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Cognitive Function in Attention Deficit Hyperactivity Disorder

Yongning Song

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Abstract

This study examined the hypothesis that individuals with attention deficit hyperactivity disorder, predominantly inattentive type (ADHD-I), show both executive function (EF) deficits and non-EF deficits. A group with ADHD-I (n = 16) and a paired control group (n = 21) completed a battery of tasks covering the major domains of EF (planning, working memory, flexibility and inhibition) and non-EF (alertness, divided attention, flexibility, sustained attention, visual field and visual scanning). EF impairments in planning, spatial working memory, flexibility, and inhibition as well as non-EF impairments in divided attention, flexibility, sustained attention and visual scanning were observed in the ADHD-I group. Our results do not support Barkley's (1997) view of ADHD which postulated that only ADHD-C and ADHD-H, but not ADHD-I, are associated with EF deficits. It suggests that ADHD-I and ADHD-C children had similar profiles of cognitive impairment, and the deficits in cognition are not good markers for the classification of ADHD subtypes in *the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V)*.

Keywords: ADHD-I, Executive function, Non-executive function, Cognitive profile

1. Introduction

Executive function (EF) is an umbrella term that refers to processes that control other cognitive processes [1]. Researchers have identified four distinct domains of EF: planning, working

memory, flexibility, and response inhibition [2-6]. The role of EF is debated, but most researchers agree that EF is involved in deliberately managing an appropriate problem solving set to attain a future goal [7-8].

A deficit in EF is postulated to account for core symptoms in psychiatric patients with no focal frontal lesions, such as those diagnosed with attention deficit hyperactivity disorder (ADHD). The evidence supporting a deficiency in EF domains in ADHD comes from a number of sources [8, 9-14].

Clarification of the neuropsychological similarities and differences in ADHD subtypes can contribute to understanding their etiological relationship. *The Diagnostic and Statistical Manual of Mental Disorders (DSM-V)* [15] classifies the symptoms of ADHD into three distinct subtypes: predominantly inattentive type (ADHD-I); predominantly hyperactive-impulsive type (HD or ADHD-H), and combined type (ADHD-C). In addition, Barkley (1997) postulated a model of ADHD in which only ADHD-C and ADHD-H, but not ADHD-I, are associated with EF deficits [16]. This is because, ADHD-C and ADHD-H exhibits the symptoms of hyperactivity/impulsivity which are believed to be caused by the deficit in response inhibition, a key process in EF.

Now, nearly all of the neuropsychological literature on ADHD pertains to the group designated as ADHD combined type (ADHD-C), while the primarily inattentive subtype of ADHD (ADHD-I) remains relatively under-investigated with regard to potentially relevant cognitive functions [17-19]. Nigg (2005) suggested that further studies of children with ADHD-C versus control children on many executive measures might no longer be needed [18]. Instead, studies to examine issues such as neuropsychological process theories of ADHD-I have been proposed.

Previous research has found many non-EF cognitive deficits in ADHD-I, such as the inconsistent alertness and orientation [20], Sluggish cognitive tempo [21], and the poor attention shifting [22]. And many non-EF symptoms rather than EF symptoms were described in DSM-V, such as often fails to give close attention to details or often loses things necessary for tasks or activities. For a long time, we failed to give much attention to the EF domain in ADHD-I, thus it is still unknown whether the EF domain are impaired in ADHD-I. Combining the hypothesis that EF weaknesses are neither necessary nor sufficient to cause all cases of ADHD [8], we predict that individuals with ADHD-I encounter not just difficulties with EF, but also show deficits in other cognitive domains (hereafter termed non-EF).

Thus, the first goal of the present study was to examine the EF weaknesses hypothesis in ADHD-I by comparing children with ADHD-I versus typically developing children in the four distinct EF domains of planning, working memory, flexibility, and inhibition. The second goal was to examine the non-EF deficit hypothesis in children with ADHD-I by comparing them with a control group on six non-EF domains: alertness, divided attention, flexibility, sustained attention, visual field and visual scanning.

2. Methods

2.1. Participants

Children diagnosed with ADHD were recruited from several child psychiatry outpatient services across the Zabei district of Shanghai. Each sample was referred from the Shanghai Pediatric Hospital where the participants were diagnosed with ADHD, primarily inattentive type.

Before testing, we obtain written consent from participants and their parents. Each family completed an unstructured screening interview based on the Child and Adolescent Psychiatric Assessment [23]. We recorded information regarding the children's medical history, developmental history and general symptoms. We excluded children with any significant comorbid psychiatric or neurological conditions, such as epilepsy, severe attention deficit hyperactivity disorder or schizophrenia. We also confirmed that the children had not been on medication for at least 3 months.

All children met DSM-V diagnostic criteria for ADHD. Any child with ADHD-H or ADHD-C was excluded. Furthermore, a 27 items version of Conners' Teacher Rating Scale (CTRS-S) [24] was completed for each child to confirm the pervasiveness of symptoms. Scoring was performed according to the test manual [25] and established cutoff points for possible and likely ADHD, primarily inattentive type were imposed. Furthermore, all children were administered the Raven's Progressive Matrices IQ test. Children exhibiting intellectual disability (IQ scores below 75) were excluded from further experiment. Finally, a total of 16 children with ADHD-I participated in the experiment.

