κ = .79). Disagreements were resolved through discussion. The reference lists of selected papers were also screened, but no eligible papers were identified, resulting in a final sample of six studies.

Data extraction and risk of bias assessment

Data were extracted by two researchers independently (H.G. and J.O.) and cross-screened for discrepancies, which were resolved through discussion. All relevant means, standard

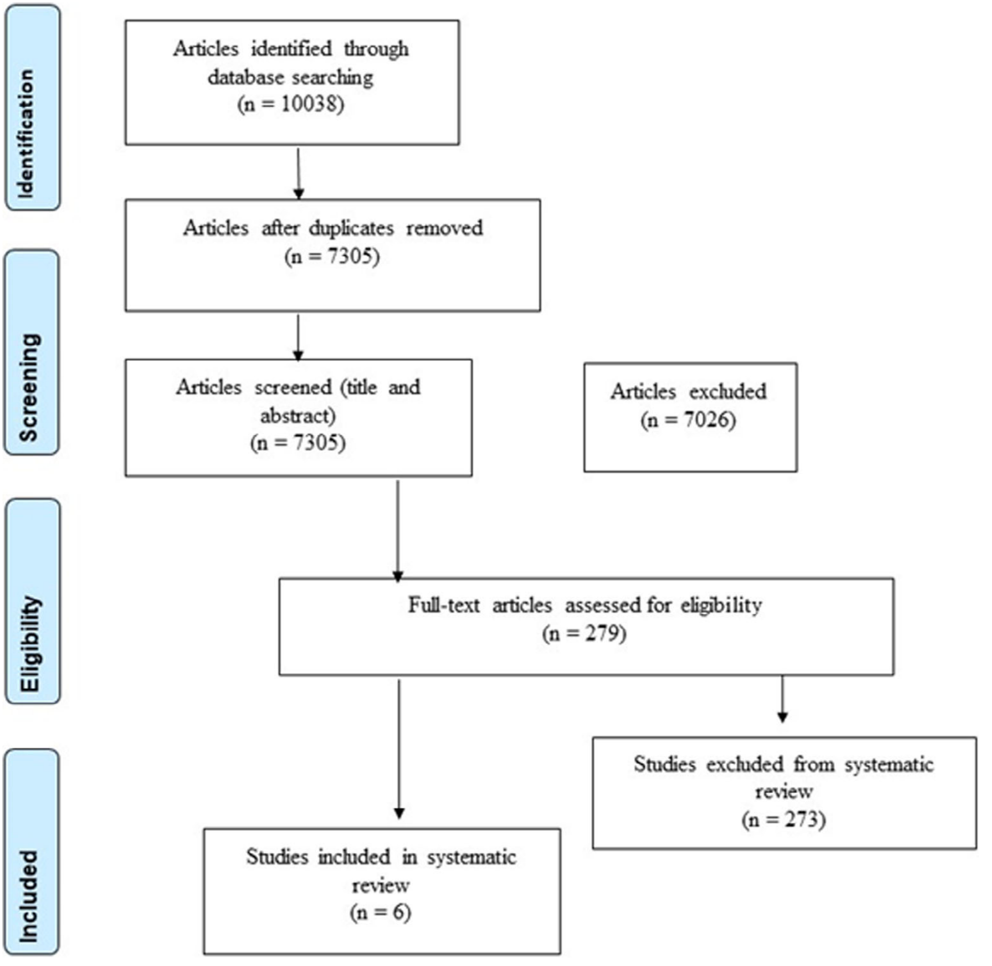

Figure 1. Flow diagram of search strategy.

deviations, and r-values were extracted directly from the texts and confidence intervals were calculated manually for each reported relationship. Risk of bias for each study was assessed using the National Institute for Health and Care Excellence (NICE) Quality appraisal checklist for quantitative studies reporting correlations and associations (NICE, 2012). All studies were rated against each of the checklist items by two researchers (E.M. and T.S.) independently: ++ indicated low risk of bias, + indicated medium risk of bias, and – indicated high risk of bias. Disagreements were resolved through discussion, and then item ratings were used to calculate an average summary rating of internal and external validity for each study, the results of which are presented in Table 2.

