Inhibitory control training improves ADHD symptoms and externalizing behavior

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Abstract

Background: The majority of cognitive and behavioral deficits in children with attention deficit- hyperactivity disorder (ADHD) originate from impaired inhibitory control. **Methods:** In the present study, thirty preschoolers with ADHD were recruited in a random clinical trial design in two equal control and intervention groups. The Color-Word Stroop test, Go/No- Go task, Swanson, Nolan, and Pelham Rating Scale, and Child Behavior Checklist were used for assessment at baseline, after intervention, and at one- month follow- up sessions. The program for attentive rehabilitation of inhibition and selective attention (PARISA) was used for intervention in 12-15 sessions. **Results:** The data demonstrate improvement in prepotent inhibition and interference control in the intervention group. Furthermore, the hyperactivity/ impulsivity symptoms were ameliorated and the externalizing behavioral problem were improved after intervention. **Conclusion:** Inhibitory control in preschoolers with ADHD is trainable and the benefit of training could be transferred to ADHD symptoms and externalizing behavior.

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Background

Attention deficit- hyperactivity disorder (ADHD) is characterized by two main classes of symptoms including inattentiveness and impulsivity- hyperactivity, and can result in significant impairments in social and academic functioning [1]. At the cognitive level, several cognitive theories have been developed to explain these behavioral symptoms. Impaired executive functions (EFs) is a well- documented cognitive theory in ADHD [2-4]. EF is an umbrella term that covers a range of cognitive functions with different levels of overlap and interactions. Thus, different definitions consider a variety of domains to explore EFs. For instance, Delis et al [5] considered EFs as flexibility of thinking, inhibition, problem-solving, planning, impulse control, concept formation, abstract thinking, and creativity[5]. Differently, Goldstein et al defined the domains of EFs as planning, working memory, attention, inhibition, self-monitoring, self- regulation, and initiation [6]. Furthermore, McCloskey and Perkins (2013) have defined over 30 domains for EFs based on their theoretical frameworks [7].

The variety of EF domains from model to model makes it difficult to target them for assessment and intervention. In such a complex construct, given the interwoven nature of EFs, determination of *core* and *basic* domain(s) would be helpful. The core domains refer to those domains that have the maximum of overlap with the others, connect the others together, and allow them to interact with each other. The basic domain has a primacy to the others in the flow of information processing, which is fundamental for the formation of other complex domains.

Diamond (2006) describes core EFs as inhibitory control, cognitive flexibility, and working memory [8]. Given these three main domains, inhibitory control is more basic than the others. Cognitive flexibility, shifting between sets, requires inhibition of the current set of information, disengagement, and engagement with the other set [9]. Similarly, working memory requires inhibition to exclude redundant and irrelevant information from its limited capacity and to update the limited capacity with more relevant information [10-12]. Impaired inhibitory control has been found in ADHD [2, 3], reading disability [13], arithmetic problems [14], and post traumatic stress disorder [15].

Inhibitory control refers to the ability to inhibit or withhold a dominant and/ or inappropriate response to execute an appropriate and/ or effective response in a goal- directed behavior [16, 17]. Intact inhibitory control enables individuals to regulate and manage their behaviors especially in social and emotional circumstances [18].

The centrality of inhibitory control in EFs has been incorporated in the cognitive theories of ADHD. Barkly (1997) states that the impaired inhibitory control is responsible for all impaired cognitive functions and behavioral symptoms in children with ADHD. He has stressed that four main cognitive problems in ADHD, including impaired working memory, self-regulation of affect-motivation-arousal, internalization of speech, and reconstitution (behavioral analysis and synthesis), are rooted in deficient inhibitory control [2]. Accordingly, inhibition sets the stage for the occurrence of the other EFs.

Cognitive rehabilitation is amplification or strengthening of cognitive functions through progressive cognitive tasks and/ or environmental modifications [19]. In cognitive rehabilitation, behavioral problems are broken into their cognitive underpinnings and the impaired cognitive functions are trained to ameliorate respective behavioral symptoms. One important issue in cognitive rehabilitation is the transferability of intervention from lab to life. The different facets of cognitive rehabilitation tasks and daily activity makes its difficult to achieve generalization of the intervention. It is worth mentioning the behavioral problems that arise from impaired cognitive function and the need to target the deficient cognitive functions properly to result in behavioral improvement. Therefore, the lack of transferability of cognitive rehabilitation could be related to improper targeted cognitive function(s) and/ or training program. The transferability, from cognitive function to behavioral symptoms, should be considered as a main criterion for the evaluation of effectiveness of a cognitive rehabilitation program.

