Executive functions among Egyptian children with attention deficit hyperactivity disorder and reading disabilities

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Background
Comorbidity of attention deficit hyperactivity disorder (ADHD) and reading disabilities is greater than what would occur by chance.

Objective
The main aim of our study was to investigate the neuropsychological functions in ADHD only, specific learning disability only, and comorbid ADHD and specific learning disability. We searched for any neuropsychological dysfunctions that could be categorized into groups and the main effect of each group of neuropsychological functions.

Participants and methods
Our study participants were divided into four groups: three patient groups [ADHD only ($n=30$), specific learning disability only ($n=30$), and comorbid ADHD and specific learning disability ($n=30$)] and one control group ($n=30$), aged 7–13 years, with IQ equal to or above 90. The executive functions of all groups were examined: working memory (verbal and visuospatial), cognitive flexibility and set shifting (Wisconsin card sorting test, trail making test, and Stroop color and word test), planning (Tower of London), and response inhibition (continuous performance test).

Results
Our study revealed that all three groups (ADHD, specific learning disability, and comorbid ADHD and specific learning disability) had a significant impairment in all executive functions, with the least scores in the comorbid ADHD and specific learning disability group, followed by the ADHD group and then the specific learning disability group.

Conclusion
ADHD and specific learning disability share the same underlying cognitive deficit.

Keywords:
ADHD, executive functions, SLD

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Introduction

Comorbidity of attention deficit hyperactivity disorder (ADHD) and reading disabilities (RD) is greater than what would occur by chance. Considering the well-documented adverse impact of both ADHD and RD on development, the presence of such conditions may lead to particularly poor outcomes in affected people [1].

Research estimates the comorbidity of RD in children with ADHD to be ∼20–40% [2]. The comorbidity of ADHD in the RD population is estimated to be 26–50% [3].

ADHD is currently defined as a cognitive developmental disorder in which all clinical criteria are behavioral. Overactivity, impulsiveness, and inattentiveness are presently regarded as the main clinical symptoms [4].

Developmental dyslexia is linked with deficits in a number of functions including phonology, perception (visual and auditory), attention, and memory [5]. Although both disorders are diagnosed in different ways (ADHD by parent reports and RD by reading tests), they share some behavioral symptoms like inattentive behavior and academic difficulties [6].

This makes differential diagnosis difficult and urges research into cognitive and neurobiological variables that might better distinguish between the two disorders [7].

There are a number of competing explanations for the comorbidity between dyslexia and ADHD. In one of the first papers to address this, Pennington *et al.* [8] proposed that the symptoms of ADHD associated with dyslexia are a secondary consequence of reading problems (‘phenocopy’ hypothesis). Other studies reported that comorbid dyslexia and ADHD is associated with a combination of the cognitive impairments seen in dyslexia and ADHD alone [9–11]. A different view of the etiology of comorbid dyslexia and ADHD is that the condition arises from shared genetic risk factors that contribute to the development of separate cognitive impairments that underlie the two disorders. In this view, those same genetic risk factors (acting in concert with other genetic and environmental risk factors) may lead to the development of both underlying cognitive impairments, in turn producing the comorbid condition ('shared etiology' hypothesis) [12].

Finally, it has occasionally been argued that comorbid dyslexia and ADHD may reflect different causal mechanisms from those operating in either condition alone ('cognitive subtype' hypothesis) [12].

Aim

The study was designed to investigate the neuropsychological functions of each group (ADHD, ADHD comorbid with SLS, and specific learning disability (SLD) and determine the specific neuropsychological deficit of each disorder, either ADHD or SLD or both ADHD and SLD, and the common neuropsychological deficit between them.

Participants and methods

This is a case–control study that was conducted in the outpatient child psychiatry clinic in the institute of psychiatry, Ain Shams University Hospital.

Participants

(1) Our sample was formed of four groups: three patient groups (30 cases were diagnosed as ADHD alone, 30 cases were diagnosed as SLD alone, 30 cases were diagnosed as ADHD and SLD) and a control group (30 healthy volunteers). Both cases and controls were matched for sex, age, intelligent quotient (IQ), and socioeconomic class to avoid selection bias.
(2) The three patient groups were recruited from the outpatient clinic across 5 days. They were chosen in a convenient manner. The study was performed from March 2011 to September 2012.