Data analysis

Data were grouped based on the aspect of cognition measured (i.e., working memory, processing speed, inhibition, and attention), as described in the included studies, and was analysed within these categories. Note that although some studies reported IQ, it was not

Table 2. Quality appraisal summary scores for external validity and internal validity

	Internal validity score	External validity score
Alloway (2011)	++	+
Åsberg Johnels et al. (2014)	+	+
Çelik et al. (2016)	+	+
Mano et al. (2017)	+	+
Mayes and Calhoun (2007)	+	−
Tamm et al. (2014)	++	+

an aim of this review to examine the relationship between general intelligence and literacy. Meta-analysis was conducted for a proportion of the data, where two or more studies used homogenous or comparable measures of cognition and literacy. This resulted in four random-effects meta-analyses being conducted, to determine the average weighted correlation between measures of: working memory and word reading, working memory and reading comprehension, processing speed and word reading, processing speed and reading comprehension. This describes the percentage of the variability in effect estimates that is due to heterogeneity rather than sampling error (chance). This was calculated using the I^2 statistic as advised by the Cochrane Handbook for Systematic Reviews (Higgins et al., 2020). This guidance outlines that values of up to 40% indicate that the variance of studies is unlikely to be important, 30–60% may suggest moderate heterogeneity, 50–90% may suggest substantial heterogeneity, and 75–100% suggests considerable heterogeneity. It is worth noting, however, that for small meta-analyses (i.e., <7 studies), it may not be possible to accurately measure heterogeneity (von Hippel, 2015) and caution should be used when interpreting the results. Data that could not be meta-analysed were synthesized narratively.

Results

Study characteristics

The final sample of studies consisted of six peer-reviewed papers, the key characteristics of which are presented in Table 3. All studies had a cross-sectional component, but two of these had a primarily case-control design (Alloway, 2011; Åsberg Johnels, Kopp, & Gillberg, 2014). The age of participants ranged from 6 to 16 years, with an approximate average of 9 years. Sample sizes were small to moderate, varying from 30 to 678, typical of developmental disorder research. The effect size and *p*-value of all relevant correlations are presented in Table 4.

Measures of literacy components were relatively consistent across studies, although there was some slight variance. Three out of six studies used a version of the Wechsler Individual Attainment Test (WIAT; Psychological Corporation, 1992), and a fourth used the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) which was developed using the WIAT and superseded by the WIAT-II. These are therefore highly comparable measures. The remaining two studies included non-English speaking participants and subsequently used alternative measures. Çelik, Erden, Özmen, and Tural Hesapçioğlu (2016) used the Oral Reading Skills and Comprehension Test (ORCT; Erden, 2012) to measure speed and accuracy of word reading, as well as reading comprehension, in Turkish. Åsberg Johnels et al. (2014) used spelling tests administered in Swedish, these being the Stavning (Rockberg & Johansson, 1994) for 6–12 year olds and the LS Test (Johanson, 1992) for participants aged 12 and above.

Table 3. Key study characteristics of included papers

Author(s), year of publication	ADHD Sample size (% female)	Age of participants (*M* [*SD*], range)	Population setting	Literacy domain(s) and measure(s)	Cognitive domain(s) and measure(s)	Key findings
Alloway (2011)	50 (14%)	9.15 years (12 months)	Community (recruited from schools)	Reading composite (word reading, spelling, reading comprehension); The Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993)	Verbal STM, Visuospatial STM, Verbal WM, Visusospatial WM; Automated Working Memory Assessment (AWMA; Alloway, 2011)	Significant positive correlations between reading composite and all STM/WM measures
Åsberg Johnels et al. (2014)	30 (100%) 19 'poor spellers', 11 'typical spellers'	10–16 years	Clinical referrals	Spelling; Stanving (9–12 year olds, Rockberg & Johansson, 1994) and LS Test (12 years and above, Johanson, 1992)	Working memory, inhibition; Digit Span subtest – WISC-III (Wechsler, 1991), Continuous Performance Test (Complex Reaction Time; Frisk, 1999)	Working memory and inhibition were both moderately correlated with spelling. Children with better verbal STM and stronger inhibitory control had better spelling scores
Çelik et al. (2016)	48 (23%)	13.66 years (1.96), 6–14 years	Clinical referrals	Reading speed, reading comprehension, reading error, reading fluency; Oral Reading Skill and Reading Comprehension Test (ORCT; Erden, 2012)	Working memory (WMI), processing speed (PSI); Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003)	Working memory significantly correlated with reading comprehension, error and fluency but not reading speed. Processing speed was not significantly correlated with any reading measures
Mano et al. (2017)	187 (38%)	Males: 9 years, grades 2–5 Females: 9.5 years, grades 2–5	Community and clinical	Basic reading, reading comprehension; Wechsler Individual Attainment Test, Third Edition (WIAT-III; Wechsler, 2009)	Rapid Automatized Naming of letters (RAN); Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999)	For boys, there were significant correlations between both reading measures and RAN. For girls, there were no significant correlations
Mayes and Calhoun (2007)	Total: 678 WISC-III: 586 (26%), WISC-IV: 92 (36%)	9 years (2–2.5), 6–16 years	Clinical referrals	Basic word reading, reading comprehension, written expression; WIAT and WIAT-II (Psychological Corporation, 1992, 2002)	Working memory (WMI), freedom from distractibility (FDI), processing speed (PSI);WISC-III (Wechsler, 1991), WISC-IV (Wechsler, 2003)	Working memory moderately correlated with all literacy measures. Processing speed moderately correlated with word reading but relationship with both reading comprehension and written expression was weaker

