Cognitive Function of Children and Adolescents with Attention Deficit Hyperactivity Disorder and Learning Difficulties: A Developmental Perspective

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Abstract

Background: The cognitive function of children with either attention deficit hyperactivity disorder (ADHD) or learning disabilities (LDs) is known to be impaired. However, little is known about the cognitive function of children with comorbid ADHD and LD. The present study aimed to explore the cognitive function of children and adolescents with ADHD and learning difficulties in comparison with children with ADHD and healthy controls in different age groups in a large Chinese sample.

Methods: Totally, 1043 participants with ADHD and learning difficulties (the ADHD + learning difficulties group), 870 with pure ADHD (the pure ADHD group), and 496 healthy controls were recruited. To investigate the difference in cognitive impairment using a developmental approach, all participants were divided into three age groups (6–8, 9–11, and 12–14 years old). Measurements were the Chinese-Wechsler Intelligence Scale for Children, the Stroop Color-Word Test, the Trail-Making Test, and the Behavior Rating Inventory of Executive Function-Parents (BRIEF). Multivariate analysis of variance was used.

Results: The results showed that after controlling for the effect of ADHD symptoms, the ADHD + learning difficulties group was still significantly worse than the pure ADHD group, which was, in turn, worse than the control group on full intelligence quotient (98.66 ± 13.87 vs. 105.17 ± 14.36 vs. 112.93 ± 13.87, $P < 0.001$). The same relationship was also evident for shift function (shifting time of the Trail-Making Test, 122.50 [62.00, 194.25] s vs. 122.00 [73.00, 201.50] s vs. 66.00 [45.00, 108.00] s, $P < 0.001$) and everyday life executive function (BRIEF total score, 145.71 ± 19.35 vs. 138.96 ± 18.00 vs. 122.71 ± 20.45, $P < 0.001$) after controlling for the effect of the severity of ADHD symptoms, intelligence quotient, age, and gender. As for the age groups, the differences among groups became nonsignificant in the 12–14 years old group for inhibition (meaning interference of the Stroop Color-Word Test, 18.00 [13.00, 25.00] s vs. 17.00 [15.00, 26.00] s vs. 17.00 [10.50, 20.00] s , $P = 0.704$) and shift function (shifting time of the Trail-Making Test, 62.00 [43.00, 97.00] s vs. 53.00 [38.00, 81.00] s vs. 101.00 [88.00, 114.00] s, $P = 0.778$).

Conclusions: Children and adolescents with ADHD and learning difficulties have more severe cognitive impairment than pure ADHD patients even after controlling for the effect of ADHD symptoms. However, the differences in impairment in inhibition and shift function are no longer significant when these individuals were 12–14 years old.

Key words: Attention Deficit Hyperactivity Disorder; Children and Adolescents; Cognitive Function; Developmental Trajectory; Learning Difficulties

Introduction

Attention deficit hyperactivity disorder (ADHD) and learning disabilities (LDs) are both neurodevelopmental disorders[1] and often co-occur.[2] The prevalence rates of ADHD without LD and LD without ADHD are both about 5%, with a comorbid rate of 20–60%.[2] A cohort study has shown that children with ADHD symptoms had a higher risk of comorbid LD in their future life.[2]

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Executive functions (EFs) including response inhibition, set-shifting, working memory, and planning have been found to be impaired in children with ADHD and children with LD.[3-5] The inhibition, switching, and working memory functions are predictive of mathematical abilities,[4] and poor reading and comprehension ability are also associated with impairment in inhibition function.[5] Moreover, for children with both ADHD and LD, the intelligence level has been found to be lower,[6] and they also tend to have poorer EF[7] than children with just one of the disorders. It has been speculated that comorbid LD may aggravate impairments in inhibition, shifting, verbal fluency, and working memory of ADHD children.[8]

However, impairments in cognitive function were reported to change with ages in children with neurodevelopmental disorders.[9] The EF of ADHD patients has been found to be significantly worse than controls at 7–9 years old but normalized at 10–12 years old.[10] Children with ADHD have been found to be comparable to 2 years younger controls on inhibition and shifting functions, and the gap between groups on inhibition function became insignificant at 13–15 years old whereas that on shifting function remained.[11] In summary, based on the previous findings on cognitive function impairment in children with ADHD, LD, and their comorbid condition, we hypothesized that the comorbid group would have more severe cognitive dysfunctions than the pure ADHD group, and they would both have more severe cognitive dysfunctions than healthy controls. To examine the influence of development on cognitive function, the sample was separated into three age groups: 6–8, 9–11, and 12–14 years old.