Inclusion criteria

(1) Age 7–13 years.
(2) IQ score equal to or greater than 90.
(3) Either sex.
(4) Written informed consent from parents for their children's participation in the study.

Exclusion criteria

(1) IQ score below 90.
(2) Presence of severe neurological disabilities.

Materials

(1) Wechsler Intelligence Scale for Children (WISC), Arabic version [13,14]: The Wechsler Intelligence Scale is a battery comprising 12 subtests; each is scored separately and divided into two parts to evaluate performance IQ: (a) the Verbal Scale Subtest and (b) the Performance Scale Subtest. Both scores yield the Full Scale IQ, which is the average index of general intellectual functioning.
(2) The Kiddie Schedule for Affective Disorders and Schizophrenia, Present and Lifetime versions (K-SADS-PL): this was used for diagnosing ADHD, and is a semistructured interview for children aged 6–18 years [15]. We used the Arabic version [16].
(3) El Ziat Scale for diagnosis of specific learning disability and assessment of severity: this was administered by using a questionnaire for evaluating specific learning disability – 'reading, writing and mathematics' disability' – which was developed by Elziat [17].
(4) Conner's Parent Rating Scale – revised – long version [18,19]: this scale was applied to assess the severity of ADHD.
(5) Fahmy and El-Sherbini's Social Classification Scale: participants were classified into social classes 1, 2, 3, and 4 according to the Egyptian classification by Fahmy and El Sherbini [20].
(6) Executive functions battery: we chose The Psychology Experiment Building Language (PEBL) battery. The software is freely downloadable (*http://pebl.sourceforge.net*) [21].

From these tests we chose the following for assessment:

(1) Working memory:
    (a) PEBL, match to sample task: this test is used to assess visuospatial working memory. Participants see a colored matrix and study it for however long they choose. Then they are shown a pair of matrices, one identical and one different. They have to choose the one they had studied [21].
    (b) Verbal working memory – digit span test [13]: it is used to assess the ability to hold and manipulate verbal information. Whereas the digits forwards segment primarily assesses attention and memory span, the digits backwards segment is a sensitive measure of verbal working memory.
(2) Set shifting and cognitive flexibility:
    (a) PEBL, Wisconsin (Berg) Card Sort Test: its aim is to assess set shifting in children. This test was originally conceptualized by Berg [22], and Grant and Berg [23]. The original design of the task involved physically placing cards in one of four piles on the basis of the characteristics of the stimuli. The rule for correctly sorting the stimuli changes regularly and the ability to switch strategies based on the shape, color, or number of stimuli is recorded. A response in which the earlier rule is incorrectly employed is considered a perseverative error [24].
    (b) PEBL, trail making test: test of visual attention and task switching [21] – it consists of two parts in which the participant is instructed to connect

a set of 25 dots as fast as possible while maintaining accuracy. It can provide information about visual search speed, scanning, speed of processing, mental flexibility, and executive functioning.

(c) PEBL, Stroop color and word test: this test is considered for measuring selective attention, cognitive flexibility, and processing speed, and is used as a tool for the evaluation of executive functions. In his experiments, Stroop administered several variations of the same test for which three different kinds of stimuli were created. In the first one, names of colors appeared in black ink. In the second, names of colors appeared in a different ink than the color named. Finally in the third one, there were squares of a given color [21].

(3) Planning:

(a) PEBL, Tower of London: this is a well-known test used in applied clinical neuropsychology for the assessment of executive functioning specifically to detect deficits in planning, which may occur in a variety of medical and neuropsychiatric conditions. It is related to the classic problem-solving puzzle known as the Tower of Hanoi [21].

(4) Response inhibition:

(a) PEBL, the Conners' continuous performance test (CPT): this test measures a person's sustained, selective attention and impulsivity. This widely used measure is a 14-min, computerized task during which participants are asked to press the space bar when any letter except the target letter is displayed [21,25].