Continued

Table 3. (*Continued*)

Author(s), year of publication	ADHD Sample size (% female)	Age of participants (*M* [*SD*], range)	Population setting	Literacy domain(s) and measure(s)	Cognitive domain(s) and measure(s)	Key findings
Tamm et al. (2014)	65 (40%)	9.1 years (1.3)	Community and clinical	Basic reading, word reading efficiency, reading comprehension;Woodcock Johnson Tests of Achievement – Third Edition (WJ-III; Woodcock, McGrew, & Mather, 2001), WIAT-III (Wechsler, 2009), Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999)	Executive attention (reaction time variability; SDRT), response inhibition (stop signal reaction time; SSRT), processing speed (mean reaction time; MRT); Stop Signal Task (SST; Logan & Cowan, 1984)	Executive attention significantly correlated with all reading measures (small effect size). Inhibition was only related to basic word reading. Processing speed was not significantly correlated with any of the reading measures

Table 4. Effect size (*r*) and reported *p*-level for each relationship included in review

Author(s), year of publication	Aspect of literacy	Aspect of cognition	*N*	*r*-value	Lower CI	Upper CI	*p*-level
Alloway (2011)	Reading achievement (composite – word reading, spelling, reading comprehension)	Verbal short-term memory	50	.39	.13	.60	<.01
		Verbal working memory	50	.45	.20	.65	<.01
		Visuo-spatial short-term memory	50	.43	.17	.63	<.01
		Visuo-spatial working memory	50	.49	.25	.68	<.01
Åsberg Johnels et al. (2014)	Spelling	Working memory	30	.41	.06	.67	<.05
		Inhibition	30	−.45	−.68	−.11	<.05
Çelik et al. (2016)	Reading comprehension	Working memory	48	.49	.24	.68	<.01
		Processing speed	48	.25	−.04	.50	ns
	Reading speed	Working memory	48	.25	−.04	.50	ns
		Processing speed	48	.17	−.12	.43	ns
	Reading error	Working memory	48	−.41	−.62	−.14	<.01
		Processing speed	48	.27	−.02	.52	ns
	Reading fluency	Working memory	48	.41	.14	.62	<.01
		Processing speed	48	.17	−.12	.43	ns
Mano et al. (2017)	Reading comprehension	Processing speed					
		Males	115	.32	.15	.48	<.001
		Females	72	.16	−.07	.38	ns
	Basic reading	Processing speed					
		Males	115	.38	.21	.53	<.001
		Females	72	.08	−.16	.31	ns
Mayes and Calhoun (2007)	Reading comprehension	Working memory					
		WISC-III	586	.53	.47	.59	NR
		WISC-IV	92	.57	.41	.69	NR
		Processing speed					
		WISC-III	586	.39	.32	.46	NR
		WISC-IV	92	.33	.13	.50	NR
	Word reading	Working memory					
		WISC-III	586	.49	.43	.55	NR
		WISC-IV	92	.58	.43	.70	NR
		Processing speed					
		WISC-III	586	.34	.27	.41	NR

Continued

Table 4. (*Continued*)

Author(s), year of publication	Aspect of literacy	Aspect of cognition	*N*	*r*-value	Lower CI	Upper CI	*p*-level
		WISC-IV	92	.52	.27	.41	NR
	Written expression	Working memory					
		WISC-III	586	.42	.35	.49	NR
		WISC-IV	92	.53	.37	.66	NR
		Processing speed					
		WISC-III	586	.43	.36	.49	NR
		WISC-IV	92	.38	.19	.54	NR
Tamm et al. (2014)	Basic reading	Inhibition	65	−.25	−.47	−.01	<.05
		Executive attention	65	−.33	−.53	−.09	<.01
		Processing speed	65	−.10	−.34	.15	ns
	Word reading efficiency	Inhibition	65	−.18	−.41	.07	ns
		Executive attention	65	−.31	−.52	−.07	<.05
		Processing speed	65	−.14	−.37	.12	ns
	Reading comprehension	Inhibition	65	−.14	−.37	.12	ns
		Executive attention	65	−.32	−.52	−.08	<.05
		Processing speed	65	−.20	−.42	.05	ns