Theoretical cognitive models and cognitive rehabilitation have a mutual advantage for each other. On the one hand, the theoretical models direct therapists to target a cognitive domain for assessment and intervention. Cognitive rehabilitation without a theoretical backbone is like a vehicle without a motor. On the other hand, cognitive rehabilitation provides experimental evidence for the interaction of model components.

In the present study, we aimed to improve inhibitory control through cognitive rehabilitation and follow its effect on the amelioration of ADHD symptoms and the improvement of other behavioral problems. We address this question via a hypothesis derived from the inhibitory control theory of ADHD.

Materials And Methods

Participants. Thirty preschoolers (6.23±.32 years old, 26 boys) with ADHD symptoms were recruited in the study and randomly allocated into two equal experimental and control groups. All participants were diagnosed with ADHD by a clinical psychologist, considering DSM- 5 criteria. None of participants has history of head injury, seizure, other neurological and psychiatric disorders, or taking medication. All participants were assessed in 3 sessions, before and after intervention and one- month- follow up. The control group was assessed with a similar time schedule and they were invited to participate in the intervention

program after the follow up assessment as an option. The experimental procedures were approved by the ethics committee for research involving human participants at Raftar Cognitive Neuroscience Research Center. The procedures were in accordance with the ethical standards of the Helsinki Declaration of 1975, as revised in 1983. The concern form was filled by the parents of participants.

Color- word Stroop task. This task has been developed for assessment of interference control and selective attention [20]. A computerized version of the task was used in the present study in which four colors of words appear on the screen and participants are instructed to press a corresponding color key on the keyboard as fast and accurately as possible. The color words and colors were red, green, blue and yellow that appeared in three stages, 50 stimuli in each stage. The three types of trials were as follows: 1) The colors of the words were in black; 2) the colors of the words were congruent with meaning; and 3) the colors of the words were incongruent with meaning in three types of trials in order. The measures obtained were reaction time in three trials and interference bias -that is the subtraction of the reaction time of the third trial from the first trial (Figure 1.a).

GO/No- Go task. This task has been developed to measure prepotent inhibition [21]. In the present study, we used an airplane, 7 × 7 cm in size and black in color, as the go stimulus and participants were instructed to press the arrow key as fast and accurately as possible, considering the direction of the airplane. In 25 out of 100 trials, a beep sound was presented as stop- signal and participants had to withhold the answer in these trials. The measures obtained were accuracy and reaction time of Go stages and accuracy of No- Go stages (Figure 1.b).

Swanson, Nolan, and Pelham Rating Scale (SNAP-IV). The SNAP-IV has been adapted from the DSM-4 for the rating of ADHD symptoms [22]. This scale consists of 18 items on a four-point Likert style scale, nine items score for inattentiveness, six for hyperactivity, and three for impulsiveness. A psychometric study in an Iranian sample found adequate validity and reliability of the scale in this population [23].

The Child Behavior Checklist (CBCL). The CBCL has been developed for rating emotional and behavioral problems in children and adolescents aged 4–18 years by their parents [24]. The scale consists of 118 items with a 3-point scale. The items aggregated into 8 main sub scales including withdrawn, somatic complaints, anxious/depressed, social problems, thought problems, attention problems, **delinquent behavior**, and aggressive behavior. There are two broad scales namely internalizing and externalizing problems. Internalizing problem encompasses anxiety/ depression, withdrawn, and somatic problems. The externalizing problem includes rule-breaking and aggressive behavior. This scale is validated for the Iranian population [25].

Intervention: Program for Attentive Rehabilitation of Inhibition and Selective Attention (PARISA). The PARISA is a cognitive training program for cognitive rehabilitation of inhibitory control [26]. The PARISA includes six computerized progressive tasks namely faces arrangement, fishing, packing, hat placement, traffic control and rabbit and turtle race as explained in table 1. Each task has 10 levels of difficulty that could be selected based on trainee performance. These tasks target three types of inhibitory control for training including interference control, prepotent inhibition, and selective attention.

Procedure. After signing a written informed consent form by parents of participants, children were randomly assigned into the experimental or comparison group. The assessment questionnaires and tests were performed in a counterbalanced order in three sessions. The intervention group received 10- 12 sessions of cognitive rehabilitation through PARISA, lasting 30-45 minutes, three sessions per week for 4-5 weeks. The comparison group was participated in a story-telling class in kindergarten.

