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Original Article

The effectiveness of cognitive rehabilitation of inhibitory control, transcranial direct current stimulation and combination of inhibitory control and transcranial direct current stimulation on inhibitory control and working memory in children with attention deficit disorder/hyperactivity

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Abstract

Inhibitory cognitive rehabilitation and Transcranial Direct Current Stimulation can be therapeutic alternatives to stimulant drugs in attention deficit/hyperactivity disorder, and there is evidence of their effectiveness in improving cognitive function and clinical symptoms. The aim of this study was to compare the effectiveness of cognitive rehabilitation of inhibitory control, transcranial direct current stimulation and the combination of inhibitory control rehabilitation and transcranial direct current stimulation on inhibitory control and working memory of children with attention deficit hyperactivity disorder. The method of the present study is quasi-experimental with an unbalanced control group design. The quasi-experimental design of the present study was pre-test-post-test and follow-up (2 months) with the control group. The population included all those with ADHD disorder in Arak in the academic year of 2019-2020. The sample consisted of 60 students in the age range of 8 -12 in Arak who referred to counseling centers and student psychological services and answered the Swanson Attention Deficit Hyperactivity Disorder Questionnaire. The students were assigned to experimental and control groups (15 individuals in each group). To collect the data, Swanson et al.'s Attention Deficit Hyperactivity Disorder Questionnaire, N-Back Kirchner test and Stroop computer test were used. The experimental group received a rescue inhibitory cognitive rehabilitation program, and transcranial direct current stimulation and a combination of these programs over the F4 points. The data were analyzed using SPSS.26 software and mixed covariance analysis with repeated measures. The results showed that inhibitory cognitive rehabilitation, Transcranial Direct Current Stimulation and combination of inhibitory cognitive rehabilitation of Transcranial Direct Current Stimulation are effective on the components of inhibitory control and working memory ($p \geq 0.001$). The results of Bonferroni post hoc tests showed that there is a significant difference between inhibitory control and working memory of experimental and control groups ($p \geq 0.01$). It can be concluded that inhibitory cognitive rehabilitation, Transcranial Direct Current Stimulation and a combination of the two can be used as a single treatment or along with other psychological therapies for children with ADHD.

Keywords

Cognitive rehabilitation of inhibitory control
Hybrid treatment
Transcranial Direct Current Stimulation
inhibitory control
Working memory
Attention deficit/hyperactivity disorder

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Introduction

Psychiatric disorders are very complex due to their genetic, biological and psychological nature and cause problems in the behavior, feelings and cognition of the sufferer in the context of a particular culture (Müller, Vetsch, Pershin, Candrian, Baschera, Kropotov, & Eich, 2019). Behavioral disorders and maladaptation in adulthood and adolescence often result from ignoring emotional-behavioral issues of children, which is one of the most complex childhood disorders that is often undiagnosed. Hyperactivity disorder is associated with attention deficit disorder that manifests itself with inattention and hyperactivity in the age range of six months to seven years and may continue to adulthood (Ahmed, Darwish, & Khalifa, 2022).