Procedure

All children referred with ADHD alone, SLD alone, or with both, and fulfilling the inclusion criteria were recruited for psychiatric interview. The approval of the Ethical Committee of the Institute of Psychiatry, Ain Shams University was obtained. Informed consent was taken, followed by assessment of IQ using the Wechsler Intelligence Scale to ensure that the IQ was above 90. Then Conner's parent rating scale was applied to assess symptom severity. These two scales were administered by the clinical psychologist. This was followed by application of the KSADS-PL to confirm the diagnosis of ADHD and determine the type, the El Ziat Scale for diagnosis of specific learning disability and assessment of severity, Fahmy and El-Sherbini's Social Classification Scale to determine social class, and finally the executive functions battery. Parents were subjected to a full family history of ADHD or SLD or both and history of delayed language development was also verified.

Statistical analysis

(1) The results of the study were obtained using the statistical package of social sciences, version 16.

(2) Statistical analyses were performed with the Pearson χ^2-test, the Student t-test, the paired t-test, multiple logistic regression analysis and Cohen's d for estimation of the effect size.

(3) Cohen's d is the difference between the means, $M_1 - M_2$, divided by SD, σ, in either group. An arbitrary grading of effect size is as follows: small, $d = 0.2$'; medium, $d = 0.5$; and large, $d = 0.8$.

Results

Demographic and clinical characteristics across groups

The three patient groups and one control group were matched for age, sex, and socioeconomic status, with no significant differences. Ages ranged from 7 to 13 years (mean age 10.18 ± 1.46) and the male to female ratio was 3 : 1 [85 men (70.83%) and 35 women (29.17%)].

Prevalence of ADHD and SLD in the sample

Our results revealed that combined ADHD was the most prevalent (63.0%) and combined dyslexia (dyslexia, dyscalculia, and dysgraphia) was more prevalent than each separately (55.0%) in our sample, as shown in Table 1.

Comparison between cases and control as regards history of delayed language development

There were statistically significant differences between cases and controls as regards history of delayed language development ($P = 0.002$*); on comparison between subgroups and controls our results revealed that history of delayed language development was a risk factor for the presence of specific learning disability, but not for ADHD (Tables 2 and 3).

WISC: Arabic version

There were statistically significant differences between cases and control as regards VIQ, PIQ, and total IQ (P-value < 0.001*,0.014*, < 0.001*) (Tables 4 and 5).

Table 1 Sociodemographic data

	N (%)
Demographic data	
Age (mean ± SD) (range)	10.189 ± 1.841 (7–13)
Sex (male : female ratio)	3 : 1
ADHD subtypes	
Combined	38 (36)
Inattentive	19 (31.7)
Hyperactive impulsive	3 (5.0)
SLD subtypes	
Dyslexia + dyscalculia + dysgraphia	33 (55)
Dyslexia alone	9 (15)
Dyscalculia alone	2 (3.3)
Dysgraphia alone	0 (0)
Dyslexia + dysgraphia	13 (21.7)
Dyslexia + dyscalculia	1 (1.7)
Dyscalculia + dysgraphia	2 (3.3)

ADHD, attention deficit hyperactivity disorder.

Executive functions

Working memory

(1) There were significant differences between cases and control in verbal working memory (digit span forward and digit span backward).
(2) With respect to visuospatial working memory, cases differed significantly from controls in mean study time and number of correct trails. When comparing between subgroups, there were significant differences in the number of correct trails ($P<0.001$), with the least scores in the comorbid ADHD and SLD group, followed by the ADHD group and then the SLD group.

Cognitive flexibility and set shifting

PEBL Wisconsin Card Sort Test: cases differed significantly from controls in terms of categories completed ($P<0.001$), correct responses ($P<0.001$), total errors ($P<0.001$), preservative error ($P=0.014$), nonpreservative error ($P<0.001$), and unique errors ($P=0.010$), and subgroup differences were seen in terms of categories completed ($P<0.001$), correct responses ($P<0.001$), total errors ($P<0.001$), nonpreservative error ($P<0.001$), and unique errors ($P=0.016$), with the least scores in the comorbid ADHD + SLD group, followed by the ADHD group and the SLD group.

PEBL TMT: there were significant differences between cases and controls in the mean total time needed to complete A and B trails ($P<0.001$) and in the mean accuracy rate for A and B trails ($P<0.001$). We found significant differences between case subgroups in the mean total time needed to complete A and B trails and in the mean accuracy rate for A and B trails ($P<0.001$), with the least scores in the comorbid ADHD and SLD group, followed by the ADHD group and the SLD group.