Methods

Participants

Children aged between 6 and 16 years were recruited from outpatients of the Peking University Sixth Hospital from September 1999 to December 2012. They were diagnosed by two experienced psychiatrists using the Clinical Diagnostic Interview Scales (CDISs) based on the Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition (DSM-IV).[12] We excluded patients with mental retardation (intelligence quotient [IQ] <70), epilepsy, and other organic disorders which could cause attention deficit and learning difficulty, or visual or hearing impairment which may affect cognitive tests. To make the description of cognitive function representative, a relatively large sample was recruited. Children with ADHD and learning difficulties constituted the ADHD + learning difficulties group (n = 1043), and patients with ADHD and without other psychiatric disorders constituted the pure ADHD group (n = 870) [Supplementary Table 1].

A total of 496 healthy participants (6–16 years old) were recruited from four local primary and middle schools. Children with any psychiatric disorders screened by the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime version[13] or who had a history of visual or hearing impairment were excluded from the study [Supplementary Table 1].

All participants were medication naive at the time of assessment. They were all native Chinese speakers. The Institutional Review Board of the Peking University Health Science Center approved the study protocol, and all participants and their parents gave informed consent.

Measurements

Diagnosis and symptoms

ADHD was diagnosed based on the CDIS.[12] The presence of learning difficulties was determined according to the academic aspect of the CDIS. Failing (a score of <60 points on a 100-point scoring system) in at least one core subject among mathematics, Chinese, and English or failing in quizzes in at least one subject three times or more in the recent school years was defined as academic underachievement in this study. The observations of parents and teachers of learning difficulty and its impact on social and academic functions were also considered.[1] ADHD core symptoms were rated by parents using the ADHD rating scale (ADHD-RS), which consists of 18 items.[14]

Intelligence

The Chinese-Wechsler Intelligence Scale for Children (C-WISC)[15] was used to assess the intelligence of the participants. Results included full intelligence quotient (FIQ), verbal intelligence quotient (VIQ), and performance intelligence quotient (PIQ). A higher score on the C-WISC indicates higher intelligence.

Stroop Color-Word Test

Participants were required to name the black words (Part 1), the color blocks (Part 2), words of Part 1 with color of Part 2 (Part 3), and the color of the same colorful words as those in Part 3 (Part 4) as quickly and correctly as possible. We used the meaning interference completion time (the time taken to complete Part 4 − the time needed to complete Part 2) as a proxy for inhibition function. A longer meaning interference completion time indicates poorer inhibition function.[16]

Trail-Making Test

The test includes two parts.[16] Part A required the participants to quickly connect 25 numbers distributed randomly over an 8 × 11 sheet in order. Part B required the participants to connect 25 numbers and letters alternately. We used the time taken to complete Part B − the time taken for Part A to reflect shift ability. A shorter shifting time indicates better shifting function.[16]

Everyday life executive function (Behavior Rating Inventory of Executive Function-Parents)

This is a parent-rated scale containing 86 items assessing EF in everyday life.[17] It is rated on a three-point Likert scale (1 = never, 2 = sometimes, and 3 = often) and a higher score indicates more severe impairment. We chose the inhibition and shift factors for comparison with the two behavioral tests mentioned above. The global score was also used.

Statistical analysis

The ADHD + learning difficulties Group (A), the pure ADHD Group (B), and the healthy control Group (C) were further divided into three subgroups separately according to age (A*i*, B*i*, and C*i*, $i = 1$ means 6–8 years subgroup, $i = 2$ means 9–11 years subgroup, and $i = 3$ means 12–14 years group). The sample was examined for normality and transformation as $\log_{10}$ was made for nonnormal data. Normal data were expressed as mean ± standard deviation (SD) and nonnormal data as median (P_{25}, P_{75}).

Multivariate analysis of variance (MANOVA) and *post hoc* least significant difference were conducted using the Statistical Product and Service Solution (SPSS) software (version 17.0; SPSS Inc., Chicago, IL, USA). Since age (F (2, 2994) = 204.22, $P < 0.001$; F (8, 2994) = 2528.34, $P < 0.001$), gender (χ^2 (2, 2994) = 320.45, $P < 0.001$; χ^2 (8, 2994) = 346.08, $P < 0.001$), IQ (F (2, 2994) = 197.34, $P < 0.001$; F (8, 2994) = 57.63, $P < 0.001$), and ADHD-RS scores (F (2, 2994) = 3205.58, $P < 0.001$; F (8, 2994) = 809.58, $P < 0.001$) were different among the three groups and the nine subgroups, they were considered as covariates in all comparisons. However, since the C-WISC is an age-standardized test, its covariates only included gender and ADHD-RS scores. ADHD-RS scores were selected as a covariate to exclude the effect of ADHD symptoms on cognitive function. IQ was considered a covariate to show the pure effect of different disorders while controlling for the influence of general intelligence. $P < 0.05$ was considered statistically significant.