Twenty-one children without ADHD were paired with the ADHD group by gender and age. We administered an unstructured screening interview based on the Child and Adolescent Psychiatric Assessment [23] for the controls and did not find any psychiatric or neurological symptoms. All children did not meet DSM-V diagnostic criteria for ADHD. Furthermore, a teacher completed the CTRS-S [24] for the control group, with t scores below 50 used to confirm the children's non-ADHD status. In addition, the non-ADHD group was administered the IQ test (CRT) to confirm that they did not have intellectual disability. Information on participants is shown in Table 1.

	ADHD-I	Control	P value
N	16	21	
Sex ratio (F/M)	12/4	14/7	Ns
Age	12 (1.43)	12 (1.41)	Ns
Range of age	9-14	9-14	
IQ(CRT-C)	89 (11.3)	92 (12)	p=.51
Range of IQ	75-122	80-123	

Table 1. Group means (*SDs*) for age and IQ

2.2. EF tests

We chose EF tests according to distinct domains of EF: planning, working memory, flexibility, and response inhibition [2-6]. Four EF tests were conducted in this study: the Spatial Working Memory Test (SWM), Stockings of Cambridge Test (SOC), Wisconsin Card Sorting Test (WCST), and Stroop/reverse-Stroop Test. With regard to response inhibition, Barkley (1997) proposed a model suggesting that a deficit in behavioral inhibition, considered a key process in EF, accounts for central impairment of ADHD [16]. In the model, Barkley distinguished three interrelated processes believed to constitute behavioral inhibition: (1) inhibition of a prepotent response; (2) cessation of an ongoing response; and (3) interference control. Researchers have long used Stroop/reverse-Stroop interference as the main paradigm to study interference control. Thus, in this study, we used the Stroop/reverse-Stroop Test [26, 27] to evaluate the level of response inhibition.

Spatial Working Memory Test (altered). This test was designed based on the SWM in the Cambridge Automated Neuropsychological Test Battery (CANTAB) [28, 29]. In this test, participants are asked to search through a number of boxes presented on the screen to find a token. The key instruction states that once a token has been found in a box, that box cannot be used again to hide a token during that particular trial. On each trial, the total number of blue tokens to be found corresponds to the number of boxes on the screen. Once a blue token is found in a particular box, that box cannot be used again to hide a token. Returning to an empty box where a target has already been found is referred to as a "between-search error."

In the original SWM, there were four types of trials with either three, four, six, or eight boxes in each. Several previous studies showed that children with ADHD made significantly more errors compared with controls only on the eight-box problems [30, 31]. Given that between-search errors may appear as a function of the number of boxes in pediatric clinical populations [32], it is possible that children with ADHD also make significantly more errors compared with controls on seven-box problems. Thus, we made a few changes to the original task, in which the independent variable of box consisted of five uninterrupted levels with three, four, five, six, or seven boxes. There were four test trials each with three, four, five, six, and seven boxes. The order of the trials was randomized, with the constraint that the same number of boxes did not occur consecutively. The dependent measure for the SWM test was the number of between-search errors on three-, four-, five-, six-, and seven-box problems.

Stocking of Cambridge Test (altered). This test was designed based on the SOC in the CANTAB [28, 29]. This test is closely related to the Tower of London task developed by Shallice and McCarthy [33]. In this test, two sets of three colored balls (one green, one blue, and one red) were presented on the screen. Participants were asked to rearrange the balls in the bottom display such that their positions matched the "goal" arrangement in the top half of the screen. The starting position of the balls was varied across trials to ensure that in any particular trial a minimum move of two, three, four, or five moves was required. Participants were instructed to examine the original position of the balls and attempt to solve it in the minimum possible number of moves. The time to complete the pattern is taken as a measure of the participant's planning ability.

In the original SOC task, there were four test trials each with two, three, four, and five moves. However, some studies failed to find that children with ADHD made significantly more extra moves than typically developing children on this task (For example, see [30,31,34]). It is possible that the short range of the minimum moves to goal state can account for the above conclusion. Thus, we made a few changes to the original task, such that the minimum moves to goal state ranged from three to seven moves. There were four test trials each with of three, four, five, six, and seven moves, and the order of the trials was randomized. The dependent measure for the SWM test was response times on three-, four-, five-, six-, and seven-move problems.

Wisconsin Card Sorting Test. Flexibility was assessed with the Computerized WCST [35-37], a widely used test to measure cognitive flexibility or set shifting. In this test, participants were asked to match a series of stimulus cards to a set of four target cards that differed by form, color, and number. The display did not disappear until a choice was made. Feedback information followed the choice, and consisted of a "×" sign if the response was correct, or a "○" sign if the response was incorrect. Response cards could be matched by number (1, 2, 3, 4), shape (triangle, star, cross, circle), or color (red, green, blue, yellow). After participants determined one of the correct dimensions, referred to as "categories" (C), 10 correct responses were required before the category was shifted to the next one. The task was terminated after a maximum of 128 trials was reached. The order of the sorting principles was randomized, with the constraint that the same sorting principles did not occur consecutively.

Continued matching to a category that is no longer correct is considered a perseverative error (PE). Other errors that occur when a participant is required to switch to another sorting principle are referred to as non-perseverative errors (NPE). The variables of interest were the number of categories achieved, percentage of perseverative errors and percentage of non-perseverative errors.

The Stroop/reverse-Stroop Test. The Stroop/reverse-Stroop Test [26, 27, 38] was used to evaluate the level of both Stroop interference and reverse-Stroop interference. The test comprised four subtests in which all color–word combinations and color patches were printed on four separate sheets of paper.