Four different aspects of cognition were measured across the studies: working memory, processing speed, inhibition, and attention. To measure working memory, three studies used sub-tests or composites from the WISC-III or WISC-IV (Åsberg Johnels et al., 2014; Çelik et al., 2016; Mayes & Calhoun, 2007), while Alloway (2011) used the Automated Working Memory Assessment (AMWA; Alloway, 2011) which has acceptable reliability ranging from .64 to .84 for different aspects of the assessment. Mayes and Calhoun (2007) administered the WISC-III to the majority of their sample (N = 586) and the WISC-IV to a smaller sub-sample of participants (N = 92) therefore the correlations between working memory and literacy measures are reported separately for each version of the WISC. It is also important to note that the WISC-III working memory composite, Freedom from Distractibility Index (FDI), differs from the WISC-IV and scores on these may reflect different cognitive components although they both include performance on the Digit Span subtest in computation of the composite score. Three different measures of processing speed were used across the four studies; Mano, Jastrowski Mano, Denton, Epstein, and Tamm (2017) used the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) to measure Rapid Automatized Naming of letters (RAN), Tamm et al. (2014) used mean reaction time (MRT) on the Stop Signal Task (SST; Logan & Cowan, 1984), and the remaining two studies (Çelik et al., 2016; Mayes & Calhoun, 2007) used the processing speed composite from the WISC-III and/or WISC-IV. The CTOPP has good reliability, ranging from .70 to .87, but reliability statistics for the SST were not reported. As with working memory, Mayes and Calhoun (2007) reported correlations between processing speed and literacy components separately for the third and fourth editions of the WISC. Inhibition was measured using two different but comparable tests; Åsberg Johnels et al. (2014) used commissions on the Continuous Performance Test (Frisk, 1999), and Tamm et al. (2014) used stop signal reaction time (SSRT; mean go-signal reaction time minus mean delay time) on the SST. Reliability statistics were not reported for either of these measures. Tamm et al. (2014) also used the reaction time variability scores from the SST to measure executive attention.

Risk of bias

It is important to acknowledge that due to the rigorous eligibility criteria of this review, the baseline quality of studies included here was already very high. The risk of bias assessment therefore represents an evaluation of the highest quality studies within this body of literature.

Internal validity (IV) was generally at low risk of bias across all studies; two studies were rated as having low risk of bias for IV (Alloway, 2011; Tamm et al., 2014) and the remaining four studies were rated as medium risk of bias (Åsberg Johnels et al., 2014; Çelik et al., 2016; Mano et al., 2017; Mayes & Calhoun, 2007). This result was likely due to items 2.1 (How was selection bias minimized?) and 3.2 (Were the outcome measures complete?); five out of six of the studies did not clearly report their recruitment strategy, nor did they describe how many children were recruited versus how many completed all outcome measures, which led to an increased risk of sample bias. By comparison, Tamm et al. (2014) clearly reported that their recruitment strategy was conducted across a variety of sources, and stated that there was no missing data for any of their participants. Two of the six studies also had a medium risk of bias for item 3.1 (Were the outcome measure and procedures reliable?) due to the use of non-standardized measures (Åsberg Johnels et al., 2014; Çelik et al., 2016).

External validity (EV) was similar across all studies; five studies were considered to have a medium risk of bias (Alloway, 2011; Åsberg Johnels et al., 2014; Çelik et al., 2016; Mano et al., 2017; Tamm et al., 2014). This was likely due to all studies scoring low for item 1.1 (Is the source population or source area well described?). The NICE Quality appraisal checklist dictates that studies should adequately describe the country, setting, location (i.e., urban/rural), and population demographics, which demands a high standard of reporting to achieve a score of ++. Almost all studies also scored low for item 1.3 (Do the selected participants or areas represent the eligible population or area?), as the uptake of participants was not reported in the majority of studies. Mayes and Calhoun's (2007) study was rated as having a high risk of bias, due to scoring high risk for items 1.1 and 1.3.

Meta-analysis

It is important to note that for Mano et al. (2017), correlations between reading measures and processing speed were reported separately for male and female participants and therefore entered separately into each meta-analysis. Similarly, in Mayes and Calhoun (2007), correlations between working memory and literacy measures are reported separately for each version of the WISC and were therefore entered separately into each meta-analysis.

Random-effects meta-analyses were conducted for correlations between word reading and working memory, as well as reading comprehension and working memory. For both of these analyses, $I^2 = 0\%$ indicating no heterogeneity between studies. When computing the overall correlation between reading achievement and working memory, a medium effect size was yielded, $r = .53$, 95% CI [0.47, 0.58], z = 14.69, $p < .001$ (Figure 2). The average weighted correlation between word reading and working memory was also of medium effect size, $r = .49$, 95% CI [0.42, 0.54], z = 13.25, $p < .001$ (Figure 3).