Results

Chinese-Wechsler Intelligence Scale for Children

Results on the C-WISC were all significantly different between any two groups (A < B < C) (FIQ, 98.66 ± 13.87 vs. 105.17 ± 14.36 vs. 112.93 ± 13.87, $P < 0.001$). For the 6–8-year-old subgroup, FIQ and PIQ were significantly different between any two groups (A1 < B1 < C1) (FIQ, 95.72 ± 13.62 vs. 104.13 ± 13.89 vs. 109.05 ± 13.69, $P < 0.001$), and VIQ was significantly different between the ADHD + learning difficulties group and pure ADHD group (A1 < B1) and between the ADHD + learning difficulties group and control group (A1 < C1) ($P < 0.001$). For the 9–11- (A2 < B2 < C2) (FIQ, 97.50 ± 14.07 vs. 105.61 ± 15.25 vs. 116.37 ± 13.65, $P < 0.001$) and 12–14-year-old (A3 < B3 < C3) (FIQ, 101.36 ± 13.35 vs. 109.08 ± 13.49 vs. 115.46 ± 13.05, $P < 0.001$) subgroups, all the results were significantly different between any of the two groups [Figure 1] [Supplementary Table 2].

Stroop Color-Word Test

The meaning interference completion time of the ADHD + learning difficulties group was significantly longer than both the pure ADHD group (A > B) (27.00 [18.00, 37.00] s vs. 29.00 [19.25, 38.00] s, $P = 0.001$) and the control group (A > C) (27.00 [18.00, 37.00] s vs. 19.50 [14.00, 26.00] s, $P < 0.001$). For the 6–8-year-old subgroup, a significant difference was only observed between the ADHD + learning difficulties group and the pure ADHD group (A1 > B1) (36.50 [27.00, 52.00] s vs. 32.00 [23.00, 44.00] s, $P = 0.003$). For the 9–11-year-old subgroup, differences were observed between any two groups (A2 > B2 > C2) (30.00 [22.00, 40.00] s vs. 27.00 [19.00, 36.00] s vs. 16.00 [12.00, 22.00] s, $P < 0.001$). For the 12–14-year-old subgroup, there was no significant difference among the three subgroups (18.00 [13.00, 25.00] s vs. 17.00 [15.00, 26.00] s vs. 17.00 [10.50, 20.00] s, $P = 0.704$) [Figure 2] [Supplementary Table 2].

Trail-Making Test

Shifting time was significantly different among the three groups (A > B > C) (122.50 [62.00, 194.25] s vs. 122.00 [73.00, 201.50] s vs. 66.00 [45.00, 108.00] s, $P < 0.001$). For the 6–8-year-old subgroup, there was a significant difference between the ADHD + learning difficulties group and control group (A1 > C1) (196.50 [128.50, 282.50] s vs. 93.00 [63.00, 145.00] s, $P < 0.05$) and between the pure ADHD group and control group (B1 > C1) (153.50 [93.50, 238.25] s vs. 93.00 [63.00, 145.00] s, $P < 0.05$). For the 9–11-year-old subgroup, there was a significant difference between the ADHD + learning difficulties group and the control group (A2 > C2) (147.00 [92.5, 204.50] s vs. 60.00 [43.00, 86.00] s, $P < 0.05$) and between the ADHD + learning difficulties group and pure ADHD group (A2 > B2) (147.00 [92.5, 204.50] s vs. 104.00 [67.50, 165.00] s, $P < 0.05$). No significant difference was observed in the 12–14-year-old subgroup (62.00 [43.00, 97.00] s vs. 53.00 [38.00, 81.00] s vs. 101.00 [88.00, 114.00] s, $P = 0.778$) [Figure 3] [Supplementary Table 2].

Behavior Rating Inventory of Executive Function-Parents

For the inhibition factor, statistically significant difference was only found between the ADHD + learning difficulties group