Test 1 was control condition for the Stroop test, in which the color patch was shown on the left side of the test sheet, requiring participants to make a choice from the five matching color–words(written in black ink) corresponding to the color of the color patch. Test 2 was the Stroop test, in which incongruent color–words were shown on the left side of the test sheet, requiring participants to make a choice from the five matching color–words (printed with black ink) according to the ink color of the color–word in the center. If the semantic content of the incongruent color–word does not affect the processing of ink color, the response to Test 1 and Test 2 should not differ. Test 3 was control condition for the Reverse-Stroop test, in which all the color–word combinations were written in black ink, requiring participants to make a choice from the five matching color patches corresponding to the color–words. Test 4 was the RI test, in which all the color–word combinations were written in incongruent ink (e.g., the word blue printed in green ink) on the left side of the test sheet, requiring participants to make a choice from the five matching color patches corresponding to the semantic meaning of the word.

Similarly, if the ink color does not affect semantic processing, the responses to Test 3 and Test 4 should not differ. Thus, we can evaluate the Stroop interference ratio and the reverse-Stroop interference ratio by comparing the responses in the four tests.

Each test consisted of 10 practice trials and 100 test trials. On the basis of the number of correct responses in each subtest (C1, C2, C3, C4), two interference ratios were calculated using the following formulas: Stroop interference ratio, (SI) = (C3–C4)/C3, and reverse-Stroop interference ratio, (RI) = (C1–C2)/C1.

2.3. Non-EF tests

To fully assess non-EF in this study, performance was assessed by a set of computer-assisted psychological tests, the Test for Attentional Performance (TAP), version 2.2, published by Zimmermann and Fimm [39]. The six subtests of alertness, divided attention, flexibility, sustained attention, visual field, and visual scanning were administered. The dependent measure for the TAP was the reaction times.

Alertness Test (TAP, subtest 1). A simple reaction time task measures response readiness to a simple visual target on the computer screen. Simple reaction time has been shown to be a valid measure of general slowness. In this test, a cross (2 cm) appeared in the middle of the screen, and the participant had to press a button as rapidly as possible. The interval between the warning and the imperative stimulus varied randomly between 300 and 700 ms. The reaction times were automatically recorded by the program (a total of 40 trials were presented in this subtest).

Divided Attention Test (TAP, subtest 5). In this subtest, participants had to deal with one visual simultaneous task. The visual task consisted of a matrix of 4 × 4 dots (size: 10 × 10 cm). Seven small Xs were superimposed randomly over the 4 × 4 dots. When four Xs formed a square, the participants had to react as quickly as possible by pressing a button. The task contained 20 visual targets out of 20 visual non-targets.

Flexibility Test (TAP, subtest 6). In this subtest, one letter and one digit were presented simultaneously, one on the left and one on the right. The digit always represented the target stimulus (50 trials). Participants needed to respond to each trial by pressing the corresponding left or right response button as quickly and as accurately as possible to judge which side of the target was displayed. The placement of the target was randomized so that participants could not anticipate where it would be displayed.

Sustained Attention Test (TAP, subtest 9). In this subtest, a sequence of stimuli was presented on the monitor. The stimuli varied in a range of feature dimensions: color, shape, size and filling. A target stimulus occurred whenever it corresponded in one predetermined stimulus dimension with the preceding stimulus (e.g., the same shape but with different color, size and filling), participants needed to respond to each trial by pressing the space key as quickly as possible (test time lasted 10 minutes).

Visual Field Test (TAP, subtest 11). To record vision in circumscribed areas of the visual field, a stimulus was presented at different points of the screen and at varying intervals. Participants

were required to fixate on the middle of the screen throughout the entire test run. Whenever the peripheral stimulus appeared the patient was to press the reaction key as quickly as possible. The reaction times to targets were recorded automatically. A total of 40 stimuli were presented in this subtask.

Visual scanning Test (TAP, subtest 12). In this subtest, a matrix-like arrangement of 5 × 5 stimuli was used. Participants were required to detect whether this arrangement included a critical stimulus. One reaction key was used for the answer "present" and another for the answer "not present." The task contained 20 visual targets out of 20 visual non-targets.

2.4. Procedure

Testing took place on four different occasions and was administered in a fixed order for both groups. During the first session, the Stroop/reverse-Stroop Test was administered. In the second testing session, the TAP battery was administered individually. In the third testing session, the WCST and SOC were administered individually. Finally, the SWM was administered individually.

3. Results

In this section, we briefly provide the statistical analyses, focusing on the performance on the EF tests (working memory, planning, flexibility and inhibition) and non-EF tests (alertness, divided attention, flexibility, sustained attention, visual field and visual scanning) between children with ADHD-I and typically developing children.

3.1. EF tests

Working memory. We performed a two-way ANOVA on the number of between search errors with the group type (ADHD-I or difficulty (three- to seven-box problems) as a within subjects factor. Results showed that the two main effects of group type, $F(1, 35) = 10.37$, $p < .01$, and task difficulty, $F(4, 140) = 27.54$, $p < .01$, were significant. The interaction effect between group type and task difficulty was significant, $F(4, 140) = 9.01$, $p < .01$. Furthermore, the simple main effect of group type was only significant in six-box problems, $F(1, 35) = 4.77$, $p = .04$ and seven-box problems, $F(1, 35) = 12.18$, $p < .01$. It was not significant in three-box problems, $F(1, 35) = .70$, $p = .41$, four-box problems, $F(1, 35) = 3.42$, $p = .07$, or five-box problems, $F(1, 35) = .01$, $p = .77$. In contrast to three- and four-box problems, in six- and seven-box problems there is a higher memory load of the task. Our findings indicate that the higher memory load task affected the ADHD-I group more than the controls.