Statistical analysis. To compare the baseline performance of the comparison and intervention groups, the Independent Samples T-tests were performed for all variables. To evaluate the effectiveness of the intervention, a series of five 2 × 3 repeated measures multivariate analyses of variance (MANOVAs) were used. Each MANOVA included a between-subject factor of group (intervention vs control), the within-subjects factor of time (baseline, after the intervention and follow up), and the group × time interaction. The interaction is the primary effect of interest, as a significant effect would support the idea that the two groups differ in their degree of change through intervention. The Shapiro-Wilk, Levin, Mauchly, and Bonferroni tests were used to evaluate normality, homogeneity of variance, sphericity, and post- hoc analysis, respectively. A significance level of $p < 0.05$ was used for all statistical comparisons.

Results

Overview. Independent T-tests found the baseline performance of intervention and comparison group were not significantly different for any measures. Tables 1 and 2 summarizes the means and standard deviations and the result of MANOVA test, including F, P- value, and partial eta square, for cognitive and behavioral measures at (I) baseline, (II) after the intervention and (III) follow up assessment sessions. In the following section, we briefly review the results of the study in two sections, referring to the effect of the intervention on inhibitory control tasks and behavioral rating scales.

Effect of training on inhibitory control

The repeated measures 3x2 MANOVA was performed for measures of Stroop task (black ink, congruent ink, incongruent ink) and found a significant main effect for the time for the first and third trials and selective attention index. The group (treatment, comparison) × time (pre-treatment, post-treatment, follow-up) interaction was significant for the first trial and selective attention index. The second stage has a non- significant effect at the level of group (treatment, comparison), time (pre-treatment, post-treatment, follow-up), and their interaction. Bonferroni Post- hoc analysis found the difference between significant measures was related to the difference between the first and second assessment (before and after intervention sessions).

For the measures of the Go/No- Go task, a 2x3 MANOVA test found a significant main effect for No-Go- accuracy at the levels of group (treatment, comparison), time (pre-treatment, post-treatment, comparison), and group × time interaction. Furthermore, a significant effect of Go reaction time at the levels of group (treatment, comparison) and group (treatment, comparison) × time (pre-treatment, post-treatment, follow-up) interaction. The accuracy of the Go stage was non- significant at all levels. Post- hoc analysis found the difference between significant measures was related to the difference between before and after intervention sessions.

Table1: The results of inhibitory control tasks

Assessment sessions /	Intervention Group, M (SD)	Control Group, M (SD)	MANOVA Results, F, Sig, η^2	I	II	III	Group	Time	Group*Time
Stroop Task									
RT ₁ (ms)	2692(666)	2563(776)	2103(802)	2034(451)	2200(560)	2849(627)	21.26**, .460	6.66**, .210	1
RT ₂ (ms)	1837(362)	2243(454)	2456(462)	1735(367)	2034(684)	2395(603)	5.84, .189	1.40, .053	3
RT ₃ (ms)	1789 (571)	1993 (316)	2169 (375)	1823 (275)	2007 (319)	2536 (620)	4.91, .615	5.21**, .173	1
SAI (RT ₃ /RT ₁)	.77(.41)	1.37(.33)	1.37(.73)	1.45(.40)	1.41(.35)	1.38(.23)	3.77, .131	5.54**, .181	5
Go/ No-Go Task									
Go accuracy	77.67(16.47)	74.66(20.47)	78.57(13.36)	70.11(15.29)	74.67(17.63)	75.96(14.34)	.478, .623	.568, .022	4
Go RT (ms)	1366 (125)	1345 (158)	1342 (148)	1449 (185)	1273 (173)	1357 (180)	4.83*, .182	2.99*, .107	2
No-go accuracy	82.96(10.08)	85.98(9.96)	90.93(8.48)	86.39(12.62)	80.47(11.69)	94.97(5.05)	8.488**, .253	2.20, .081	4

Abbreviation: M: mean, SD: standard deviation, MANOVA: mixed analysis of variance, F: F-ratio, Sig: significance at the level of .05 (*) or 0.1 (**), I: base line assessment session, II: the second/ after intervention assessment session, III: the third/ follow up assessment session, RT₁₋₃: the reaction time of first to third stages of Stroop test, ms: millisecond, SAI: selective attention index.