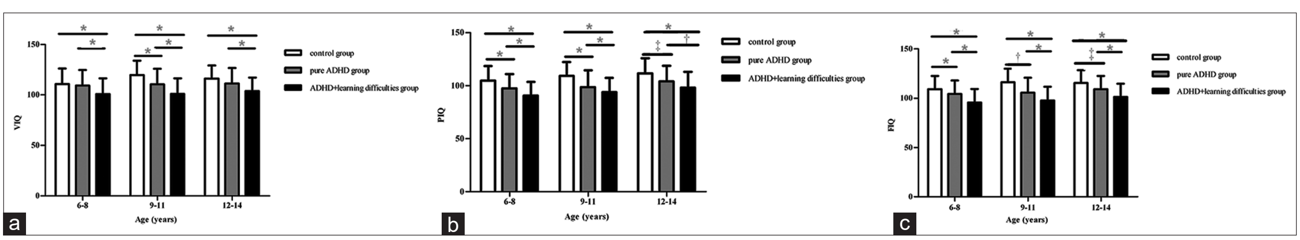

Figure 1: Mean intelligence level of children and adolescents in the attention deficit hyperactivity disorder + learning difficulties group, the pure attention deficit hyperactivity disorder group, and the normal control group. (a) The verbal intelligence level (VIQ); (b) the performance intelligence quotient (PIQ); and (c) full intelligence quotient (FIQ). *$P < 0.001$; †$P < 0.01$; ‡$P < 0.05$. ADHD: Attention deficit hyperactivity disorder.

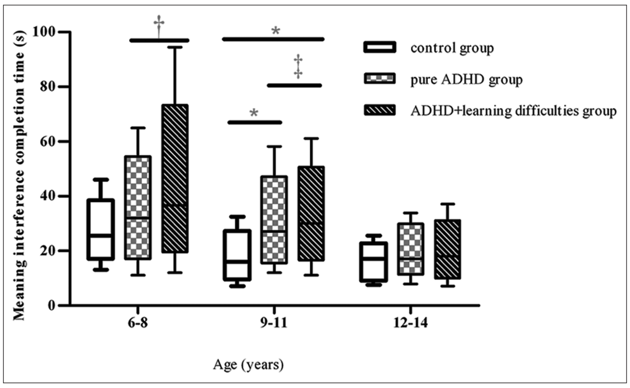

Figure 2: Mean meaning interference completion time of children and adolescents in the attention deficit hyperactivity disorder + learning difficulties group, the pure attention deficit hyperactivity disorder group, and the normal control group. *$P < 0.001$; †$P < 0.01$; ‡$P < 0.05$. ADHD: Attention deficit hyperactivity disorder.

and pure ADHD group (A > B) (17.70 ± 4.77 vs. 16.93 ± 4.37, $P = 0.008$). For the 6–8- and 12–14-year-old subgroups, there was no statistically significant difference ($P > 0.05$). For the 9–11-year-old subgroup, there was a statistically significant difference between the ADHD + learning difficulties group and the pure ADHD group (A2 > B2) (17.13 ± 4.58 vs. 16.03 ± 4.03, $P = 0.019$) [Figure 4] [Supplementary Table 2].

For the shift factor, there were statistically significant differences between any two groups (A > B > C) (12.62 ± 2.73 vs. 11.94 ± 2.47 vs. 11.07 ± 2.16, $P \leq 0.001$), which was also observed in the 6–8-year-old subgroup (A1 > B1 > C1) (12.39 ± 2.70 vs. 11.37 ± 2.48 vs. 10.74 ± 2.13, $P = 0.003$). In the 9–11-year-old subgroup, a statistically significant difference was found between the ADHD + learning difficulties group and the control group (A2 > C2) (12.45 ± 2.84 vs. 11.09 ± 2.12, $P = 0.01$). No statistically significant difference was found in the 12–14-year-old subgroup ($P > 0.05$) [Figure 4] [Supplementary Table 2].

For the total Behavior Rating Inventory of Executive Function-Parents (BRIEF) score, statistically significant differences were observed between any of the two groups (A > B > C) (145.71 ± 19.35 vs. 138.96 ± 18.00 vs. 122.71 ± 20.45, $P < 0.001$) and subgroups (A1 > B1 > C1, A2 > B2 > C2, A3 > B3 > C3) ($P < 0.05$) [Figure 4] [Supplementary Table 2].

Discussion

Cognitive function impairment of children and adolescents with attention deficit hyperactivity disorder and learning difficulties

We found that the intelligence level of the ADHD + learning difficulties group was lower than the pure ADHD group while their intelligence levels were both lower than healthy controls. These findings are consistent with previous studies. Patients with ADHD and reading disability (RD) have been reported to perform worse than patients with pure ADHD on verbal working memory evaluated by the freedom from distractibility factor of the WISC.[18] ADHD patients with and without LD had statistically significant differences on working memory and processing speed on the WISC,[7] and processing speed was identified as the shared cognitive deficit of ADHD and LD.[19] However, since intelligence tests require knowledge and basic learning skills, LD may also cause poor performance on the WISC in the absence of cognitive impairment.[20] In addition, LD could decrease the motivation for studying and lead to lower IQ.[21] Therefore, the intelligence results alone might only partly reflect any underlying cognitive impairment in these individuals.