Planning. We performed a two-way ANOVA on the reaction times with the group type (ADHD-I or control) as a between subjects factor and the task difficulty (three- to seven-move problems) as a within subjects factor. Results showed that the two main effects of group type, $F(1, 35) = 10.17$, $p < .01$, and task difficulty, $F(4, 140) = 21.32$, $p < .01$, were significant. The interaction effect between group type and task difficulty was significant, $F(4, 140) = 2.77$, $p <$.

05. Furthermore, the simple main effect of group type was only significant in five-move problems, $F (1, 35) = 5.02$, $p < .05$, six-move problems, $F (1, 35) = 6.63$, $p < .05$, and seven-move problems, $F (1, 35) = 3.80$, $p < .05$. It was not significant in three-move problems, $F (1, 35) = 3.29$, $p = .08$, and four-move problems, $F (1, 35) = .48$, p = .23. This showed that with difficulty level of planning task increases, ADHD-I exhibited poor performance on the planning task.

Flexibility. We performed an independent-samples t test on the categories achieved by the two groups. Results showed that the effect of group type, $t (35) = 3.06$, $p < .01$, was significant. In addition, we performed a two-way ANOVA on the number of errors with the group type as a between-participants factor and the error type (PE and NPE) as a within participants factor. Results showed that the two main effects of group type, $F (1, 35) = 4.20$, $p < .05$, and error type, $F (4, 140) = 233.91$, $p < .01$, were significant. The interaction effect between group type and test condition was significant, $F (4, 140) = 7.05$, $p < .01$. Furthermore, the simple main effect of group type was only significant in PE, $F (1, 35) = 6.01$, $p < .05$. It was not significant in NPE, $F (1, 35) = 1.42$, $p = .24$. This finding suggests that cognitive flexibility was impaired in ADHD-I.

Inhibition. We performed a two-way ANOVA on the interference ratios with the group type (ADHD-I or control) as a between subjects factor and the interference type (SI and RI) as a within subjects factor. Results showed that the two main effects of group type, $F (1, 35) = 3.63$, $p = .06$, and interference type, $F (1, 35) = .76$, $p = .39$, were not significant. The interaction effect between group type and interference type was significant, $F (1, 35) = 3.52$, $p < .05$. Furthermore, the simple main effect of group type was only significant in reverse-Stroop interference, $F (1, 35) = 7.52$, $p < .01$, whereas Stroop interference was not significant, $F (1, 35) = .37$, $p = .55$. This finding suggests that ADHD-I showed a selective impairment in interference control.

EF domain	Tasks	ADHD-I	Control	Contrast
Working Memory	SWM			
	BSE on 3-box problems	.13(.34)	.01(.22)	Ns
	BSE on 4-box problems	1.31(1.85)	.43(1.03)	Ns
	BSE on 5-box problems	.88(1.41)	.71(1.82)	Ns
	BSE on 6-box problems	4.38(4.56)	1.81(2.52)	ADHD-I>NC
	BSE on 7-box problems	9.83(7.95)	2.79(4.15)	ADHD-I>NC
Planning	SOC			
	TT on 3-move problems	17.27(6.71)	14.20(3.41)	Ns
	TT on 4-move problems	27.76(15.18)	33.14(11.80)	Ns
	TT on 5-move problems	62.81(38.92)	37.05(31.08)	ADHD-I>NC
	TT on 6-move problems	70.68(30.00)	49.24(20.64)	ADHD-I>NC
	TT on 7-move problems	73.20(39.23)	48.32(37.85)	ADHD-I>NC
Flexibility	WCST			
	C	6.50(2.00)	8.29(1.55)	ADHD-I<NC
	PE	13.94(9.47)	6.76(8.31)	ADHD-I>NC
	NPE	25.44(5.97)	23.10(5.88)	Ns
Inhibition	Stroop/reverse-Stroop Test			

EF domain	Tasks	ADHD-I	Control	Contrast
	SI	.23(.21)	.19(.13)	Ns
	RI	.30(.15)	.17(.11)	ADHD-I>NC

Note: ADHD-I=ADHD Pre-dominantly Inattentive type; SWM: Spatial Working Memory; SOC=Stocking of Cambridge; WCST =Wisconsin Card Sorting Test; BSE=the number of Between Search Errors; TT: Response Times; C= the number of Categories Achieved; PE=the number of Perseverative Errors; NPE= the number of Non-Perseverative Errors; SI=Stroop Interference ratio; RI=reverse-Stroop Interference ratio.

Table 2. Means and standard deviations (*SDs*) for EF test results

3.2. Non-EF tests

We performed multivariate analysis (Pillai's trace) with group type (ADHD group or non-ADHD group) as a fixed factor and reaction times on the six subtests as a dependent factor. Results showed that the effect of group type, $F (6, 28) = 4.42$, $p <.01$, was significant. The tests of between-subjects effect indicated that the group type effect was significant for divided attention, $F (1, 35) =8.18$, $p <.01$, flexibility, $F (1, 35) =8.15$, $p <.01$, sustained attention, $F (1, 35) =4.57$, $p <.05$, and visual scanning, $F (1, 35) =13.41$, $p <.01$. It was not significant for alertness, $F (1, 35) =.07$, $p =.98$, or visual field, $F (1, 35) =.06$, $p =.79$.