Effect of training on behavioral symptoms

To measure the effect of training on behavior, an ADHD rating scale and a behavioral rating scale were used to evaluate any symptom amelioration and change in general behavioral performance. The univariate tests for the 3x2 MANOVA showed a significant main effect of time (pretreatment, post-treatment, follow-up), group (treatment, comparison) and interaction of time and group for the hyperactivity subscale and the total score of SNAP-IV. The subscale of attention disorder on the SNAP-IV showed a non-significant effect at all levels of time, group, and group × time interaction. Post-hoc analysis found the difference between significant measures was related to both the difference between baseline and follow up assessment sessions and differences between the second and third assessment sessions.

The 2x3 MANOVA found a significant main effect for group (treatment, comparison), time (pre-treatment, post-treatment, follow-up), and the group × time interaction for total score of CBCL and some subscales including anxious/depressed, attention problems, [delinquent behavior](#), aggressive behavior, and externalizing problems. Bonferroni post-hoc analysis found the difference between significant measures was related to the difference between before and after intervention sessions, and differences between the baseline (first) and follow up (third) assessment sessions.

Table 2: The results of behavioral rating scales

Assessment sessions /	Intervention Group, M (SD).	Control Group, M (SD).	MANOVA Results, F _(p2) , Sig.						
Measures	I	II	III	I	II	III	Group	Time	Group
SNAP-IV									
Attention Deficit		1.25(.45)	1.15(.43)	1.01(.50)	1.17(.49)	1.19(.33)	1.22(.34)	.52, .210	1.22,
Hyperactivity		1.54(.60)	1.54(.60)	1.04(.47)	1.51(.38)	1.51(.38)	1.45(.42)	10.51**, .296	6.27**
Attention Deficit-hyperactivity		1.39(.25)	1.34(.22)	1.03(.39)	1.34(.22)	1.35(.25)	1.33(.29)	6.49**, .206	5.66**
CBCL									
Anxious/Depressed		63.14(6.92)	62.07(7.87)	56.93(10.00)	57.08(9.59)	58.54(10.86)	56.38(7.96)	3.41*, .120	1.54,
Withdrawn		55.14(7.41)	52.07(7.90)	51.43(9.78)	53.92(7.38)	52.77(7.13)	50.23(8.22)	3.92*, .623	.34, .0
Somatic Complaints		59.36(11.46)	57.50(9.84)	58.36(12.84)	55.38(11.26)	56.23(11.89)	56.08(10.80)	.65, .003	.45, .0
Social Problems		62.71(8.35)	57.79(8.47)	60.00(9.40)	58.15(7.78)	59.23(9.47)	60.85(6.10)	1.08, .041	2.40,
Thought Problems		63.86(9.57)	59.64(11.06)	62.00(10.93)	59.92(9.63)	58.77(9.32)	57.46(10.66)	1.64, .062	.78, .0
Attention Problems		76.71(3.04)	62.86(9.55)	61.14(9.92)	72.69(3.70)	74.77(4.72)	74.92(5.57)	16.63**, .40	29.93, .545
Rule-breaking Behavior		74.93(6.75)	66.50(11.27)	69.79(10.49)	71.08(9.13)	71.62(7.85)	71.92(6.99)	4.26*, .146	5.70**
Aggressive Behavior		74.57(8.89)	62.14(11.25)	61.50(12.31)	70.46(8.98)	71.38(8.85)	67.23(8.47)	11.34*, .312	7.74**
Internalizing Problems		62.36(7.30)	6.07(7.00)	59.29(7.58)	57.69(9.24)	58.31(9.97)	56.31(8.03)	1.97, .073	.82, .3
Externalizing Problems		74.93(5.06)	63.64(10.09)	65.07(9.13)	71.23(7.61)	72.00(6.69)	70.85(6.89)	11.78**, .320	13.12, .346
CBCL- Total Scores		71.64(8.51)	63.79(8.78)	63.71(7.61)	68.38(7.35)	69.62(7.50)	67.77(7.00)	9.23**, .270	10.66, .299

Abbreviation: M: mean, SD: standard deviation, MANOVA: mixed analysis of variance, F: F- ratio, Sig: significant at the level of .05 (*) or 0.1 (**), I: base line assessment session, II: the second/ after intervention assessment session, III: the third/ follow up assessment session, CBCL: child behavior checklist, SNAP-IV: Swanson, Nolan, and Pelham rating scale.

Discussion

The results found that PARISA improves interference control and prepotent inhibitory control in children with ADHD. Furthermore, the improvement of inhibitory control leads to amelioration of ADHD symptoms, especially on the hyperactivity subscale. In addition, some domains of the behavioral checklist including rule- breaking and aggressive behavior, attention problem, and externalizing problems showed improvement. The improved domains were maintained at least one month until the follow- up assessment.