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Attention Deficit Hyperactivity Disorder is one of the most common childhood and adolescent psychiatric disorders characterized by persistent symptoms of inattention, impulsivity, and inactivity (Maoz, Gvirts, Sheffer, & Bloch, 2019). The Fifth Edition of the American Psychiatric Association's Diagnostic and Statistical Manual distinguishes three subtypes of Attention Deficit / Hyperactivity Disorder: Type of Attention Deficit 2. Hyperactivity Disorder and Impulsive type 3. Hybrid type (Symptoms of Attention Deficit Hyperactivity Disorder) (Mueller, Tucha, Koerts, Groen, Lange, & Tucha , 2014). Nowadays, the dimensional approach used in the American Psychiatric Association's Diagnostic and Statistical Manual for Classifying Attention Deficit / Hyperactivity Disorder subtypes is questionable. Studies show that these subtypes are not only homogeneous (Elia, Arcos-Burgos, Bolton, Ambrosini, Berrettini, & Muenke , 2009; Rubia, Westwood, Aggensteiner, & Brandeis, 2021), but also the diagnostic signs of this disorder are incremental phenomenon that change over time (Larsson, Dilshad, Lichtenstein, & Barker, 2011). For example, the Attention Deficit Hyperactivity Disorder subgroup may include children who previously assessed the criteria for hyperactivity-impulsivity or hybrid type, but now have no symptoms of hyperactivity-impulsivity (Larson et al., 2011). The prevalence of this disorder in the world is 9% and in Iran is 3.5 to 4.9%. However, lifelong presentation and response to treatment of its symptoms is very heterogeneous and is associated with a set of physical and psychological complications (Shahwan, Suliman, & Jairoun, 2020). Children with Attention Deficit / Hyperactivity Disorder may experience disorders such as low cognitive abilities, poor social skills, behavioral concerns, and poor comprehension compared to their peers (Wilcox, 2017). Many people with Attention Deficit / Hyperactivity Disorder have significant problems in a wide range of contexts and dimensions, especially those who classified in the subgroup of inattention (Chambers, 2016). Neurocognitive disorders are thought to be a major part of the symptoms of this disorder. Neurological disorders such as Attention Deficit Disorder, Executive Functions (EF), Working Memory (Tarle, Alderson, Arrington, & Roberts, 2021) and Self-Regulation (Shaw, Stringaris, Nigg, & Leibenluft, 2014; Tarle et al., 2021) are mostly reported in people with Attention Deficit / Hyperactivity Disorder (Luo, Weibman, Halperin, & Li, 2019). Children with Attention Deficit / Hyperactivity Disorder have less capacity for sustained attention than their peers. Also, different studies have reported deficits in inhibitory control, cosustained and selective attention in children with this disorder (Bennett, 2018). Although executive functions are defined in a variety of ways, there is a general agreement that these functions are a type of cognitive process that serves ongoing and goal-oriented behaviors (Barkley, 2011). Executive functions can in fact be considered as actions that a person performs in order to self-regulate and regulate cognitive output (Madani, Alizadeh, Farrokhi and Hakimi Rad, 1396; Jahangiri, Alizadeh, Pezeshk & Farrokhi, 2021). Research has also shown that the frontal cortex, using working memory, directs the behavior and attention of an individual by the use of relevant information to deter inappropriate behaviors, thoughts and feelings. These processes form the basis of what is now referred as executive function, which includes attention regulation, planning, impulse control, mental flexibility, and the initiation and monitoring of behavior (Doebel, 2020). Barkley believes that executive functions provide a tool for behavior control, self-organization, self-regulation, foresight, and time management (Barkley, 2011. Castellanos, Kronenberger, & Pisoni, 2018). Damage to these functions causes the child to live in the present moment (Barkley, 2013, Roselló, Berenguer, Baixauli, Mira, Martinez-Raga, & Miranda, 2020) and it has a detrimental and destructive effect on his ability to manage daily affairs through which a person prepares himself for the near and distant future (Barkley, 2011; Jahangiri et al., 2021).

Findings of Lou et al. (2019) have shown that in children with attention deficit hyperactivity disorder, abnormal functioning of working memory may be associated with attention deficit and inhibitory control. Due to the adverse effects of these deficits in children with attention deficit hyperactivity disorder, educational-cognitive interventions have recently been considered for rehabilitation in the areas of working memory, attention and response inhibition. Cognitive rehabilitation treatment is an approach to increase the abilities and executive functions of the child with attention deficit hyperactivity disorder in the areas of attention, memory, inhibition and organization, planning and decision making and so on. Cognitive rehabilitation used to treat and rehabilitate cognitive disorders, provides medical services to strengthen damaged areas or to replace new patterns of disorder compensation (Tajik-Parvinchi, Wright, & Schachar, 2014). Cognitive rehabilitation includes a set of programs to train the brain that lead to improved mental and neurological function in a person, resulting in personal development in areas such as education, employment, and social relationships (Owen, Hampshire & Grahn, 2010).

Lambez, Harwood-Gross, Golumbic, & Rassovsky (2020) concluded that in attention deficit hyperactivity disorder, computer-based cognitive educational intervention had positive effects on working memory, attention and response inhibition. Renou & Doyen (2019) conducted a study entitled Cognitive Rehabilitation with Neuropsychological Education (NEAR) approach in adolescents with Attention Deficit / Hyperactivity Disorder and Autism Spectrum Disorder. Interventions were performed on executive functions such as memory, attention, visual-spatial abilities and metacognitive dimensions. The results showed that this program is adaptable and applicable for children and adolescents in the target group and has a significant effect on the improvement of memory, attention and planning. Nejati (2020) in a study aimed at cognitive rehabilitation in children with attention deficit hyperactivity disorder and possibility of transferring to the field of cognition and behavior concluded that cognitive rehabilitation with effect on inhibitory control had a successful role and reduced risky decision-making and delayed response.