	Tasks	ADHD-I	Control	Contrast
Alertness	TAP, subtest 1	350.67(54.44)	345.17(64.88)	Ns
Divided attention	TAP, subtest 4	1434.17 (432.73)	1097.09 (265.93)	ADHD-I>NC
Flexibility	TAP, subtest 6	560.75(92.43)	480.00(74.42)	ADHD-I>NC
Sustained attention	TAP, subtest 9	560.56(59.50)	515.96(61.07)	ADHD-I>NC
Visual field	TAP, subtest 11	503.97(107.96)	496.36(90.83)	Ns
Visual scanning	TAP, subtest 12	5454.91(1270.07)	4114.94 (898.77)	ADHD-I>NC

Note: TAP = Test for Attentional Performance.

Table 3. Means and standard deviations (*SDs*) for non-EF test results

4. Discussion

4.1. EF domains

Working memory. Results of the two-way ANOVA indicated a significant group-by-task difficulty interaction: the ADHD-I differed significantly from controls only on six- and seven-box problems. This result is consistent with several previous studies in which children with ADHD-C exhibited deficits in multiple components of working memory [30, 40, 41]. These results suggest that working memory is impaired in both ADHD-C and ADHD-I.

Planning. Analysis of thinking times on three-, four-, five-, six- and seven-move problems indicated that children with ADHD-I took more time to complete the five-, six- and seven-

move problems than controls. The current findings are in contrast to previous studies (For example, see [30, 42]) that failed to find a significant divergence between ADHD-C and controls on three difficulty levels of SOC: two or three moves necessary to solve the problem (lowest difficulty level), four moves (medium difficulty level), and five moves (highest difficulty level). We argued that the short level range (the maximum move to goal state is five) may account for the no-difference findings in these studies. Numerous studies (For example, see [8, 31]) have reported poor performance on planning tasks in individuals with ADHD-C. Evidence from our research and previous studies support the hypothesis that planning is impaired in both ADHD-C and ADHD-I. And we made a modification to the original SOC task by changing the minimum moves to goal state ranged from three to seven moves and the results show that the modified SOC task is a more useful tool to evaluate the individual's planning ability.

Flexibility. Results showed that the categories achieved by the ADHD group were fewer than the categories achieved by controls, and the simple main effect of group type was only significant for perseverative errors and not significant for non-perseverative errors. This indicates that the ADHD-I group exhibited a deficit in flexibility relative to typically devel-oping children. Although a few studies have shown no statistically significant differences from controls on the WCST in individuals with ADHD [42-43], more than half of the investigations have shown statistically significant differences from controls [14,45-48]. Moreover, Houghton et al. (1999) found no differences between inattentive and combined subtypes on WCST [49, 50]. These results support the hypothesis that flexibility is impaired in both ADHD-C and ADHD-I.

Inhibition. We found an asymmetric phenomenon between Stroop interference and reverse-Stroop interference for ADHD-I participants. This finding replicated our recent results reporting an ADHD-I impairment in reverse-Stroop interference but not in Stroop interference [37]. A number of studies have used the Stroop test to examine interference control in ADHD, but results have been inconsistent. Recently, Mourik, Oosterlaan, & Sergeant (2005) completed a meta-analytic review that systematically examined 17 studies of Stroop interference control in ADHD [51]. They concluded that the Stroop color-word task does not provide strong evidence for a deficit in interference control in ADHD. Lansbergen, Kenemans, and Van Engeland (2007) conducted another meta-analytic review of 19 studies that administered the Stroop tests to groups with ADHD [52]. In contrast, consistency analysis of ratio scores across those 19 studies revealed that interference control was consistently compromised in individ-uals with ADHD. We have few studies available on reverse-Stroop interference in ADHD-C. This is possibly because the reverse-Stroop has seldom been discussed in ADHD because it cannot be observed in oral responses [53]. It is difficult to conclude that individuals with ADHD-I or ADHD-C exhibit the same deficit in reverse-Stroop interference until more studies on this question are conducted.

4.2. Non-EF domains

Deficits in divided attention, flexibility, sustained attention, and visual scanning relative to controls indicate that individuals with ADHD-I also exhibited impairment on the non-EF domains. We know that the cognitive and behavioral characters (the attention trait, hyperac-

tivity and impulsivity) are the main criterion for the subtypes of ADHD in DSM-V. However, the DSM-V does not provide specific examples of the cognitive difference between ADHD-C and ADHD-I.

With regard to non-EF domains, previous studies have suggested that ADHD-I shows a deficit in speed of information processing, generally, and in focused or selective attention, specifically [54, 55], while deficits in ADHD-C are characterized as sustained persistence [16]. However, one recent study has shown that ADHD-I and ADHD-C children had similar profiles of vigilance impairment indexing a lack of sustained attention [56]. Furthermore, in the present research, we found that ADHD-I is also associated with a sustained attention deficit. Moreover, Geurts, Vert´ec, Oosterlaana, Roeyersc, and Sergeanta (2005) found no differences between inattentive and combined ADHD subtypes on non-EF tasks, such as response execution, short-term memory, visual-motor integration and categorization [57]. Based on combined results of the current research and previous studies, we wonder whether the deficits in non-EF cognitive abilities can be used as good markers for the validation of ADHD subtypes in DSM-V.

5. General discussion

The present study was designed to investigate the hypothesis that those with ADHD-I exhibit both EF deficits and non-EF deficits by comparing typically developing controls with boys carefully diagnosed with ADHD-I on an extensive battery of tasks that cover the major EF and non-EF domains.