PEBL Stroop color and word test: although there were no significant differences between cases and controls as regards Stroop interference in word reading ($P=0.968$) and color naming ($P=0.579$), there were significant differences between cases ($n=40$, 44.4%) and controls ($n=2$, 2.2%) as regards the presence of error rate ($P<0.001$*). Also, we found no significant differences between subgroups as regards Stroop interference in word reading ($P=0.892$), color naming ($P=0.112$), and error rate ($P=0.863$).

Planning

PEBL TOL: cases differed significantly from controls in the mean time needed to complete the test ($P=0.002$)

Table 2 Comparison between cases and controls as regards history of delayed language development

Developmental delay in language	Groups [*N* (%)] Cases	Control
No abnormality detected.	67 (55.83)	30 (25.00)
Delayed language development	23 (19.17)	0 (0.00)
Total	90 (75.00)	30 (25.00)
χ^2		
χ^2	9.485	
P-value	0.002**	

**Highly significant.

Table 3 Comparison between subgroups and controls as regards history of delayed language development

Developmental delayed language development	Subgroups SLD	ADHD	ADHD comorbid with SLD	Control
Delayed language development				
N (%)	10 (8.33)	3 (2.50)	10 (8.33)	0 (0.00)
Total				
N (%)	30 (25.00)	30 (25.00)	30 (25.00)	30 (25.00)
χ^2				
χ^2	9.720	1.404	9.720	
P-value	<0.001***	0.236	<0.001***	

ADHD, attention deficit hyperactivity disorder.
***Very highly significant.

Table 4 Comparison between cases and controls as regards VIQ, PIQ, and TIQ

	Cases	Control	*t*-Test *t*	*P*-value
VIQ				
Range	84–126	97–126	−4.648	<0.001***
Mean ± SD	100.256 ± 8.629	108.567 ± 8.012		
PIQ				
Range	80–126	92–131	−2.483	0.014**
Mean ± SD	101.056 ± 9.241	105.833 ± 8.773		
TIQ				
Range	90–125	95–131	−4.109	<0.001***
Mean ± SD	100.456 ± 8.551	107.900 ± 8.719		

PIQ, performance intellectual quotient; TIQ, total intellectual quotient; VIQ, verbal intellectual quotient.
**Highly significant
***Very highly significant.

Table 5 Comparison between subgroups as regards VIQ, PIQ, and TIQ

	Subgroups						ANOVA	
	SLD		ADHD		ADHD + SLD			
	Mean	SD	Mean	SD	Mean	SD	*f*	*P*-value
VIQ	**97.27**	6.37	105.10	10.64	98.40	6.14	8.426	< 0.001***
PIQ	100.20	9.16	104.47	10.19	**98.50**	7.41	3.506	0.034*
TIQ	98.37	6.34	105.03	10.38	**97.97**	6.63	7.393	< 0.001***

ADHD, attention deficit hyperactivity disorder; ANOVA, analysis of variance; PIQ, performance intellectual quotient; TIQ, total intellectual quotient; VIQ, verbal intellectual quotient.
Bold values represents the least group.
*Highly significant.
***Very highly significant.

and the number of extra moves ($P=0.002$). Also, we found significant differences between case subgroups in the mean time needed to complete the test ($P<0.001$) and in the number of extra moves ($P=0.004$), with the least scores in the comorbid ADHD and SLD group, followed by the ADHD group and the SLD group.

Response inhibition

PEBL CPT: cases differed significantly from controls in target accuracy rate ($P<0.001$), foil accuracy rate ($P<0.001$), commission error ($P<0.001$), omission error ($P<0.001$), correct response time mean ($P=0.009$), correct response time standard deviation ($P<0.001$), error response time mean ($P=0.003$), and error response time standard deviation ($P<0.001$). There were also significant differences between case subgroups in terms of correct response time mean ($P=0.004$), correct response time standard deviation ($P=0.004$), error response time mean ($P=0.005$), error response time standard deviation ($P=0.005$), with the least scores in the comorbid ADHD and SLD group, followed by the ADHD group and the SLD group (Tables 6–8).

Discussion

Dyslexia and ADHD are both common childhood disorders. It is widely accepted that the proximal cognitive cause of dyslexia is a phonological deficit [26], whereas the predominant account of ADHD sees it as arising from an impairment in executive functions that affects both cognitive and motivational systems [27].