Attention and working memory training also reduced response time and delay.
However, newer therapies tend to be non-invasive and mild in certain areas of the brain, including trans-cortical electrical stimulation therapies such as Transcranial Pulse Current Stimulation (tPCS), Transcranial Direct Current Stimulation (tDCS), Transcranial Random Noise Stimulation (tRNS) and Transcranial Alternate Current Stimulation (tACS). Transcranial Direct Current Stimulation of brain is a non-invasive tool to modulate cortical irritability (Chase, Boudewyn, Carter, & Phillips, 2020). To perform this stimulation, a very weak current is established in the cerebral cortex and this current flows through two conductive rubber electrodes with sponges soaked in saline solution or impregnated with conductive gel (Stagg and Nietzsche, 2011). Modulation of cortical irritability depends on the polarity of the electrodes. Typically, a anode polarity increases the irritability of the cerebral cortex, while a cathode portion, reduces this irritability. This modification is due to the change in the potential of the resting membrane in the areas of the cerebral cortex where current flows (Stagg and Nietzsche, 2011. D'Urso et al., 2017). Breitling et al (2016) in a study entitled Improving Intervention Control Using Transcranial Direct Current Stimulation in Patients with Attention Deficit / Hyperactivity Disorder, examined the true effect of this treatment on 42 patients. The results of their study showed that tDCS treatment compared to the experimental group had a significant effect on improving intervention control in patients with attention deficit / hyperactivity disorder.

Westwood, Radua, & Rubia (2021) in systematic and meta-analysis review of non-invasive brain stimulation in children and adults with attention deficit / hyperactivity disorder found that Transcranial Direct Current Stimulation improved some executive functions in ADHD. The results of 1 to 5 sessions of meta-analysis showed that Transcranial Direct Current Stimulation was effective on the activity of the prefrontal cortex, especially at the level of inhibition and processing speed. But in attention problems, it was not effective enough. In another study by Lipka, Ahlers, Reed, Karstens, Nguyen, Bajbouj, & Kadosh (2020) regarding the elimination of heterogeneity due to Transcranial Direct Current Stimulation for attention deficit hyperactivity disorder, it was concluded that heterogeneity in the protocols used in Transcranial Direct Current Stimulation and patients' profiles in response to the effect of Transcranial Direct Current Stimulation can affect its effectiveness. Overall, the results of this study supported the effectiveness of Transcranial Direct Current Stimulation on attention deficit hyperactivity disorder.

Overall, due to the fact that a wide range of cognitive and psychiatric research has examined the effectiveness of various therapies to improve the symptoms of this disorder and inconsistent findings have been obtained in this regard; research needs to be done to determine which of the current scientific developments can be one of the most effective treatments for people with ADHD disorder. On the other hand, in explaining the necessity of the present study, it is worth mentioning that due to the deficiency of executive function components in children with attention deficit hyperactivity disorder and due to the contradictory results of the research background and due to the importance of non-pharmacological and non-invasive methods to solve the problem of children with attention deficit hyperactivity disorder, the need for research was felt. On the other hand, the research gap in the country on this issue was felt in such a way that one by one the main components of executive functions were examined with pre-test, post-test and follow-up methods. Therefore, this study seeks to answer the question whether there is a difference between cognitive rehabilitation of inhibitory control, Transcranial Direct Current Stimulation and the combination of inhibitory control rehabilitation and Transcranial Direct Current Stimulation in terms of effectiveness on inhibitory control and working memory of children with attention deficit hyperactivity disorder?