With regard to the EF domains, results are consistent with findings in previous studies of EF and ADHD. That is, ADHD is associated with weaknesses in several key EF domains, but the strongest and most consistent effects are obtained on measures of response inhibition, vigilance, spatial working memory and some measures of planning [8, 41, 56-58]. The deficits on EF domains revealed in ADHD-I also suggest that the pathology of ADHD-I is related to deficits in managing an appropriate problem or attaining a future goal. Furthermore, results did not yield evidence for the model of ADHD in which only ADHD-C and ADHD-H, but not ADHD-I, are associated with EF deficits.

With regard to non-EF domains, findings revealed that the children with ADHD-I also demonstrated deficits in these domains, such as, divided attention, flexibility, sustained attention and visual scanning. This suggests that children with ADHD-I not only show deficits in EF, but also experience deficits in other non-EF domains.

Discriminating among disorders is particularly important. However, there are no objective diagnostic tests for ADHD-I [59]. Considering the fact that neither EF nor non-EF domains distinguish ADHD-I from ADHD-C, examination of other factors, such social, emotional and behavioral characteristics [60, 61] may be needed to support the validity of ADHD subtypes in the DSM-V.

6. Limitations

A limitation of our study findings is the small sample size and potential response bias from those who agreed to participate. To gather more reliable data and validate the results of the present study, future research should focus on selecting larger samples to engage in the same tasks. Furthermore, to examine whether EF and non-EF tests can distinguish ADHD-I from ADHD-C, it would be useful to make a direct comparison between ADHD-C and ADHD-I in the battery of EF and non-EF tests used in the study. Future studies should be conducted using the same tasks with an ADHD-C group.

Acknowledgements

Author details

Yongning Song[*]

Address all correspondence to: ynsong@psy.ecnu.edu.cn

School of Psychology and Cognitive Science, East China Normal University, China

References

[1] Chan RCK, Shum D, Toulopoulou T, Chen EYH. Assessment of executive functions: Review of instruments and identification of critical issues. Archives of Clinical Neuropsychology. 2008; 3 (2): 201-216. DOI: 10.1016/j.acn.2007.08.010

[2] Hughes C. Executive function in preschoolers: Links with theory of mind and verbal ability. British Journal of Developmental Psychology. 1998;16: 233-253. http://dx.doi.org/10.1111/j.2044-835X.1998.tb00921.x

[3] Miyake A, Friedman, N, Emerson, M, Witzki, A, Howerter, A, Wager, T. The unity and diversity of executive functions and their contributions to complex " frontal lobe" tasks: a latent variable analysis. Cognitive Psychology. 2000; 41: 49-100. DOI: 10.1006/cogp.1999.0734

[4] Ozonoff S. Components of executive function in autism and other disorders. In J. Russell (Ed.), Autism as an executive disorder. New York, USA: Oxford University Press; 1997.179–211p.

[5] Robbins TW. Dissociating executive functions of the prefrontal cortex. Philosophical Transactions of the Royal Society London. 1996; 351: 1463-1471. DOI: 10.1098/rstb. 1996.0131

[6] Welsh MC, Pennington BF,Groisser DB. A normative developmental study of executive function: a window on prefrontal function in children. Developmental Neuropsychology. 1991;7: 131-149. DOI: 10.1080/87565649109540483

[7] Welsh MC,Pennington BF. Assessing frontal lobe functioning in children: Views from developmental psychology. Developmental Neuropsychology. 1988; 4: 199-230. DOI: 10.1080/87565648809540405

[8] Willcutt EG, Doyle AE, Nigg JT, Faraone SV,Pennington BF. Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. Biological Psychiatry. 2005;57: 1336-1346. DOI: 10.1016/j.biopsych.2005.02.006

[9] Boucagnani LL,Jones RW. Behaviors analogous to frontal dysfunction in children with attention deficit hyperactivity disorder. Archives of Clinical Neuropsychology. 1989;4: 161-73. DOI: 10.1093/arclin/4.2.161

[10] Castellanos FX,Tannock R. Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. Nature Reviews Neuroscience. 2002; 3: 617-628. DOI: 10.1038/nrn896

[11] Levin PM. Restlessness in children. Archives of Neurology and Psychiatry. 1938; 39: 764-770. doi:10.1001/archneurpsyc.1938.02270040120006.

[12] Pennington B,Ozonoff S. Executive functions and developmental psychopathology. Journal of Child Psychology and Psychiatry. 1996; 37: 51– 87. DOI: 10.1111/j. 1469-7610.1996.tb01380.x

[13] Pineda DA, Restrepo MA,Sarmiento RJ. Statistical analyses of structural magnetic resonance imaging of the head of the caudate nucleus in Colombian children with attention-deficit hyperactivity disorder. Journal of Child Neurology. 2002; 17: 97-105. DOI: 10.1177/088307380201700202

[14] Shue KL,Douglas VI. Attention deficit hyperactivity disorder and the frontal lobe syndrome. Special Issue: The role of frontal lobe maturation in cognitive and social development. Brain and Cognition. 1992; 20: 104-124. DOI: 10.1016/0278-2626(92)90064-S

[15] American Psychiatric Association (APA). Diagnostic and statistical manual of mental disorders. 5th ed. Washington, DC: American Psychiatric Association. 2013.