In our study, the prevalence of ADHD combined type was 63.3%, that of ADHD inattentive type was 31.7%, and that of ADHD hyperactive–impulsive type was 5.0%. Similar to our finding, Khalil *et al.* [28] examined 60 children with ADHD aged 6–16 years and showed that ADHD combined type was 76.6%, ADHD inattentive type was 18.3%, and ADHD hyperactive–impulsive type was 5%. Also, the prevalence of combined dyslexia, dyscalculia, and dysgraphia was 55%, which was in line with the observations made by Mayes and Calhoun [29], who studied LD prevalence in different diagnoses and found that LD percentage in ADHD combined type was 71% and that in ADHD inattentive type was 66%. Barkley [30] cited comorbid occurrence rates of 8–60% for learning disability in ADHD children depending on the definition of LD as well as achievement areas that are measured.

In this study, history of delayed language development was a risk factor for the development of SLD. This was consistent with the results of Poll and Miller [31], who found that reports of no word combination at age 2 predicted weak reading comprehension and math abilities at age 8. There was evidence of a relationship between late talking and reading comprehension in middle childhood [32,33], and between contemporary measures of oral language and reading comprehension [34,35].

Although total IQ, verbal IQ, and performance IQ were all in the average and above average range, there were statistically significant differences between cases and control as regards verbal IQ, performance IQ, and total IQ. This finding might explain why ADHD children or SLD children or both ADHD and LD children performed poorly in school compared with their peers of similar age and IQ. This was in line with the results of Tripp *et al.* [36], who compared children diagnosed with ADHD combined type aged 6–10 years with a sex-matched group of children without behavioral problems, and found that children with ADHD obtained significantly lower scores on the WISC – 3rd ed. IQ, compared with controls and performed more poorly across the range of frontal lobe tests.

Working memory

Our results revealed that cases were significantly impaired in verbal, visuospatial working memory, and short-term memory compared with controls, and all patient groups shared working memory deficit but differed in severity; the most affected group was the ADHD comorbid with SLD group, followed by the ADHD group and the SLD group. This was consistent with the results of Bental and Tirosh [37], who compared four groups of children (19 ADHD, 17 RD, 27 ADHD comorbid with RD, and 23 controls) on reading measures, attention, and executive functions as well as on functions of phonemic awareness and rapid naming. They found that the group with ADHD comorbid with RD shared the basic characteristic impairment in attention and executive functions with the pure ADHD group and with the pure RD group and more severe impairment in working memory.

Since 2004, three meta-analyses [38,39,40] have evaluated studies on working memory in ADHD children and

