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The Domains of Impaired Inhibitory Control in Children with Attention-Deficit/Hyperactivity Disorder (ADHD)

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Abstract

Theoretical models of attention deficit hyperactivity disorder (ADHD) have suggested that inhibitory control (IC) is a primary deficit in children with ADHD. Inhibition is considered a multidimensional construct with various aspects. Multiple domains of IC are attentional inhibition(AI), response inhibition(RI), and motor inhibition(MI). Although the literature supports that inhibitory deficiencies are the fundamental problem underlying ADHD, it seems that children with ADHD may have deficits with certain domains of inhibition but not with other domains. The purpose of the present study is a comparison of multiple domains of IC in children with and without ADHD. A sample of 80 children ages 6-12 (46 boys) with ADHD (n=40) and without ADHD (n=40) symptoms participated in the study. Stroop Task (ST), Go/No-Go Task (GNGT), and Circle Tracing Task (CTT) respectively for evaluation of AI, RI and MI were performed by the participants. It was observed that children with ADHD showed worse performance in GNGT and CTT while the performance of children with and without ADHD symptoms did not differ in ST. Children with ADHD symptoms comparing typically developing (TD) children exhibited deficits with certain forms of inhibition. they had impaired performance on prepotent response inhibition and stopping ongoing response, however, no deficit was found in interference control.

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1. Introduction and preliminaries

Attention Deficit Hyperactivity Disorder (ADHAD) is defined as a control function disorder. Theoritical models have suggested that inhibitory control (IC) is a primary deficit in ADHD [1]. IC deficits lead them to engage in high-risk behaviors such as car accidents, sexual behaviors, or conflict with the law and makes ADHD patients more at risk of premature death from unnatural events than the general population [2].

IC is often assessed by response inhibition tasks, which include maintaining or delaying a prepotent response or the individual's ability to perform a non-dominant task [3]. While commonly the ability to suppress an automatic dominant response or prepotent response is considered inhibition, inhibition also includes interference control, guided forgetfulness, emotion control, and motor control [4]. The various terms of inhibition in studies indicate that different forms of inhibition have been studied [5]. Barkley (1997) suggested that inhibition includes two types of response inhibition processing and interference control [6]. Various aspects of IC in studies have referred to two forms of inhibition which include response inhibition (RI) and attentional inhibition(AI) [e.g., 7-9].

The RI (also mentioned as 'Cognitive Inhibition', 'Prepotent Response Inhibition', 'Behavioral Inhibition', and 'Motor Inhibition') is defined as the inhibition of a response with a prepotent or the initial dominant response to an event [5, 3]. RI involves ongoing response inhibition or motor inhibition. Motor inhibition (MI) is defined as the ability to stop responding to an ongoing response [10]. AI (also mentioned as 'Perceptual Inhibition', 'Interference Control', and Interference Suppression) [5, 11] is defined as the ability to filter opponent information [10].

Each domain of inhibition is evaluated by tasks designed in specific paradigms. For example, RI or prepotent response inhibition is assessed by tasks in the go/no go and stop signal paradigm, or CPT, while Flanker and Simon paradigms or Stroop-like tasks are used to assess interference control or AI [10]. Ongoing response inhibition tasks included tasks with a stronger motor component [3] such as the circle tracing task. The findings suggest that ADHD patients may have deficits in some domains of inhibition compared to their peers with typical development while there are not in other domains. Some meta-analytic studies reported weaker prepotent response inhibition and inhibitory motor control [e.g., 12, 6, 13, 1, 14, 15], and impairment of interference control [e.g., 10, 16] in children with ADHD while some others reported a lack of interference control deficits in ADHD children based on studies using the Stroop test [e.g., 17, 11]. ADHD is a neurodevelopmental disorder and there is an inverted U-shaped relationship between age and IC development, So improvement of IC appears during childhood and decreases in late adulthood [18]. Although school age has been proposed as an important period in the development of inhibition and IC changes occur at the age of 6-15 years [19], some studies revealed improvements in inhibitory functions may occur relatively fast in preschool children [e.g., 20-23]. Some evidence suggests age-related increases in IC functions are found in childhood and continue to mature until the age of twelve [18, 24, 25].

As mentioned, there are different domains of inhibition. Some studies indicated that improvement of the motivational domain of inhibition relative to the perceptual domain of inhibition becomes smaller in the school-age years and its developmental changes continue throughout adolescence [3]. Some meta-analytic studies reported the greatest improvement in the prepotent RI may occur between the ages of 5 and 8 [18]. In other studies, different developmental pathways have been observed for different forms of control functions in normal children, for example, the main change in RI occurs at 7-8 years of age, error monitoring at 6-9 years of age, or attentional disengagement is seen at the age of 7-9 [19]. In the study of Berger, Slobodin, Aboud, Melamed, & Cassuto (2013), significant progress has been reported from the age of 7 to 9 years and 9 to 11 years on behavioral measures of inhibition by the continuous performance test (CPT).