Method

Participants

The method of the present study is quasi-experimental with an unbalanced control group design. The quasi-experimental design of the present study was pre-test-post-test and follow-up (2 months) design with control group. The population included all students with ADHD in Arak, in the academic year of 2019-2020. Initially, district 2 was selected between the two departments of education of Arak, using one-stage random cluster sampling method, and from all children aged 8 to 12 years with a diagnosis of ADHD within the first trimester academic year 2019-2020 referred to the counseling and psychological services center of District 2 of Arak city (counseling center). SNAP-IV Rating Scale (1980) was administered. Among them, 60 people with purposive sampling method who had the highest score were chosen. Using purposive sampling method with random replacement, 15 individuals entered the cognitive inhibition rehabilitation program, 15 individuals entered the electrical brain stimulation program, 15 individuals entered the hybrid program (cognitive inhibitory rehabilitation and electrical brain stimulation) and 15 individuals entered the control group.

Instrument

Self-Report Persian Form of SNAP-IV Rating Scale):

The Attention Deficit Hyperactivity Disorder (SNAP-IV) Questionnaire was designed and developed by Swanson, Nolan, and Pelham (1980) to assess Attention Deficit Hyperactivity Disorder in children and is completed by the child's parent or teacher. This questionnaire has 18 questions and 2 components and assesses attention deficit hyperactivity disorder in children. The first 9 questions are related to the diagnosis of Attention Deficit Disorder (ADD) and the second 9 questions are related to the diagnosis of Attention Deficit Hyperactivity Disorder

(HD), so with the help of this scale, 3 subtypes of the disorder can be diagnosed. Results are rated based on a 4-point Likert scale (never = 0, too low = 1, much = 2, too much = 3). The obtained scores are added together. The minimum possible score will be 0 and the maximum will be 54. A score between 0 and 18 indicates a low level of disorder, a score between 18 and 36 indicates a moderate level of disorder, and a score above 36 indicates a high level of disorder. The criterion validity of the test is 0.48 and according to the factor analysis, this test has 3 factors that explain a total of 0.56 variance. Content validity is also approved by experts. The retest reliability coefficient is 0.82, Cronbach's alpha is 0.90 and the halving coefficient is 0.76. The cut-off point for the whole scale and each of the subscales of attention deficit and hyperactivity are 1.57, 1.45 and 1.9, respectively (Swanson et al., 2001). According to Kiani and Hadianfard (2015), Cronbach's alpha coefficient, Spearman-Brown coefficient and Guttmann halving coefficient were 0.81, 0.81 and 0.80 for the inattention dimension and 0.75, 0.65 and 0.64 for the hyperactivity / impulsivity dimension, respectively.

N-Back test:

This test was first introduced in 1958 by Kirchner. A task of measuring cognitive function is related to executive actions, and since it involves the storage of cognitive information and their manipulation, it is known to be very suitable for measuring the performance of working memory. In this test, a number of visual and auditory stimuli are presented consecutively at a speed of 300 milliseconds on a computer screen, and the subject must compare the stimulus he sees at that moment with the stimulus he saw the previous time. And if any stimulus is similar to the previous one, number one key of the computer and if it is not similar, number two key of the computer should be pressed. The interval between the presentation of each image and the previous one is about 2 seconds. This test uses a set of 32 images that contain meaningless images, and the response time is recorded by a computer. In the 1-back countdown task, the target stimulus is a stimulus that is similar to the new stimulus immediately before it, and the subject must compare the new stimulus with the previous one and must press the key if it matches. In the 2-back countdown task, the most recent stimulus is the target stimulus when the stimulus that appears is similar to the two stimuli before it, and the subject must return mentally to the previous two steps, and if they are the same, he must press the key. In the 3-back countdown task, the target stimulus is a stimulus that is similar to the three stimuli before it, and the subject must compare each stimulus that appears with the three stimuli presented before it and must press the key if it matches. The stimuli used in the n-countdown task can be auditory, visual-spatial, color, shape, number, and so on. In this test, the overall result and reaction time are measured (Chen, Mitra, & Schlaghecken, 2008). Van Leeuwen, Van den Berg, Hoekstra, & Boomsma (2007) reported correlation coefficient of this test 0.20 and its validity was reported as a very acceptable indicator of working memory performance. Khayyer, Nejati and Fathabadi (2014) used convergent validity to determine validity, so that they performed a short-term memory number expansion test on a sample of 62 students and obtained a correlation coefficient of 0.46. The reliability of the N-Back test in this study was 0.76 using Cronbach's alpha method.