Trainability of inhibitory control

The present study found improvement in inhibitory control in children with ADHD through PARISA. The enhancement of inhibitory control in typically developing preschoolers through PARISA has been found earlier [26]. Inhibitory control has also been found to be a trainable cognitive function based on meta- analysis study [27]. Also, inhibitory control has also been trained successfully in preschoolers [28]. An electrophysiological study suggested that inhibitory control training modulates the inhibitory control- related neural underpinnings in a sample of preschoolers [29]. In terms of the specific technique, there are several training programs that have been used for inhibitory control training [30-32]. In fact, just a progressive task in stop- signalling improved inhibitory control [33] A program that includes increasing the difficulty of the task is an important factor for cognitive training, and the variety of stimuli and task paradigms is a crucial factor for transfer of cognitive training gain to untrained domains. Indeed, without various progressive tasks, the improvement in cognitive training is the effect of task repetition without any transferability [34].

Amelioration of ADHD symptoms through inhibitory control training

The current study found some amelioration of ADHD symptoms, especially in the hyperactivity/ impulsivity domain, after inhibitory control training. This result confirms the pivotal role of inhibitory control in ADHD symptoms. This finding suggests a causal relationship between ADHD symptoms and inhibitory control in line with Barkley's theory of ADHD that states ADHD is underpinned by deficient inhibitory control in preschoolers [2]. Similarly, a regression study in preschoolers found that inhibitory control, rather than other EFs, was associated with ADHD symptoms [35]. Notably, twenty- six out of thirty participants in our study were boys and the stronger relation between inhibition and ADHD symptoms has been found in boys [36].

Transferability of inhibitory control training

The improvement of externalizing problems after inhibitory control training in the present study found that these behavioral problems originated from deficient inhibitory control. Correlational studies have previously found a reciprocal relationship between externalizing behavior and inhibitory control in both kindergarteners [37, 38] and schoolers [39]. There is an association between externalizing behavior and ADHD symptoms and their emotional functioning [40-43]. In addition, some interventional studies found a positive impact of inhibitory control training on the improvement of externalizing behavior in preschoolers [44]. Consistent with this, there was also a significant improvement in aggressive behavior subscale after inhibitory control training in our study. In line with this finding, aggression has been reduced through self- control training in aggressive individuals [45]. It is worth mentioning that other interventional programs without an emphasis on inhibitory control, such as Promoting Alternative Thinking Strategies (PATHS) and Positive Parenting Program (Triple-P) have not found a significant impact on children externalizing behavior [46].

Conclusion

The present study showed that inhibitory control training effect transfers to the behavior, externalizing problems and hyperactivity symptoms. Transferability could be considered as a crucial indicator of cognitive rehabilitation programs [47]. Some studies found the transfer of inhibitory control training to gains to other cognitive domains such as problem solving and working memory, without considerable transfer to other inhibitory control tasks [48]. Considering the new conceptualization of transfer as both vertical and horizontal transfer that consider transfer to the other cognitive domains as horizontal and transfer to the behavior as vertical [47], all of the cognitive domains that were evaluated in Aydmune's study fall into the horizontal transfer category. Although we can consider the horizontal transfer as an index of effectiveness of training, the main factor that guarantees the generalization of intervention from lab to life is the vertical transfer, from cognitive function to behavior. Some investigators found no transfer effect from inhibitory training to some behaviors such as eating behavior [49]. However, the transferability of computerized inhibitory control training has been found to some behavioral skills such as self- regulation [50], appetitive behaviors [51], health- related behaviors [52], and academic performance [53].

Some limitations should be taken into account in the present study. The comparison group in the present study receives the usual kindergarten program. It would be better if we had an alternative intervention for the control group. Furthermore, a longer follow- up assessment could be considered for future studies.

Declarations

Ethical Considerations. All procedures performed in studies involving human participants were in accordance with the ethical standard of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. The procedure approved by ethical committee of Raftar cognitive neuroscience research center.

Availability of data and material. Data of the study are available for researcher on request through email to the author.

Competing interests. The author declares that they have no competing interests.

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Authors' contributions. V.N. conceptualized and designed the study, analyzed the data, and wrote the manuscript and. FF gathered the data. S.R. critically revised the manuscript.

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Figures

Figure 1

Shown are schematic figures of tasks conducted in the study. (a) three stages of Stroop task and (b) Go/No-Go task.