Although inhibitory deficiencies are the fundamental problem underlying ADHD, it seems that children with ADHD may have deficits in some aspects of IC but not in other aspects. On other hand, ADHAD is a neurodevelopmental disorder and ADHD children indicate poorer performance than their peers in a number of cognitive functions, such as IC, especially at school age, So studies that investigate the various domains of IC deficits of ADHD at school age can lead to more reliable and practical findings to improve interventional and rehabilitation programs. Therefore, the aim of this study was to compare the performance of school-aged children with ADHD symptoms and their unaffected peers in multiple aspects of behavioral inhibition (RI or prepotent response inhibition, MI or inhibition of ongoing response, and AI or interference control) in both genders.

2. Materials and Methods

2.1 Participants and Procedure

Forty Iranian children with ADHD symptoms (57% boy) ages 6-12 years among students of elementary schools were selected to participate in the study and forty TD children without any history of behavior problems (57% boy) were recruited out of their classmates. The control participants did not significantly differ in age, gender, educational performance, and socioeconomic level of the family from children with ADHD symptoms. Group differences on these variables were tested using an overall alpha level of .05. Demographic comparisons of participants are presented in Table 1. The data on these variables were collected from the principal and the teacher of the students.

Children with ADHD symptoms were included if they met a score above the clinical cut-off point on the ADHD subscale of SCI-4 (at least 6 of the 18 inattention or hyperactivity–impulsive symptoms) according to their teacher complaints. Then they were selected during a supplementary diagnostic and clinical interview based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM5) criteria for ADHD. The inclusion criteria for the group without ADHD symptoms were the absence of criteria for ADHD. Exclusion criteria for all participants included a normal auditory or visual acuity, nervous system diseases which would make an impact on cognition (e.g., epilepsy), a history of head trauma, autism, or learning disabilities. Participants were screened for a current psychiatric disorder. This information was collected from the parents of the children. After the parents filled out an informed consent form, the participants were tested.

Participants were tested individually in an interview room and testing often took place within one session for approximately 45 - 60 minutes. Computerized tasks including go/no-go task (GNGT), Stroop task (ST), and circle tracing task (CTT) were administered in a set order GNGT, ST, and CTT to all participants. Participants were seated comfortably, approximately 0.5 m from the screen. The training step was performed first in each task and after making sure that the participants understood the instructions, the main assessment was performed; also they were allowed to have short breaks between each task. None of the children were on medication, which would affect the IC's abilities.

Table1. Demographic comparisons of participants.

		Participant with ADHD symptoms (N= 40)	Participant without ADHD symptoms (N=40)	T	P
Age (months):	M (SD)	115.45 (21.44)	114.45 (22.84)	0.20	0.84
Gender	boy	23	23	ns	
	girl	17	17		
CSI-4	M(SD)	9.07(2.50)	3.12(1.30)	13.32	.001
Educational performance	Very Good	9	11	ns	
	Good	23	23		
	Acceptable	8	6		

Note: M = Mean; SD = Standard Deviation; ADHD: attention-deficit hyperactivity disorder, CSI- 4 score represent severity of ADHD score.

2.2 Measures

In this study, multiple aspects of IC were measured. children with and without ADHD symptoms completed the GNGT, ST, and CTT which are widely used as measures of RI, AI, and MI.

2.2.1 Go/No-Go Task (GNGT)

RI or the prepotent response inhibition was assessed using the GNGT in this study. 50 stimuli in the form of a black airplane (7 × 7 cm) were presented to the participants on a white screen. Subjects were instructed in the "Go condition" to press the arrow key as fast and accurately as possible in accordance with the airplane's direction. In the " No go condition", a sound “beep” was heard immediately after the plane was displayed, and the subject should refuse to answer. Two conditions of Go and No go appear on the screen in random order. 75 percent of trials were Go stimuli and the remaining 25% were No go stimuli. The percentage of the correct response to Go stimuli, the percentage of the correct response to No go stimuli, and reaction time (RT) were computed as execution accuracy index, inhibition accuracy index, and speed index respectively. Inhibition accuracy examines prepotent response inhibition as an index of IC [26]. This task has been a modified version of the revised stop signal test proposed by Carter et al. (2003). For full descriptions of these procedures, see our previous work [8].