Random-effects meta-analyses were also conducted to calculate the overall correlation between word reading and processing speed, and reading comprehension and processing speed. Heterogeneity assessments revealed that caution should be taken when interpreting the findings. For word reading and processing speed $I^2 = 63.63\%$, indicating substantial heterogeneity between studies. Similarly, for reading comprehension and

Study name	Outcome	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Celiket al (2014)	Reading & WM	0.490	0.239	0.680	3.596	0.000
Mayes & Calhoun (2007A)	Reading & WM III	0.530	0.469	0.586	14.249	0.000
Mayes & Calhoun (2007B)	Reading & WM IV	0.570	0.413	0.694	6.109	0.000
		0.533	0.478	0.583	15.902	0.000

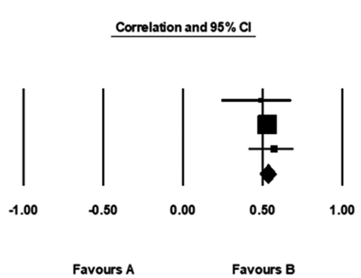

Figure 2. Forest plot for reading comprehension and working memory meta-analysis. Note. Correlations for participants who undertook the WISC-III and those who took the WISC-IV were presented separately in Mayes and Calhoun (2007) and therefore were entered into the analysis separately (III = WISC-III, IV = WISC-IV).

Study name	Outcome	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Celiket al (2016)	Reading fluency & WM	0.410	0.142	0.622	2.922	0.003
Mayes & Calhoun (2007A)	Word reading & WM III	0.490	0.426	0.549	12.943	0.000
Mayes & Calhoun (2007B)	Word reading & WM IV	0.580	0.426	0.701	6.250	0.000
		0.497	0.440	0.550	14.605	0.000

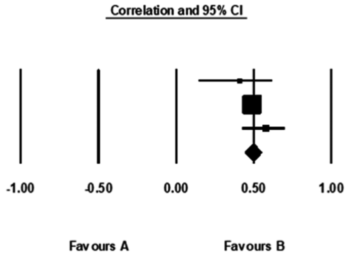

Figure 3. Forest plot for word reading and working memory meta-analysis. Note. Correlations for participants who undertook the WISC-III and those who took the WISC-IV were presented separately in Mayes and Calhoun (2007) and therefore were entered into the analysis separately (III = WISC-III, IV = WISC-IV).

Study name	Outcome	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Celik et al (2016)	Reading comp & processing speed	0.250	-0.037	0.499	1.713	0.087
Mano et al (2017A)	Reading comp & processing speed (F)	0.160	-0.074	0.378	1.341	0.180
Mano et al (2017B)	Reading comp & processing speed (M)	0.320	0.145	0.475	3.510	0.000
Mayes & Calhoun (2007A)	Reading comp & processing speed (III)	0.390	0.319	0.457	9.943	0.000
Mayes & Calhoun (2007B)	Reading comp & processing speed (IV)	0.330	0.134	0.501	3.234	0.001
Tamm et al (2014)	Reading comp & processing speed	0.200	-0.046	0.423	1.596	0.110
		0.320	0.243	0.393	7.789	0.000

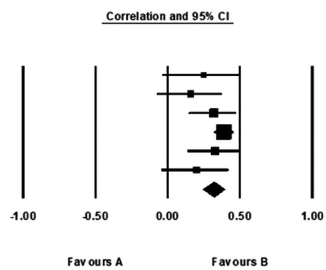

Figure 4. Forest plot for reading comprehension and processing speed meta-analysis. Note. Correlations for male and female participants were presented separately in Mano et al. (2017) and therefore were entered into the analysis separately (F = female participants, M = male participants). Correlations for participants who undertook the WISC-III and those who took the WISC-IV were presented separately in Mayes and Calhoun (2007) and therefore were entered into the analysis separately (III = WISC-III, IV = WISC-IV).

processing speed $I^2 = 52.43\%$, indicating moderate to substantial heterogeneity between studies. The analysis calculating the average weighted correlation between word reading and processing speed yielded a small effect size, $r = .29$, 95% CI [0.22, 0.35], z = 8.2, $p < .001$ (Figure 4). Similarly, the average weighted correlation between reading comprehension and processing speed was small, $r = .35$, 95% CI [0.28, 0.41], z = 9.99, $p < .001$ (Figure 5).