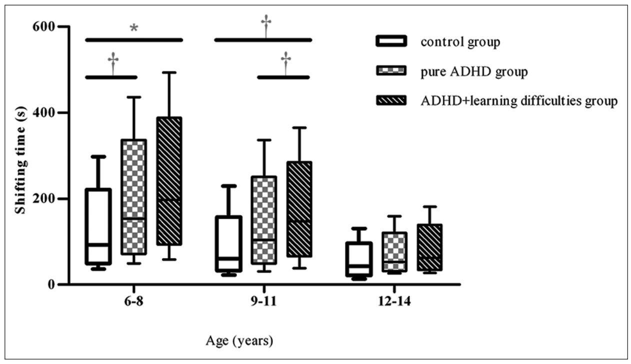

Figure 3: Mean shifting time of children and adolescents in the attention deficit hyperactivity disorder + learning difficulties group, the pure attention deficit hyperactivity disorder group, and the normal control group. *$P < 0.01$; †$P < 0.05$. ADHD: Attention deficit hyperactivity disorder.

We found that the inhibition and shifting functions were impaired in both the ADHD + learning difficulties group and the pure ADHD group. Inhibition is thought to be the core impairment of ADHD which could not be explained by intelligence, academic achievement, or other disorders.[22] Moreover, some evidence suggests that inhibition dysfunction may be correlated with the mathematical ability[23] and reading comprehension.[5] It has been hypothesized that inhibition function coordinates the temporal and spatial processes of mathematics and filters irrelevant information during calculation and reading.[5] At the same time, the shifting function has been considered a potential endophenotype for ADHD[24] and may account for the variance in reading, mathematics, and spelling for children with ADHD.[25] The same results have also been reported in LD.[26] Impaired attention shifting might be the reason for the poor performance of LD children in reading, writing, and arithmetic.[27] These findings support our results that both the ADHD + learning difficulties group and the pure ADHD group may have impaired inhibition and shifting functions.

Regarding the comorbid ADHD + learning difficulties group, we found that they had poorer inhibition and shifting functions than the pure ADHD group. Similarly, a previous study had reported that the comorbid group performed worse in EF than ADHD children without LD.[28] Another study with 437 children had reported that children with ADHD + learning difficulties scored significantly lower on the composite of EF than children with ADHD only.[7] Results from another previous study also showed that

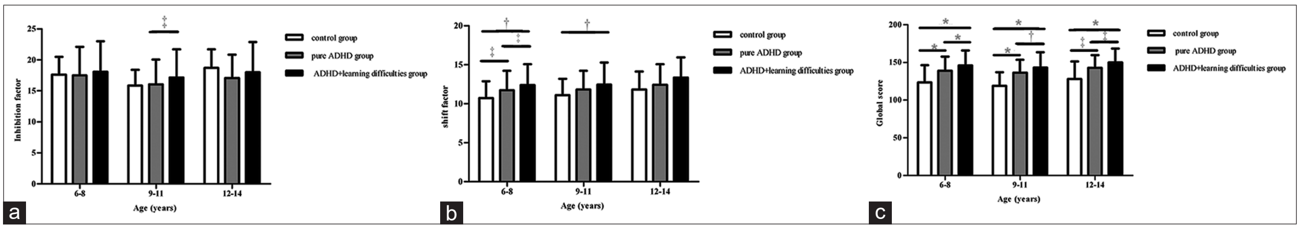

Figure 4: Behavior Rating Inventory of Executive Function-Parents mean score of children and adolescents in the attention deficit hyperactivity disorder + learning difficulties group, the pure attention deficit hyperactivity disorder group, and the normal control group. (a) Inhibition factor; (b) shift factor; and (c) global score. $^*P < 0.001$; $^†P < 0.01$; $^‡P < 0.05$. ADHD: Attention deficit hyperactivity disorder.

children with ADHD + learning difficulties performed more poorly in inhibition and shifting tests than either children with pure ADHD or children with ADHD + oppositional defiant disorder/conduct disorder.[16] These results suggest that comorbid LD may aggravate the inhibition and shifting impairments of ADHD.[7]

Our results from the BRIEF were slightly different from the behavioral tests in this study. The shifting factor of the BRIEF showed the same rank order of the three groups as the results from the Trail-Making Test. The inhibition factor of the BRIEF also showed difference between the ADHD + learning difficulties group and pure ADHD group as the Stroop test whereas there was no significant difference between the diagnostic groups and the control group on the inhibition factor. Indeed, previous studies had reported that everyday EF captured by the BRIEF had little overlap with behavioral measurements.[29] It has also been suggested that the BRIEF scale captures functions in real life, which are more complicated and may include more than one dimension.[30] However, the importance of everyday EF problems in ADHD was emphasized since they were predictors of comorbid psychopathology[31]

Cognitive function impairment in children and adolescents with attention deficit hyperactivity disorder and learning difficulties in different age groups