2.2.2 Stroop Task (ST)

In this study, the spatial version of the Stroop task is used for the assessment of AI or interference control in which nine static squares were presented on the screen, and an arrow appeared in four directions up, down, left, and right in the squares. participants were instructed to press an arrow key on the keyboard regarding the direction of the target arrow as fast as possible. In the first stage or neutral condition, all arrows with different directions appear in a specified square and the participant should answer the direction of it with arrow keys. During the second stage of congruent trials, the arrow direction matches the location in which appears (e.g., it appears at the top square whenever the arrow direction is up, or at the bottom square whenever it is down). During the third stage or incongruent condition, the arrow appears in a location that conflicts with their direction (e.g., while the direction of the arrow is upwards, it appears at the bottom square, and participants should respond to the arrow direction and inhibit where it appears. There were 100 stimuli for each stage and the next stimulus was presented after the participants' response. The attention bias index (ABI) is an interference control index. ABI is measured by subtracting incongruent RT (third stage) from neutral RT (first stage) [27].

2.2.3 Circle Tracing Task (CCT)

In this test which is designed to assess MI or ongoing response inhibition, participants were instructed to trace with their preferred finger over a circle as slowly as possible. Faster detection indicates a lack of IC [27]. In the children's version, the two Conditions of the turtle and the rabbit are designed so that the child has to follow a circular and winding path by moving the finger, from the turtle to the lettuce and from the rabbit to the carrot. The difference is that participants were instructed to move their fingers in the rabbit condition with the highest possible speed and in the turtle condition with the lowest possible speed. The MI index in this task is duration. The difference in the RT of the two conditions is an indicator of MI.

2.3 Data Analysis

The data were analyzed using SPSS Version 22.0 (SPSS, Inc., Chicago, IL). Demographic characteristics were investigated using the Chi-square test for nominal variables and the independent t-test for continuous variables. All variables were generally normally distributed. Group (with and without ADHD symptoms) was the independent variable and scores on three IC tasks were the dependent variables. Age was included as a covariate. Group differences in scores of three IC tasks were examined with multivariate analysis of covariance (MANCOVA). In case of significant group effects ($p < .05$), Post hoc, univariate analyses for group comparisons were conducted. Correlations of main scores of IC and ADHD scores were also computed to investigate associations between impairments in three domains of IC and the severity of ADHD symptoms.

3. Results

As can be seen from Table 1, the participants with and without ADHD symptoms were not significantly different in demographic characteristics (age, gender, and educational performance). The group means and standard deviations for IC task scores are presented in Table 2.

The results of the correlation analysis of the IC indexes with the severity of ADHD symptoms are presented in Table 3. The performance of participants in IC tasks such as GNGT and CTT were significantly correlated with the severity of ADHD symptoms but not in the IC index of ST.

As can be seen, children with ADHD symptoms had poor performance than groups without ADHD symptoms in all response inhibition scores. Multivariate analysis of covariance (MANCOVA) was used to compare group differences in measures of three domains of IC. In order to control the age effect, this variable was covaried for all dependent measures. The results are shown in Table 4.

3.1 GO/NOGO Task (GNGT)

To compare the prepotent response inhibition of two groups, multivariate analysis of covariance (MANCOVA) was used. One of the prerequisites for this analysis is the homogeneity of the response inhibition variance matrix among the groups (Mbox = 10.36, F=1.66, p=0.12). A MANCOVA with the group as the between-subject variable and GNGT including the three IC scores (Execution accuracy scores, inhibition accuracy scores, and speed index) as the dependent measures and age as covariate variable resulted in a significant multivariate effect of Group, Wilks' $\lambda = .11$, $F(3,75) = 3.18$, $p = .02$. As shown in Table 4, Post hoc, Univariate analyses revealed significant group differences for execution accuracy and inhibition accuracy as an index of prepotent response inhibition.

3.2 Stroop Task (ST)

To compare the interference control of the two groups, MANCOVA was used. One of the prerequisites for this analysis is the homogeneity of the interference control variance matrix among the groups (Mbox = 113.44, F=4.15, p=0.01). A MANCOVA with the group as the between-subject variable and IC indexes of Stroop task including accuracy incongruent and attention bias index (ABI) as the dependent measures and age as covariate variable resulted in a significant multivariate effect of Group, Pillai's trace = .13, $F(6,72) = 1.85$, $p = .10$, $\eta 2$ .13. MANCOVA results indicated that neither of Stroop scores differed significantly and the performance of participants with and without ADHD symptoms was not different for interference control.