Sensitivity analysis was undertaken where each study was removed in turn to determine the unique contribution and to ensure that no paper was having an undue influence. The results show that for each meta-analysis, no paper influenced the overall effect size unduly. For word reading and working memory, effect size estimates continued to range from .485 to .527. Similarly for reading comprehension and working memory, effect size estimates ranged from .527 to .544, suggesting that no single paper impacted

Study name	Outcome	Statistics for each study				
		Correlation	Lower limit	Upper limit	Z-Value	p-Value
Celik et al (2016)	Reading fluency & processing speed	0.170	-0.120	0.433	1.152	0.249
Mano et al (2017A)	Females Basic reading & processing speed	0.080	-0.155	0.306	0.666	0.505
Mano et al (2017B)	Males Basic reading & processing speed	0.380	0.212	0.526	4.234	0.000
Mayes & Calhoun (2007A)	Word reading & processing speed III	0.340	0.266	0.410	8.550	0.000
Mayes & Calhoun (2007B)	Word reading & processing speed IV	0.520	0.353	0.655	5.437	0.000
Tamm et al (2014)	Basic reading & processing speed	0.100	-0.147	0.336	0.790	0.430
		0.323	0.266	0.379	10.393	0.000

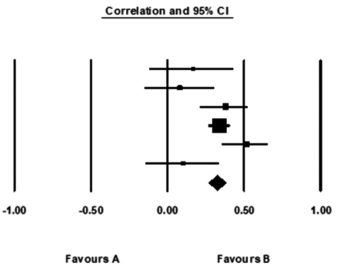

Figure 5. Forest plot for word reading and processing speed meta-analysis. Note. Correlations for male and female participants were presented separately in Mano et al. (2017) and therefore were entered into the analysis separately (F = female participants, M = male participants). Correlations for participants who undertook the WISC-III and those who took the WISC-IV were presented separately in Mayes and Calhoun (2007) and therefore were entered into the analysis separately (III = WISC-III, IV = WISC-IV).

the overall effect size. For the word reading and processing speed meta-analysis, effect size estimates ranged from .297 to .341. Finally, for reading comprehension and processing speed when removing Mayes and Calhoun (2007) correlation for participants who completed the WISC-III, the effect size reduced to .266. With rounding, however, this does not change the overall effect size. For the other studies, the effect sizes ranged from .344 to .356 when each study was removed in turn.

Narrative synthesis

Working memory

Four studies examined the relationship between working memory and an aspect of literacy (Alloway, 2011; Åsberg Johnels et al., 2014; Çelik et al., 2016; Mayes & Calhoun, 2007), resulting in a total of 15 relevant correlations reported (Table 4). The different literacy components examined included: word reading (Çelik et al., 2016; Mayes & Calhoun, 2007), reading comprehension (Çelik et al., 2016; Mayes & Calhoun, 2007), spelling (Åsberg Johnels et al., 2014), written expression (Mayes & Calhoun, 2007) and a composite reading achievement score comprising word reading, spelling and reading comprehension (Alloway, 2011). The meta-analysis demonstrated that word reading was moderately correlated with working memory, although when looking at other sub-tests of reading not included in the meta-analysis, the relationship between reading speed and working memory was found to be small and not statistically significant ($r = .25$, 95% CI [−0.04, 0.5], $N = 48$). This suggests that working memory may be relevant for the ability to read words, but not for the speed at which the words can be read. Both studies also found working memory to be moderately and significantly correlated with reading comprehension (all r's $> .4$; see Table 4). Åsberg Johnels et al. (2014) found that working memory was positively moderately correlated with spelling ($r = .41$, 95% CI [0.06, 0.67], $N = 30$) and was the only study to consider this relationship. Similarly, written expression was moderately correlated with working memory ($r = .42$, 95% CI [0.35, 0.49], $N = 586$; Mayes & Calhoun, 2007), which is unsurprising given that this sits within the same component of literacy as spelling (i.e., writing). Finally, reading achievement was moderately correlated with four different working memory tasks, tapping both visuo-spatial and verbal components (all r's > .39; see Table 4).

Processing speed

Four studies considered the relationship between literacy components and processing speed (Çelik et al., 2016; Mano et al., 2017; Mayes & Calhoun, 2007; Tamm et al., 2014), resulting in a total of 17 correlations reported (Table 4). Relationships between processing speed and literacy were mixed, although the majority of studies reported small correlations. All four studies considered both word reading and reading comprehension, and one study considered written expression (Mayes & Calhoun, 2007).