[16] Barkley RA. Behavioral inhibition, sustained attention, and executive function: constructing a unified theory of ADHD. Psychological Bulletin. 1997; 121: 65-94.http://dx.doi.org/10.1037/0033-2909.121.1.65

[17] Milich R, Balentine A,Lynam D. ADHD combined type and ADHD predominantly inattentive type are distinct and unrelated disorders. Clinical Psychology: Science and Practice. 2001; 8: 463-488. DOI: 10.1093/clipsy.8.4.463

[18] Nigg JT. Neuropsychologic theory and findings in attentiondeficit/ hyperactivity disorder: the state of the field and salient challenges for the coming decade. Biological Psychiatry. 2005; 57: 1424-35. DOI: 10.1016/j.biopsych.2004.11.011

[19] Nigg JT, Blaskey LG, Huang-Pollock CL,Rappley MD. Neuropsychological executive functions and DSM-IV ADHD subtypes. Journal of the American Academy of Child and Adolescent Psychiatry. 2002; 41: 59-66. DOI: 10.1097/00004583-200201000-00012

[20] McBurnett K, Pfiffner LJ,Frick PJ. Symptom properties as a function of ADHD type: An argument for continued study of sluggish cognitive tempo. Journal of abnormal child psychology. 2001; 29(3): 207-213. DOI: 10.1023/A:1010377530749

[21] Carlson CL,Mann M. Sluggish cognitive tempo predicts a different pattern of impairment in the attention deficit hyperactivity disorder, predominantly inattentive type. Journal of Clinical Child and Adolescent Psychology. 2002; 31(1): 123-129. DOI: 10.1207/S15374424JCCP3101_14

[22] Song Y,Hakoda Y. The interference of local over global information processing in children with attention deficit hyperactivity disorder of the inattentive type. Brain and Development. 2012; 34(4): 308-317. DOI: 10.1016/j.braindev.2011.07.010

[23] Angold A, Prendergast A, Cox R, Harrington E, Simonoff E,Rutter M. The child and adolescent psychiatric assessment (CAPA). Psychological Medicine. 1995; 25: 739-753. DOI: http://dx.doi.org/10.1017/S003329170003498X

[24] Conners CK. Rating scales in attention deficit hyperactivity disorder use in assessment, and treatment and monitoring. Journal of Clinical Psychiatry. 1998; 59: 24-30.

[25] Conners CK. The Conners rating scales: Instruments for the assessments of childhood psychopathology. Durham, NC: Duke University. 1995.

[26] Hakoda YJ,Sasaki M. Group version of the Stroop and reverse-Stroop test: The effects of reaction mode, order and practice. Japanese Journal of Educational Psychology. 1990; 38: 389-394.

[27] Hakoda YJ,Sasaki MTwo interferences based on new Stroop test and reaction model (Report No. 3). Fukuoka: Japan, Kyushu University, Department of Information Systems. 1991

[28] Luciana M,Nelson CA. Neurodevelopmental assessment of cognitive function using the Cambridge Neurospychological Testing Automated Battery (CANTAB): Validation and future goals. In M. ErnstJ. Rumseyy (Eds.), The foundation and future of

functional neuroimaging in child psychiatry. Cambridge University Press. 2000. http://dx.doi.org/10.1111/1469-7610.00152

[29] Sahakian B,Owen A. Computerised assessment in neuropsychiatry using CANTAB. Journal of the Royal Society of Medicine. 1992; 85: 399-402.

[30] Goldberg MC, Mostofsky SH, Cutting LE, Mahone EM, Astor BC,Denckla MB. Subtle executive impairment in children with autism and children with ADHD. Journal of Autism Developmental Disordors. 2005; 35: 279-293. DOI: 10.1007/s10803-005-3291-4

[31] Kempton S, Vance A, Maruff P, Luk E, Costin J,Pantelis C. Executive function and attention deficit hyperactivity disorder: stimulant medication and better executive function performance in children. Psychological Medicine. 1999; 29: 527-538. DOI: 10.1017/S0033291799008338

[32] Joyce E, Blumenthal S,Wessely S. Memory, attention, and executive function in chronic fatigue syndrome. Journal of Neurology, Neurosurgery and Psychiatry. 1996; 60: 495-503.

[33] Shallice T. Specific impairments of planning. Philosophical Transactions of the Royal Society of London, 1982; 298, 199-209. DOI: 10.1098/rstb.1982.0082

[34] Luciana M. Practitioner Review: Computerized assessment of neuropsychological function in children: Clinical and research applications of the Cambridge Neuropsychological Testing Automated Battery (CANTAB). Journal of Child Psychology and Psychiatry. 2003; 44: 649-663. DOI: 10.1111/1469-7610.00152

[35] Grant DA, Berg EA. A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card sorting problem. Journal of Experimental Psychology. 1948; 34: 404-411. http://dx.doi.org/10.1037/h0059831

[36] Heaton RK. Wisconsin Card Sorting Test manual. Odessa, FL: Psychological Assessment Resources. 1981

[37] Heaton R.K, Chelune G.J, Talley JL, Kay G.G,Curtiss G. Wisconsin Card Sorting Test manual. Odessa, FL: Psychological Assessment Resources, Inc. 1993.

[38] Song Y,Hakoda Y. An Asymmetric Stroop/Reverse-Stroop Interference Phenomenon in ADHD. Journal of Attention Disorders. 2011; 15(6): 499-505. DOI: 10.1177/1087054710367607

[39] Zimmermann P,Fimm B. A test battery for attentional performance. In: Leclercq M. Applied neuropsychology of attention. London: Psychology Press. 2002.