Table 2. Descriptive Statistics on IC tasks for Groups with and without ADHD symptoms.

IC tasks	Source	Participant with ADHD symptoms (N= 40)	Participant without ADHD symptoms(N=40)
		M (SD)	M (SD)
GNGT	Execution accuracy (Go)	.71(.22)	.81(.19)
	Inhibition accuracy (NoGo)	.84(.10)	.90(.09)
	Speed index (Time)	1.23(.26)	1.29(.23)
ST	Accuracy 1	87.97(9.96)	94.89(4.94)
	RT1	1703.93(1376.43)	1396.20(533.96)
	Accuracy2 congruent	92.65(9.32)	96.97(3.56)
	RT 2	1631.91(1108.57)	1430.14(447.62)
	Accuracy3 incongruent	91.56(11.14)	93.64(7.42)
	RT3	2024.22(1608.99)	1765.13(713.64)
	ABI	320.29(595.65)	368.92(416.93)
CTT	RT condition1	3.70(1.26)	3.45(1.23)
	RT condition2	52.07(36.55)	157.57(177.42)
	Circle tracing time (Sec)	48.37(36.52)	154.12(177.16)

Note: M = Mean; SD = Standard Deviation; ADHD: attention-deficit hyperactivity disorder, GNGT: Go/No-Go Task, ST: Stroop task, CTT: Circle Tracing Task, RT = Response Time; ABI: Attention Bias Index

Table 3: Correlation of IC indexes and ADHD symptoms.

IC tasks	Sources	Participant with and without ADHD symptoms (N= 80)	
		R	P
GNGT	Inhibition accuracy NoGo	- 0.34**.	0.002
ST	Accuracy incongruent	- 0.19.	0.14
	ABI	- 0.07	0.09
CTT	Circle tracing time (Sec)	- 0.54**.	0.001

**Correlation is significant at the 0.01 level (2-tailed).

Note: ADHD: attention-deficit hyperactivity disorder, GO NOGO: inhibition task, One-Back: working memory task, GNGT: Go/No-Go Task, ST: Stroop task, CTT: Circle Tracing Task, Inhibition accuracy NoGo: RI index, ABI (Attention Bias Index): AI index, Circle tracing time: MI index

3.3 Circle Tracing Task(CTT)

To compare the ongoing response inhibition of two groups, MANCOVA was used. One of the prerequisites for this analysis is the homogeneity of the response inhibition variance matrix among the groups (Mbox = 72.45, F=23.48, p=0.01). A MANCOVA with the group as the between-subject variable and IC scores of CTT as the dependent measures and age as the covariate variable resulted in a significant multivariate effect of Group, Pillai's trace = .16, $F(3,76) = 7.66$, $p = .001$, $\eta 2 = .16$). As shown in Table 4, Post hoc, Univariate analyses revealed significant group differences for the ongoing response inhibition or MI index.

Table 4. MANCOVA results to compare the measures of IC in two groups.

Tasks	Sources	Univariate				
		df	Mean square	F	Significance	η2
GNGT	Accuracy Go	1	.20	4.80	**.03**	.05
	Inhibition accuracy NoGo	1	.05	5.64	**.02**	.06
	Speed index (Time)	1	.06	1.12	.29	.01
ST	Accuracy incongruent	1	96.650	1.134	.29	.015
	ABI	1	46414.18	0.17	.68	.002
CTT	Circle tracing time (Sec)	1	223424.067	13.56	**.001**	.15

Note. Significant results are highlighted (p ≤ .05) in bold. ADHD: attention-deficit hyperactivity disorder, GNGT: Go/No-Go Task, ST: Stroop task, CTT: Circle Tracing Task.

4. Discussion

A large body of evidence has indicated that impairment of IC is the core deficit of ADHD [e.g., 13, 10, 23, 16, 1, 25, 28, 21, 29, 30, 20]. Therefore according to some etiological models proposed for ADHD as a control function disorder, children with ADHD symptoms are expected to have poorer performance than children with typical development in IC. While inhibition is defined as the ability to inhibit a dominant response or the process of suppressing an inappropriate behavior, the concept of inhibition is considered a construct with different domains [31, 4]. Multiple aspects of inhibition include perceptual inhibition or AI, cognitive inhibition or RI, and motor inhibition or MI [3, 5]. The findings suggest that ADHD patients may have deficits in some domains of inhibition compared to their TD peers, while there are not in other domains. In the present study, the performance of children with ADHD symptoms relative to TD children in different domains of inhibition is evaluated by tasks designed in specific paradigms. Stroop as a perceptual inhibition task, go nogo as a cognitive inhibition task, and Circle tracing task as an inhibition task with a strong motor component are used to assess AI, RI, and MI respectively.