Table 6 Comparison between cases and control as regard executive function tests

	(1) Working memory			
	Forward		*t*-Test	
	Range	Mean ± SD	*t*	*P*-value
(a) Verbal working memory				
Cases	4.0–7.0	5.189 ± 0.898	− 3.730	< 0.001***
Control	5.0–8.0	5.900 ± 0.923		
	Backward		*t*-Test	
	Range	Mean ± SD	*t*	*P*-value
Cases	0.0–4.0	2.500 ± 0.824	− 6.722	< 0.001***
Control	2.0–5.0	3.633 ± 0.718		
(b) Match to sample task: (visuospatial part of working memory)				
			t-Test	
	Cases	Control	*t*	*P*-value
Mean response time				
Range	1223.6–13016.6	2379.9–8393.1	− 0.222	0.825
Mean ± SD	4435.88 ± 1912.92	4518.39 ± 1211.89		
Mean study time				
Range	1359.9–25396.6	3251.7–13950.0	− 2.312	0.023***
Mean ± SD	5884.14 ± 3255.64	7416.87 ± 2775.35		
Number of correct trails				
Range	13–30	25–30	− 7.954	< 0.001***
Mean ± SD	22.589 ± 22.589	28.233 ± 28.233		
	(2) Cognitive flexibility and set shifting			
			t-Test	
	Cases (mean ± SD)	Control (mean ± SD)	*t*	*P*-value
(a) WCST				
Categories completed	0.599 ± 0.278	0.856 ± 0.052	− 5.010	< 0.001***
Trails to complete first cat	19.600 ± 19.907	17.467 ± 7.546	0.572	0.568
Correct responses	52.990 ± 15.728	75.537 ± 6.092	− 7.645	< 0.001***
Total errors	47.001 ± 15.728	24.454 ± 6.092	7.645	< 0.001***
Perservative responses	36.090 ± 19.891	35.203 ± 6.418	0.239	0.811
Perseverative errors	22.201 ± 13.991	15.710 ± 4.634	2.490	0.014**
Nonperservative errors	24.796 ± 21.433	8.740 ± 3.325	4.076	< 0.001***
Unique errors	4.312 ± 8.063	0.442 ± 0.604	2.619	0.010**
(b) Trail making test				
Mean total time				
A	65458.56 ± 43756.35	36207.66 ± 12267.04	3.605	< 0.001***
B	109021.99 ± 65199.86	64930.83 ± 26207.79	3.600	< 0.001***
Mean accuracy rate				
A	0.787 ± 0.171	0.922 ± 0.048	− 4.258	< 0.001***
B	0.653 ± 0.177	0.873 ± 0.088	− 6.554	< 0.001***
(c) Stroop color and word test				
Stroop interference in word reading	− 228.96 ± 372.20	− 231.74 ± 148.80	0.040	0.968
Stroop interference in color naming	− 327.24 ± 421.38	− 282.94 ± 191.36	− 0.556	0.579
Error rate		*N* (%)		
Cases		40 (44.4)		
Control		2 (2.2)		
χ^2				
χ^2		32.595		
P-value		< 0.001***		
	(3) Planning			
			t-Test	
	Cases (mean ± SD)	Control (mean ± SD)	*t*	*P*-value
Tower of London (TOL)				
Mean time	55403.743 ± 32673.645	35210.902 ± 17969.714	3.221	0.002**
Number of extra movies	241.789 ± 119.940	166.033 ± 84.829	3.199	0.002**
	(4) Response inhibition			
			t-Test	
	Cases (mean ± SD)	Control (mean ± SD	*t*	*P*-value
Continuous performance test (CPT)				
Target accuracy rate	0.916 ± 0.067	0.969 ± 0.025	− 4.242	< 0.001***
Foil accuracy rate	0.291 ± 0.183	0.458 ± 0.220	− 4.100	< 0.001***
Commission error	7.607 ± 2.415	5.700 ± 2.448	3.734	< 0.001***
Omission error	8.126 ± 6.550	2.922 ± 2.376	4.249	< 0.001***
Correct response time mean	516.567 ± 98.501	465.718 ± 63.233	2.647	0.009**
Correct response time standard deviation	273.797 ± 111.992	182.169 ± 68.952	4.216	< 0.001***
Error response time mean	503.150 ± 127.288	425.054 ± 96.668	3.075	0.003**
Error response time standard deviation	246.901 ± 147.124	142.431 ± 137.073	3.424	< 0.001***

WCS T, Wisconsin Card Sort Test.
**Highly significant.
***Very highly significant.

Table 7 Comparison between subgroups as regard executive function tests

	Subgroups							
	SLD		ADHD		ADHD + SLD		ANOVA	
	Mean	SD	Mean	SD	Mean	SD	f	*P*-value
Working memory								
Verbal working memory								
Forward	5.17	0.87	5.50	0.94	4.90	0.80	3.554	0.033*
Backward	2.77	0.57	2.63	0.76	2.10	0.96	6.124	0.003**
Visuospatial working memory								
Number of correct trails	24.40	3.05	22.63	4.43	20.73	2.86	8.156	<0.001***
Cognitive flexibility and set shifting								
WCST								
Categories completed	0.77	0.07	0.65	0.24	0.38	0.30	23.711	<0.001***
Correct responses	62.31	9.71	57.39	14.96	39.27	11.67	29.173	<0.001***
Total errors	37.68	9.71	42.60	14.96	60.72	11.67	29.171	<0.001***
Nonperservative errors	13.80	7.08	20.26	17.42	40.33	25.69	17.002	<0.001***
Unique errors	2.03	4.42	3.25	6.42	7.65	10.99	4.341	0.016**
TMT								
Mean total time								
A	47304.74	14728.59	54431.80	42928.24	94639.14	49684.56	12.945	<0.001***
B	77220.17	25758.87	92569.53	47806.61	157276.27	79763.60	17.449	<0.001***
Mean Accuracy rate								
A	0.86	0.07	0.82	0.15	0.68	0.21	11.207	<0.001***
B	0.75	0.10	0.69	0.17	0.52	0.16	19.876	<0.001***
Stroop color and word test								
Error rate	ADHD [*N* (%)]		SLD [*N* (%)]		ADHD + SLD [*N* (%)]			
Word reading	5 (16.7)		6 (20.0)		7 (23.3)			
Color naming	6 (20.0)		9 (30.0)		7 (23.3)			
χ^2								
χ^2				0.294				
P-value				0.863				
Planning								
	Subgroups							
	SLD		ADHD		ADHD + SLD		ANOVA	
	Mean	SD	Mean	SD	Mean	SD	*f*	*P*-value
Tower of London								
Mean time	40213.9	14959.7	52892.7	30682.0	73104.5	39265.9	9.14	<0.001***
Mean Number of extra moves	189.90	63.54	245.00	124.11	290.47	139.51	5.867	0.004**
Response inhibition								
Continuous performance test								
Correct response time mean	478.47	70.39	510.81	113.84	560.42	91.31	5.840	0.004**
Error response time mean	468.15	98.80	477.48	125.36	563.81	135.98	5.694	0.005**