We found that the intelligence level of the ADHD + learning difficulties group was always lower than the pure ADHD group; however, the difference in inhibition and shifting functions decreased with age. It has been reported that the EF of ADHD patients was significantly worse than healthy controls at the age of 7–9 years, which became insignificant at the age of 10–12 years.[10] In a previous study, our team had found that children with ADHD were comparable to controls who were 2 years younger on inhibition and shifting, and at the age of 13–15 years, while the difference in inhibition function between ADHD and healthy children became insignificant, the difference in shifting function persisted.[11] On the other hand, the developmental trajectory of LD has rarely been explored. In children with mathematics disability, it was reported that 10-year-old patients scored at the level of 5-year-old normal children.[32] Our results suggest that the adverse effect of comorbid LD on inhibition is most significant at 6–11 years old, whereas for shifting ability, the effect was most significant at 9–11 years old. By 12–14 years old, the ADHD + learning difficulties group and the pure ADHD group appeared to have caught up with the healthy controls in these two functions. However, it is possible that the executive tests were too simple for older children.

Possible mechanism of shared cognitive function impairment of attention deficit hyperactivity disorder and learning disability

An increasing number of studies have suggested that comorbid conditions such as ADHD and LD may have shared genetic predispositions,[33] which could explain the shared cognition impairment of children with ADHD and LD as we found. The reaction time variability and verbal memory were reported to be both phenotypic and genetic associated with ADHD and RD in a large-sample twin study, which might be the important cognitive processes underlying the comorbid condition.[34] Moreover, twin analyses also showed that the processing speed impairment of both ADHD and LD was due to common genetic influences.[35] However, it has been speculated that children with ADHD with poor inhibition function and attention shifting function may experience learning difficulties and, thus, lead to LD.[25] Hence, the relationship among cognitive deficits, ADHD, and LD needs to be further investigated.

Implications for clinical practice and future studies

For clinical practice, we found that the comorbid group impaired worse than the pure ADHD group on all cognitive aspects; hence, the comorbidity situation needs to be taken seriously and the early intervention on the cognitive function should be considered.[20]

There were some limitations in this study. First, the patients included could only be described as having learning difficulties rather than LDs because there was no standard measurement of LD in China. According to DSM-IV, LDs are considered when an individual's results on standardized administered reading, writing, or mathematics tests were below that expected for age, schooling, and level of intelligence, and it influences academic achievement or daily activities.[1] Since failing in school suggested a more serious function impairment, especially for high IQ children and adolescents,[1] the results of this study might represent the LD children with severe symptoms. Second, the ADHD + learning difficulties group did not exclude other psychological disorders which could influence the cognitive manifestation, and most patients were ADHD-predominantly inattentive type and ADHD-combined type; hence, the interpretation of results should be cautious. Moreover, this was a cross-sectional study and the description of developmental trajectory was limited. Besides, the age phases did not include 15–17 years old because of small sample. For further investigation, the standard evaluation tools for LD in Chinese should be introduced, and more longitudinal studies are needed to explore the developmental trajectories.

In summary, as this study aimed to explore the cognitive function of ADHD children and adolescents with learning difficulties at different age stages, we found in general that children and adolescents with ADHD and learning difficulties had worse cognitive function impairments compared with the pure ADHD patients and healthy controls, which was significant at early age as 6–11 years and insignificant at older stage as 12–14 years of age.

Supplementary information is linked to the online version of the paper on the Chinese Medical Journal website.

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Conflicts of interest

Prof. Yu-Feng Wang has served on an advisory board and received funding for research, lectures, and travel from Xi'an Janssen Pharmaceutical and the advisor of Eli Lilly and Company.

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Supplementary Table 1: Demographic and clinical characteristics