Reaction time and accuracy are two important indices of IC tasks. However, no between-group differences were observed on some IC measures, Consistent with the previous studies, children with ADHD symptoms demonstrated slower reaction times, made more errors, were slower to inhibit responses, and were more variable than children without ADHD symptoms in the time it took them to respond and generally performed poorer than TD children in all behavioral inhibition tasks [e.g., 10, 23, 16, 1, 28-30, 20].

Regarding the between-group differences in MANCOVA's analysis of GNGT and CTT, the different performances of two groups of children with and without ADHD symptoms were significant in two domains of IC such as RI (prepotent response inhibition) and MI (ongoing response inhibition). The results are in line with meta-analytic studies that reported impairment of ADHD patients in prepotent response inhibition and inhibitory motor control [e.g., 12, 6, 13, 1, 14, 15].

The lack of between-group differences on ST, although consistent with some meta-analytic studies that reported a lack of interference control in ADHD children based on studies using Stroop tests [e.g., 17, 11], is inconsistent with the findings of some other studies [e.g., 10, 16]. The lack of group differences in ST can be explained by the useful age range of each task. In the spatial Stroop test, the automatic response of the location in which arrows appeared has to be suppressed and prevented from interfering with the direction of arrows. The task demand of this version of Stroop is spatial conflict. The Spatial Stroop tests have been used for measuring perceptual inhibition. Paterson (2016) pointed out that perceptual inhibition develops earlier than other domains of IC so, in the evaluation of perceptual aspects of IC, the Stroop tasks showed the youngest useful age range, While studies have shown that fundamental IC changes occur at the age of 6-15 years and school age has been proposed as an important period in the development of inhibition [18, 24, 25], some studies revealed different developmental trajectories for different domains of IC [19, 3]. The development of perceptual inhibition occurs at younger ages and the development of motivational inhibition appears at older ages [3]. For example, a meta-analysis study pointed out that the greatest improvement in prepotent response inhibition is observed after the age of 5 years [18] while Children's performance on tasks in the Stroop paradigm is improved in the preschool period [24, 3, 30, 20]. In other studies, different developmental pathways have been observed for different forms of control functions in normal children [19]. one explanation could be that the spatial Stroop task is designed to assess the perceptual inhibition, which developed at earlier ages relative to other domains of IC so for studying interference control deficits in ADHD patients, this paradigm may not be specific enough to differentiate school-aged children with and without ADHD symptoms.

Another considerable reason for the lack of group differences on ST can be related to the sample selection and the absence of a group with a diagnosis of ADHD. As mentioned, in the present study, two groups of children with and without ADHD symptoms were selected from school-aged students. Previous studies have shown that deficits in cognitive functions have a high relationship with the severity of ADHD symptoms [32], Therefore, in studies comparing groups are children with and without ADHD symptoms, the difference in ST may not be obvious.

It should be mentioned that measuring multiple aspects of IC simultaneously using a set of inhibition tasks designed for evaluation of three main domains of IC (AI, RI, MI) in two groups of children with and without ADHD symptoms and control of two of variables age, gender and some confounding variables by statistical control or matching individuals in two groups are some of the strengths of the present study. The importance of studying IC at school age is another strength, because not only the age after 5 years, is an important period of change for many cognitive components [4] but also by ignoring this period the developmental profile of cognitive functions is incomplete. the effects of IC deficits in school age are more visible too. The study of IC in primary school age is also important methodologically. For example, school-aged children show fewer problems with understanding instructions and they are less likely to feel fatigued and some common executive problems in comparison with preschoolers.

4.1 **Limitations And Future Directions**

This study was a primary attempt towards enhancing our understanding of impairment in multiple domains of IC in school-aged children with ADHD symptoms. In general, it seems that in addition to methodological considerations and the importance of selection and characteristics of the sample groups in evaluating IC construct, task selection can play an important role in showing between-group differences. Petersen et al. (2016) argued that the same task may not reflect the same construct at different ages. longitudinal studies are suggested to be used in future studies to investigate the developmental effects on ADHD children in order to reduce the problem of the validity of using a simple task designed for younger children, which may not be specific enough to evaluate the function of older children. Also, the selection of a group with a certain diagnosis of ADHD with a larger sample size can lead to more reliable and generalizable findings which were all limitations of the present study.

5. Conclusion

We can conclude that our study supported the hypothesis that Children with ADHD exhibited deficits in some domains of inhibition but not in other domains, they have impaired performance in RI and MI, however, no deficit was found in AI.

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