ADHD, attention deficit hyperactivity disorder; CPT, continuous performance test; WCST,Wisconsin Card Sort Test.
*Significant.
**Highly significant.
***Very highly significant.

adolescents. These studies found moderate effect sizes ranging from 0.55 to 0.63 for impairments in ADHD children and adolescents compared with non-ADHD controls on seven different verbal working memory tasks [41]. This was in contrast to the results of our study. In verbal working memory, we found a large effect size (1.3) between the ADHD group and controls, a mild effect size (0.2) between the ADHD and SLD groups, and a moderate effect size (0.6) between the ADHD group and the ADHD comorbid with SLD group. This discrepancy could be explained by methodological differences as we used digit backwards for verbal working memory only. Others like Martinussen *et al.* [38] identified and grouped tasks as either storage or central executive [42]. They also found large effect sizes ranging from 0.63 to 1.04 for impairments in children and adolescents diagnosed with ADHD compared with non-ADHD controls in five spatial working memory tasks [41], which was similar to our finding in visuospatial working memory, in which we found a large effect size (1.7) between the ADHD group and controls, a moderate effect size (0.4, 0.5) between the ADHD and SLD groups and between ADHD and ADHD comorbid with SLD groups.

Cognitive flexibility and set shifting

In our study Wisconsin Card Sort Test (WCST) helped us to differentiate between cases and controls with regard to many different parameters (categories completed, correct responses, total errors, perseverative errors, nonperservative errors, and unique errors), as well as at the level of subgroups (categories completed, correct responses, total error, nonperservative errors, and unique errors). The ADHD comorbid with SLD group was the most affected in cognitive flexibility, compared with the ADHD-alone and SLD-alone groups.

Four recent meta-analyses [39,40,43,44] computed small (0.35) to medium (0.52) effect sizes for the differences in mean perseverative errors between ADHD individuals

Table 8 Cohen' *d* in ADHD versus SLD and in ADHD versus ADHD + SLD and in ADHD versus control

	Subgroups		
	Cohen's *d* (ADHD vs. SLD)	Cohen's *d* (ADHD vs. ADHD + SLD)	Cohen's d (ADHD vs. control)
Verbal working memory			
Forward	0.533	0.687	0.429
Backward	0.208	0.612	1.35
Visuospatial working memory			
Number of correct trails	0.465	0.509	1.7
Cognitive flexibility			
WCST			
Perseverative errors	0.149	0.116	0.656
Categories completed	0.678	0.993	1.186
Total correct responses	0.390	1.35	1.588
Total errors	0.390	1.350	1.588
Stroop interference			
In word reading	0.027	0.144	0.125
In color naming	−0.148	0.386	−0.008
Trail making test			
Mean accuracy rate B	0.430	1.029	1.351
Mean total time B	0.777	0.824	0.716
Response inhibition: CPT			
Commission error	0.162	0.418	0.611
Planning (TOL)			
Mean time	0.525	0.573	0.703
Mean number of extra moves	0.558	0.344	0.742
Mean weighted effect size	0.367429	0.666786	0.909786

ADHD, attention deficit hyperactivity disorder; CPT, continuous performance test.

and non-ADHD controls on the WCST. ADHD individuals made more perseverative errors on the WCST than did non-ADHD controls, suggesting that ADHD is associated with impaired cognitive flexibility [38]. This was in line with our study that found a medium sized effect (0.65) between ADHD and controls in perseverative error.