	Total			6-8 years old groups			9-11 years old groups			12-14 years old groups		
	A (*n* = 1043)	B (*n* = 870)	C (*n* = 496)	A1 (*n* = 301)	B1 (*n* = 513)	C1 (*n* = 194)	A2 (*n* = 331)	B2 (*n* = 276)	C2 (*n* = 224)	A3 (*n* = 411)	B3 (*n* = 81)	C3 (*n* = 74)
Male (%)	890 (85.33)	713 (81.95)	373 (75.20)	242 (80.40)	420 (81.87)	146 (75.26)	280 (84.59)	224 (81.16)	166 (74.11)	368 (89.54)	69 (85.19)	59 (79.73)
Age (months) (SD)	129.48 (29.47)	107.02 (22.94)	118.50 (21.24)	93.65 (9.42)	91.72 (10.13)	95.20 (9.38)	122.96 (9.45)	120.48 (9.39)	124.31 (8.76)	160.98 (8.92)	158.06 (9.94)	158.39 (9.72)
ADHD subtype (%)												
ADHD-I	600 (57.53)	474 (54.48)	-	157 (52.16)	258 (50.29)	-	170 (51.36)	169 (61.23)	-	273 (66.42)	48 (59.26)	-
ADHD-H	22 (2.11)	64 (7.36)	-	8 (2.66)	46 (8.97)	-	7 (2.11)	14 (5.07)	-	7 (1.70)	3 (3.70)	-
ADHD-C	421 (40.36)	332 (38.16)	-	136 (45.18)	209 (40.74)	-	154 (46.53)	93 (33.70)	-	131 (31.87)	30 (37.04)	-
ADHD-RS score (SD)	31.51 (8.33)	30.59 (8.01)	-	33.48 (8.27)	31.35 (7.75)	-	31.66 (7.93)	29.49 (8.16)	-	30.59 (8.61)	30.31 (8.75)	-
Comorbidity (%)												
Disruptive behavior	462 (44.30)	-	-	93 (30.90)	-	-	150 (45.32)	-	-	219 (53.28)	-	-
Anxiety disorder	143 (13.71)	-	-	37 (12.29)	-	-	46 (13.90)	-	-	60 (14.60)	-	-
Mood disorder	64 (6.14)	-	-	7 (2.33)	-	-	13 (3.93)	-	-	44 (10.71)	-	-
Tics	172 (16.49)	-	-	41 (13.62)	-	-	61 (18.43)	-	-	70 (17.03)	-	-

A: The ADHD + LD group; B: The pure ADHD group; C: The healthy control group; A1: 6–8 years old ADHD + LD subgroup; B1: 6–8 years old pure ADHD subgroup; C1: 6–8 years healthy control subgroup; A2: 9–11 years old ADHD + LD subgroup; B2: 9–11 years old pure ADHD subgroup; C2: 9–11 years old healthy control subgroup; A3: 12–14 years old ADHD + LD subgroup; B3: 12–14 years old pure ADHD subgroup; C3: 12–14 years old healthy control subgroup; LD: Learning disability; ADHD: Attention deficit hyperactivity disorder; ADHD-I: Attention deficit hyperactivity disorder inattentive type; ADHD-H: Attention deficit hyperactivity disorder hyperactive-impulsive type; ADHD-C: Attention deficit hyperactivity disorder combined type; ADHD-RS: ADHD rating scale; SD: Standard deviation.

Supplementary Table 2: Performance of the ADHD + LD, pure ADHD, and control groups on cognitive function tests

	Total			6–8 years old groups			9–11 years old groups			12–14 years old groups			Effects ($P<0.05$)
	A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3	
C-WISC FIQ													
n	942	799	427	270	472	161	295	257	203	377	70	63	A < B < C
Mean (SD)	98.66 (13.87)	105.17 (14.36)	112.93 (13.87)	95.72 (13.62)	104.13 (13.89)	109.05 (13.69)	97.50 (14.07)	105.61 (15.25)	116.37 (13.65)	101.36 (13.35)	109.08 (13.49)	115.46 (13.05)	A1 < B1 < C1
F		98.24			40.34			53.38			24.78		A2 < B2 < C2
P		<0.001			<0.001			<0.001			<0.001		A3 < B3 < C3
C-WISC VIQ													
n	942	799	427	270	472	161	295	257	203	377	70	63	A < B < C
Mean (SD)	102.18 (14.71)	109.91 (15.41)	115.28 (14.88)	100.86 (15.48)	109.18 (15.47)	110.81 (15.40)	101.02 (15.45)	110.59 (15.27)	119.51 (14.37)	103.77 (13.37)	111.09 (15.43)	116.05 (12.95)	A1 < B1
F		88.85			26.53			51.08			19.14		A1 < C1
P		<0.001			<0.001			<0.001			<0.001		A2 < B2 < C2
													A3 < B3
													A3 < C3
C-WISC PIQ													
n	942	799	427	270	472	161	295	257	203	377	70	63	A < B < C
Mean (SD)	94.83 (14.33)	98.55 (14.63)	107.52 (13.60)	90.73 (12.94)	97.44 (13.67)	104.96 (13.45)	93.93 (13.64)	98.61 (15.96)	109.40 (13.05)	98.15 (14.95)	104.21 (14.64)	111.81 (14.30)	A1 < B1 < C1
F		63.29			37.05			33.22			16.53		A2 < B2 < C2
P		<0.001			<0.001			<0.001			<0.001		A3 < B3 < C3

Contd...