The results of the meta-analyses for the relationship between processing speed and word reading indicated a small effect size, and similarly, a small relationship was found between processing speed and reading comprehension. As previously mentioned, Mano et al. (2017) reported correlations separately for males and females, both of which were small effect sizes. The relationship appeared larger for males (r = .32, 95% CI [0.15, 0.48], N = 115) compared with females (r = .16, 95% CI [−0.07, 0.38], N = 72), however Fisher's r-to-z transformation was conducted and indicated no significant difference between the effect sizes (z = 0.81, p = .21). Two studies (Çelik et al., 2016; Tamm et al., 2014) reported small and non-statistically significant effect sizes across their reading measures (all r's < .27; see Table 4), and this was also true for the female sample in Mano et al. (2017). Interestingly, Mayes and Calhoun (2007) report a stronger relationship between word reading and processing speed as measured by the fourth edition of the WISC (r = .52, 95% CI [0.35, 0.66], N = 92), compared with the third edition (r = .34, 95% CI [0.27, 0.41], N = 586) (z = 1.95, p = .21). Finally, written expression was found to be moderately correlated with processing speed (r = .43, 95% CI [0.36, 0.49], N = 586; Mayes & Calhoun, 2007).

Inhibition

Two studies considered the relationship between inhibition and literacy, although for different components of literacy. Åsberg Johnels et al. (2014) examined only spelling, whereas Tamm et al. (2014) considered word reading and reading comprehension. Spelling was found to be negatively correlated with inhibition (r = −.45, 95% CI [−0.68, −0.11], N = 30), in that children with poorer inhibition had poorer spelling. For word reading and reading comprehension, the relationship with inhibition was small (all r's < .25; see Table 4), and all confidence intervals indicate that relationships are not statistically significant.

Attention

Tamm et al. (2014) was the only study within this review to consider attention and its relationship with literacy for children with ADHD. They found a small-to-moderate relationship between executive attention (reaction time variability) and all three of their reading measures; basic reading (r = −.33, 95% CI [−0.53, −0.09], N = 65), word reading efficiency (r = −.31, 95% CI [−0.52, −0.07], N = 65) and reading comprehension (r = −.32, 95% CI [−0.52, −0.08], N = 65). Although these were reported as statistically significant in the original paper, it is important to note that the confidence intervals calculated in the present review indicate that this may not be the case.

Discussion

This systematic review and meta-analysis has successfully drawn together existing literature examining relationships between different aspects of cognition and literacy for children with ADHD. The findings have shown that although cognition is broadly relevant for literacy, the strength of these relationships varies when broken down into components. Poorer working memory performance was consistently found to be associated with poorer performance on multiple measures of literacy, specifically reading comprehension, word reading, writing, and spelling. There is a vast literature demonstrating the broad importance of working memory for academic learning in typical development (e.g., Cortés Pascual, Moyano Muñoz, & Quílez Robres, 2019; Nouwens et al., 2020); synthesizing the literature on this relationship in ADHD has therefore made an important contribution to the field. By comparison, processing speed was not found to be consistently important for aspects of literacy; for example, the strength of its relationship with word reading and reading comprehension varied between studies. One possibility for this is that processing speed is less important for literacy compared with working memory; indeed, the studies that found significant relationships between performance on these measures tended to report small effect sizes. Another possibility is that the tasks used to measure processing speed varied across studies, more so than measures of working memory; across all studies, four different measures of processing speed were used, compared with two different measures of working memory. This inconsistency was acknowledged in the test of heterogeneity within the meta-analyses, highlighting caution should be taken when interpreting the findings. Finally, it is important to acknowledge that processing speed appeared to be relevant for writing despite only being examined in a single study. It is therefore vital that future work focuses on examining all aspects of literacy, as opposed to only focusing on reading components.

It was not possible to meta-analyse effect sizes for relationships between inhibition and literacy, or attention and literacy. Nonetheless, the findings were narratively synthesized. This review found that inhibition may be more important for spelling, compared with word reading and reading comprehension, although more evidence is required to assess whether these differences are statistically significant. It is possible that the ability to inhibit one's responses may not be broadly relevant for literacy, but useful for being able to spell accurately. Finally, this review found attention to be vastly overlooked in terms of its relation to literacy in ADHD; only one study was identified, reporting that executive attention was weakly associated with reading.

Strengths and limitations

The heterogeneity of studies, their samples, and measurement choices was anticipated at the outset of this review, but despite this, it was possible to meta-analyse a proportion of data from the included studies. Due to the aforementioned heterogeneity, particularly in relation to the processing speed analyses, caution must be exercised when interpreting the findings. It is important to acknowledge, however, that the formal assessment of heterogeneity, the I^2 statistic, may not be accurate when used within small meta-analyses (von Hippel, 2015). As previously mentioned, the assessments of processing speed used within the included studies varied more than other cognitive measures, which may be the source of this heterogeneity.