Another widely used tool for assessing cognitive flexibility was trails-B [45]. In our study, there were statistically significant differences between cases and controls as regards time needed to complete the task and in terms of accuracy rate. Two meta-analyses [40,43]reported medium effect sizes ($d = 0.55$ and 0.59, respectively) as evidence of reduced cognitive flexibility in ADHD versus control children based on trails-B scores. This was in line with our study, which revealed a medium weighted effect size in ADHD and controls (0.7) in mean time to complete the task, and a large weighted effect size (1.35) in mean accuracy rate. We also found a medium effect size (0.430 and 0.777) between ADHD and SLD in mean accuracy rate and mean total time, which means that the differences between ADHD and SLD were moderate, and a large weighted effect size between ADHD and ADHD comorbid with SLD groups (1.02 and 0.824) in mean accuracy rate and mean total time, which means that ADHD children comorbid with SLD were more affected in cognitive flexibility compared with ADHD alone or SLD alone.

In the Stroop task, in our study, we found no statistically significant differences between cases and controls as regards Stroop interference in word reading and color naming. Yet, there was a statistically significant difference between cases and controls in error rate, which means that cases made more errors compared with controls. The number of studies using the Stroop color and word test with ADHD and other clinical groups was sparse and specificity to ADHD was equivocal, which was in line with our study in which we could not discriminate between ADHD, SLD, and ADHD comorbid with SLD children [45].

Planning

In our study, cases were significantly impaired in planning compared with controls, and a medium weighted effect size (0.7) was found between the ADHD group and the control group in mean total time and mean number of extra moves in the Tower of London, which was in line with the results of Willcutt *et al.* [40], who provided a meta-analytic review of 27 studies on planning in ADHD. Fifty-nine percent of these studies showed a deficit in planning in an ADHD group (as compared with a typical control group), and the meta-analysis showed a moderate effect size for the ADHD group in performance on planning tasks.

Response inhibition

Commission errors (or false alarms) in CPTs are often used as a marker for response inhibition deficits in ADHD children [41].

Our results revealed that all patient groups had statistically significant differences in all parameters of CPT (commission errors, omission errors, correct response time mean, and rrror response time mean), which was in line with many studies. Pollak *et al.* [46] compared the performance of children with ADHD on a CPT embedded within a virtual reality classroom (VR-CPT) with the currently used test of variable of attention CPT. The study comprised 37 boys, aged 9–17 years, with ADHD ($n = 20$) and without ADHD ($n = 17$). They concluded that children with ADHD performed more poorly on all CPTs, which was consistent with our finding.

Since 2004, three meta-analyses [40,39,43] have examined the strength of the association between CPT commission errors and ADHD diagnosis in studies that included children and teens, and calculated Cohen's d effect sizes. The results of CPT commission errors were in the moderate range ($d = 0.51–0.56$), which was consistent with our study, which revealed a median effect size of commission errors (0.6) between ADHD children and controls, a small effect size (0.16) between ADHD and SLD, and a medium effect size (0.6) between ADHD and ADHD comorbid with SLD.

In this study, all patient groups (the ADHD group, the ADHD comorbid with SLD group, and the SLD group) showed impaired executive functions; the most affected group was the ADHD comorbid with SLD group, similar to our finding. Willcutt [47] found that the ADHD comorbid with RD group was the most impaired on virtually all measures of neuropsychological functions compared with persons with ADHD without RD [48]. Also, Seidman *et al.* [49] studied the effect of comorbid reading or arithmetic learning disability on neuropsychological function in ADHD. They found that children who had both ADHD and learning disability were significantly more impaired on both executive and nonexecutive functions compared with ADHD children without LD. Neuropsychological performance was most impaired in ADHD with combined arithmetic and reading disability. These data indicated that comorbid learning disability, especially arithmetic disability, significantly increased the severity of executive function impairment in ADHD.

Conclusion

ADHD and SLD share the same underlying cognitive deficit. ADHD comorbid with SLD carry poorer prognosis than each disorder alone.

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Conflicts of interest

There are no conflicts of interest.

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