[40] Corbett BA, Constantine L.J, Hendren R, Rocke D,Ozonoff S. Examining executive functioning in children with autism spectrum disorder, attention deficit hyperactivity disorder and typical development. Psychiatry Research. 2009; 166: 210-222. DOI: 10.1016/j.psychres.2008.02.005

[41] Martinussen R, Hayden J, Hogg-Johnson S,Tannock R. A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. Jour-

nal of the American Academy of Child and Adolescent Psychiatry. 2005; 44: 377-384. DOI: 10.1097/01.chi.0000153228.72591.73

[42] Geurts HM, Verte S, Oosterlaan J, Roeyers H,Sergeant JA. How specific are executive functioning deficits in attention deficit hyperactivity disorder and autism? Journal of Child Psychology and Psychiatry. 2004; 45: 836-854. DOI: 10.1111/j. 1469-7610.2004.00276.x

[43] Pennington BF, Groisser D,Welsh MC. Contrasting cognitive deficits in attention deficit hyperactivity disorder versus reading disability. Developmental Psychology. 1993; 29: 511-523.

[44] Weyandt LL,Willis WG. Executive functions in school-aged children: Potential efficacy of tasks in discriminating clinical groups. Developmental Neuropsychology. 1994; 10: 27-38. DOI: 10.1080/87565649409540564

[45] Amaral AH,Guerreiro MM. Attention deficit hyperactivity disorder: proposal of neuropsychological assessment. Arq Neuropsiquiatr. 2001; 59 (4): 884-888. DOI: 10.1590/ S0004-282X2001000600009

[46] Reeve WV,Schandler SL. Frontal lobe functioning in adolescents with attention deficit hyperactivity disorder. Adolescence. 2001; 36: 749-765.

[47] Semrud CM, Steingard RJ,Filipek P. Using MRI to Examine Brain-Behavior Relationships in Males With Attention Deficit Disorder with Hyperactivity children. Journal of the American Academy of Child and Adolescent Psychiatry. 2000; 39(4): 477-484. DOI: 10.1097/00004583-200004000-00017

[48] Tripp G, Ryan J,Peace K. Neuropsychological functioning in children with DSM-IV combined type Attention Deficit Hyperactivity Disorder. Australian and New Zealand Journal of psychiatry. 2002; 36: 71-779. DOI: 10.1046/j.1440-1614.2002.01093.x

[49] Houghton S, Douglas G,West J. Differential patterns of executive function in children with attention-deficit hyperactivity disorder according to gender and subtype. Journal of Child Neurology. 1999; 14: 801-805. DOI: 10.1177/088307389901401206

[50] Schmitz M, Cadore, L, Paczko M, Kipper L, Chaves M,Rohde LA. Neuropsychological performance in DSM-IV ADHD subtypes: An exploratory study with untreated adolescents. Canadian Journal of Psychiatry. 2002; 47: 863-869.

[51] Mourik R, Oosterlaan J,Sergeant JA. The Stroop revisited: A meta-analysis of interference control in AD/HD. Journal of Child Psychology and Psychiatry. 2005; 46: 150-165. DOI: 10.1111/j.1469-7610.2004.00345.x

[52] Lansbergen MM, Kenemans JL,Van Engeland H. Stroop interference and attention-deficit/hyperactivity disorder: A review and meta-analysis. Neuropsychology. 2007; 21(2): 251-262. http://dx.doi.org/10.1037/0894-4105.21.2.251

[53] Stroop JR. Studies of interference in serial verbal reactions. Journal of Experimental Psychology. 1935;18: 643-662. http://dx.doi.org/10.1037/0096-3445.121.1.15

[54] Goodyear E,Hynd, G. Attention deficit disorder with (ADD/H) and without (ADD/WO) hyperactivity: Behavioral and neuropsychological differentiation. Journal of Clinical Child Psychology. 1992; 21: 273-304. DOI: 10.1207/s15374424jccp2103_9

[55] Lahey BB,Carlson CL. Validity of the diagnostic category of attention deficit disorder without hyperactivity: A review of the literature. In S.E. ShaywitzB. Shaywitz (Eds), Attention deficit disorder comes of age: Toward the twenty-first century. Austin, TX: Pro-Ed. 1992. 119-144p.

[56] Chhabildas N, Pennington BF,Willcutt EG. A comparison of the Neuropsychological Profiles of the DSM-IV Subtypes of ADHD. Journal of Abnormal Child Psychology. 2001;29: 529-540. DOI: 10.1023/A:1012281226028

[57] Geurts, HM, Vert´ec S, Oosterlaana J, Roeyersc H,Sergeanta HA. ADHD subtypes: do they differ in their executive functioning profile? Archives of Clinical Neuropsychology. 2005; 20: 457-477.DOI: 10.1016/j.acn.2004.11.001

[58] Riccio CA, Homack S, Jarratt KP,Wolfe ME. Differences in academic and executive function domains among children with ADHD Predominantly Inattentive and Combined Types. Archives of Clinical Neuropsychology. 2006; 21: 657-667. DOI: 10.1016/j.acn.2006.05.010

[59] Aaron P, Joshi RM,Phipps J. A cognitive tool to diagnose predominantly inattentive ADHD behaviour. Journal of Attention Disorders. 2004; 7: 125-135. DOI: 10.1177/108705470400700301.

[60] Gadow KD, Sprafkin J,Nolan EE. DSM–IV symptoms in community and clinic pre-school children. Journal of the American Academy of ChildAdolescent Psychiatry. 2001; 40: 1383-1392. DOI: 10.1097/00004583-200112000-00008

[61] Graetz BW, Sawyer MG, Hazell PL, Arney F, Baghurst P. Validity of DSM-IV ADHD subtypes in a nationally representative sample of Australian children and adolescents. Journal of the American Academy of Child and Adolescent Psychiatry. 2001; 40: 1410-1417. DOI: 10.1097/00004583-200112000-00011