Supplementary Table 2: Contd...													
	Total			**6–8 years old groups**			**9–11 years old groups**			**12–14 years old groups**			**Effects (P<0.05)**
	A	**B**	**C**	**A1**	**B1**	**C1**	**A2**	**B2**	**C2**	**A3**	**B3**	**C3**	
Stroop Color-Word Test meaning interference													
n	548	471	282	155	262	104	183	161	137	210	48	41	A > B
Median (P_{25}, P_{75}) (s)	27.00 (18.00, 37.00)	29.00 (19.25, 38.00)	19.50 (14.00, 26.00)	36.50 (27.00, 52.00)	32.00 (23.00, 44.00)	25.50 (21.00, 30.75)	30.00 (22.00, 40.00)	27.00 (19.00, 36.00)	16.00 (12.00, 22.00)	18.00 (13.00, 25.00)	17.00 (15.00, 26.00)	17.00 (10.50, 20.00)	A > C A1 > B1
F		9.13			4.37			11.30			0.351		A2 > B2 > C2
P		<0.001			0.013			<0.001			0.704		
Trail-Making Test shifting time													
n	526	459	281	138	252	103	178	159	137	210	48	41	A > B > C
Median (P_{25}, P_{75}) (s)	122.50 (62.00, 194.25)	122.00 (73.00, 201.50)	66.00 (45.00, 108.00)	196.50 (128.50, 282.50)	153.50 (93.50, 238.25)	93.00 (63.00, 145.00)	147.00 (92.5, 204.50)	104.00 (67.50, 165.00)	60.00 (43.00, 86.00)	62.00 (43.00, 97.00)	53.00 (38.00, 81.00)	101.00 (88.00, 114.00)	A1 > C1 B1 > C1
F		7.23			3.79			3.64			0.251		A2 > B2
P		0.001			0.023			0.027			0.778		A2 > C2
BRIEF inhibition factor													
n	380	391	188	124	242	63	113	119	103	143	30	22	A > B
Mean (SD)	17.70 (4.77)	16.93 (4.37)	17.13 (2.71)	18.08 (4.92)	17.51 (4.58)	17.59 (2.90)	17.13 (4.58)	16.03 (4.03)	15.85 (2.56)	18.04 (4.82)	17.07 (3.77)	18.72 (2.96)	A2 > B2
F		3.56			0.86			3.14			1.12		
P		<0.001			0.424			0.045			0.392		
BRIEF Shift factor													
n	380	391	188	124	242	63	113	119	103	143	30	22	A > B > C
Mean (SD)	12.62 (2.73)	11.94 (2.47)	11.07 (2.16)	12.39 (2.70)	11.73 (2.48)	10.74 (2.13)	12.45 (2.84)	11.81 (2.40)	11.09 (2.12)	13.34 (2.62)	12.43 (2.63)	11.82 (2.32)	A1 > B1 > C1
F		12.92			5.82			3.77			2.81		A2 > C2
P		<0.001			0.003			0.024			0.063		
BRIEF global score													
n	380	391	188	124	242	63	113	119	103	143	30	22	A > B > C
Mean (SD)	145.71 (19.35)	138.96 (18.00)	122.71 (20.45)	146.01 (19.88)	139.02 (18.60)	123.35 (23.01)	143.26 (20.29)	136.66 (16.93)	118.91 (18.17)	150.04 (18.18)	142.78 (16.98)	127.89 (23.39)	A1 > B1 > C1 A2 > B2 > C2
F		55.99			21.46			23.23			10.55		A3 > B3 > C3
P		<0.001			<0.001			<0.001			<0.001		

A: The ADHD + LD group; B: The pure ADHD group; C: The healthy control group; A1: 6–8 years old ADHD + LD subgroup; B1: 6–8 years old pure ADHD subgroup; C1: 6–8 years healthy control subgroup; A2: 9–11 years old ADHD + LD subgroup; B2: 9–11 years old pure ADHD subgroup; C2: 9–11 years old healthy control subgroup; A3: 12–14 years old ADHD + LD subgroup; B3: 12–14 years old pure ADHD subgroup; C3: 12–14 years old healthy control subgroup; C-WISC: Chinese-Wechsler Intelligence Scale for Children; IQ: Intelligence quotient; FIQ: Full intelligence quotient; VIQ: Verbal intelligence quotient; PIQ: Performance intelligence quotient; BRIEF: Behavior Rating Inventory of Executive Function-Parents. All the means were adjusted for the gender, age, IQ, ADHD symptoms (ADHD-RS total score) except the results of C-WISC which were only adjusted for gender and ADHD symptoms (ADHD-RS total score). All the F and P values represented the multivariate analysis of variance among three groups. The median (P_{25}, P_{75}) was shown for nonnormal data; LD: Learning disability; ADHD: Attention deficit hyperactivity disorder; ADHD-RS: ADHD rating scale; SD: Standard deviation.