In terms of the heterogeneity of samples, two of the included studies (Mano et al., 2017; Tamm et al., 2014) only used samples of children who had co-occurring 'reading difficulties'; in other words, only children who had a standard score of 90 (25th percentile) or lower for reading were included. This is problematic, potentially leading to higher chance of error and lower reliability of data. That said, reading difficulties are known to commonly co-occur with ADHD (e.g., DuPaul et al., 2016) making this a complex issue to address. Not all included studies reported the range of reading scores, however, two studies indicate that their samples also represented a large number of children with reading difficulties; Alloway (2011) report a mean reading composite score of 82.24 (*SD* = 16.96) for their sample of 50 children with ADHD, and 65% of Mayes and Calhoun's (2007) sample were defined as having a learning disability in writing and 30–52% had a reading disability (based on significant differences between literacy and IQ scores). Although methods are available to correct for these artefacts (e.g., Hunter & Schmidt, 2004), the information required to do so was not reported in the included papers. This should however be acknowledged when interpreting the findings of this study.

With regards to measurement, it is important to recognize the heterogeneity of tasks across studies when interpreting the findings of the current review. Two out of six studies used widely regarded standardized assessments of cognition. Of those using non-standardized assessments, two reported acceptable reliability statistics, and two did not report reliability of measures. Research has shown that less reliable measures of cognition can impact the strength of correlations (Parsons, Kruijt, & Fox, 2019), which should be taken into account when interpreting the findings of the current review. The fact that a range of different studies were captured by this review is a clear strength, despite the difficulties it raises with regards to comparing studies with one another.

An additional strength of this review was the high standard set by the eligibility criteria. This meant that only studies including officially diagnosed samples of children with ADHD were included, and therefore the data evaluated here is highly representative of the source population. Whilst we do view this as a strength, it is important to consider that this led to a reduced sample size in the current review. Here, we only included studies that clearly reported confirmation of diagnosis in line with official diagnostic criteria (i.e., DSM-IV, DSM-5, ICD-10, ICD-11). Research has shown that although around 1% of children in the United Kingdom are diagnosed with ADHD, around 5% of children are functionally impaired by ADHD symptoms worldwide (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007), suggesting the disorder is under-diagnosed. By only including studies with samples of children clinically evaluated for ADHD, we may have excluded eligible populations, whose data would have strengthened our understanding of the relationship between cognition and literacy.

Given the cognitive and academic difficulties faced by many children with ADHD, this review aimed to understand the relationships between these abilities by reviewing the relevant literature. It is already widely known that these relationships are strong for typically developing populations (Lubin et al., 2016; Nouwens et al., 2020), therefore the current review did not directly compare these different populations. That said, it is important to recognize that this review cannot draw conclusions about whether ADHD diagnosis moderates the relationships between literacy and cognition. Furthermore, given that only two of the included studies had a typically developing comparison group, it was not possible to answer this question. Future research should aim to investigate this further, in order to establish the relevance of ADHD diagnosis for these associations.

Finally, in this review, two authors double screened 20% of the full-text studies ($N = 281$) and achieved good inter-rater reliability (98.21%). This is a common technique for conducting systematic reviews (McHugh, 2012); however, there is a small risk that some relevant studies were missed and it is important to recognize this when interpreting the findings.

Implications and future directions

This review demonstrated the importance of examining relationships between components of cognition and literacy in isolation, given that different cognitive domains were associated with aspects of literacy differentially. This new knowledge can be used to inform educational practice, reinforcing the importance of differentiating work for children with ADHD, given the impact of their cognitive difficulties upon literacy performance. Strategies to support working memory difficulties should be a priority, given the broad relevance of this cognitive domain. As processing speed was found to be implicated in writing tasks, giving children additional time to complete these tasks, or providing support with processing instructions and planning would be an appropriate measure to put in place for children with these difficulties. Furthermore, given that only a small number of studies were returned from this review, it is clear that additional research into this area is needed. Future research should focus on high-quality examinations of relationships between cognitive domains and components of literacy for children with ADHD. Understanding these differential relationships further could facilitate the development of learning interventions for children with ADHD, targeting key components of cognition to support specific literacy difficulties.

Conflicts of interest

All authors declare no conflict of interest.

Author Contribution

Emily McDougal: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – original draft (equal); Writing – review & editing (equal). **Hannah Gracie:** Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – review & editing (equal). **Jessica Oldridge:** Data curation (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – review & editing (equal). **Tracy Stewart:** Conceptualization (equal); Funding acquisition (equal); Investigation (equal); Methodology (equal); Supervision (equal); Writing – review & editing (equal). **Josephine N Booth:** Conceptualization (equal); Funding acquisition (equal); Investigation (equal); Methodology (equal); Supervision (equal); Writing – review & editing (equal). **Sinéad M Rhodes:** Conceptualization (equal); Investigation (equal); Methodology (equal); Supervision (equal); Writing – review & editing (equal).

Data Availability Statement

Research data are not shared due to privacy or ethical restrictions.

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