Computerized Stroop Test:

The Stroop test (color-word) was first developed in 1935 by Ridley Stroop to measure selective attention and cognitive flexibility. In fact, the Stroop test is not a single test, but so far different forms have been developed for research purposes. This test is used to measure the performance of the forehead, intervention control, executive control and consists of three steps (25 stimuli each step): A) In the first stage, which is the stage of concerted efforts; the names of the four main colors appear in black in the center of the screen, and the child must press one of the blue, red, yellow, or green keys on the keyboard as soon as possible based on the color names. B) In the second step, the names of the four primary colors, each in its own color, appeared in the center of the computer screen, and the child had to press the key corresponding to each color on the keyboard as soon as possible. C) The third stage is the stage of uncoordinated efforts or intervention. The names of the four primary colors each appeared on the screen in a different color from their own, and the child was asked to press the corresponding key on the keyboard as quickly as possible based on the color of the word. The indicators measured by the Stroop test include accuracy (number of correct responses) and speed (average reaction time of correct responses to the stimulus in thousandths of a second). Research on this test indicates its validity and reliability in measuring inhibition in adults and children. Based on Golden's (1987) studies, the reliability and validity of this test were evaluated as 0.81 (by retest method) and 0.74 (by concurrent method with physiological tests), respectively. The reliability of this test has been reported through retesting in the range of 0.80 to 0.91 (Assef, Capovilla, & Capovilla, 2007). In the study of Soltaninejad and Arabzadeh (2019) the reliability of this test for the first cards is 0.88 and for the second and third cards is 0.80.

Program for attentive rehabilitation of inhibition and selective attention (PARISA):

This program is designed based on the method of restorative cognitive rehabilitation by Nejati (2018) and has a structure of 10 sessions (three sessions of 45 minutes per week) and for three types of inhibitory control functions, including intervention or selective attention, inhibition in running, and harnessing previous rewards, has separate computer tasks. Tasks include face sorting, fishing, packing, hat picking, traffic management, and rabbit and turtle racing. Each task has 10 levels and becomes more difficult based on the number of stimuli and task instructions (Nejati, 2018).

Table 1. Cognitive Rehabilitation Group Protocol (Nejati, 2018)

Session	Session content
1st	Practice for face sorting, fishing, packing, hat selection, traffic management and level 1 rabbit and turtle racing
2nd	Practice for face sorting, fishing, packing, hat selection, traffic management and level 2 rabbit and turtle racing
3rd	Practice for face sorting, fishing, packing, hat selection, traffic management and level 3 rabbit and turtle racing
4th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 4 rabbit and turtle racing
5th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 5 rabbit and turtle racing
6th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 6 rabbit and turtle racing
7th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 7 rabbit and turtle racing
8th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 8 rabbit and turtle racing
9th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 9 rabbit and turtle racing
10th	Practice for face sorting, fishing, packing, hat selection, traffic management and level 10 rabbit and turtle racing

Transcranial Direct Current Stimulation device from the skull:

This method is a non-invasive stimulus that in recent decades has made it possible to understand the relationship between the brain and behavior in different ways. In the present study, ActivaDose iontophoresis (ActivaTek, Taiwan) was used to stimulate the brain. The current source of this device is a 9-volt battery with a maximum current of 4 mA and a maximum voltage of 80 volts as DC. Stimulation is provided by placing the anode electrode on the right dorsolateral prefrontal cortex (DLPFC) or point F4. It should be noted that the electric current will be of direct type with an intensity of 1 mA and a duration of 10 minutes for 10 sessions (three sessions per week). One group received stimulation, one group did not stimulate, and one group performed PARISA rehabilitation program at the same time as stimulation. In this way, after 5 minutes of stimulation, the execution time of the program begins and if the stimulation period of 10 minutes ends, the execution of the program continues until its end; because the effects of stimulation last up to two hours after stimulation.

Transcranial Direct Current Stimulation:

The method of stimulation was such that the sponge pad, which is actually considered the coating of the electrodes, was sufficiently moistened with normal saline solution and the electrodes were placed inside it. This reduces the resistance of the electrodes to contact with the head and the person does not feel burning. The anode electrode was placed on the right dorsolateral prefrontal cortex (DLPFC) or point F4 according to the International System of 10-20 and was fixed on the head with a special elastic band. A special EEG cap was used to ensure the correct placement of the electrodes. Direct current was used with intensity of 1 mA and duration of 10 minutes for 10 individual sessions and 3 sessions per week.

Hybrid method of cognitive rehabilitation and Transcranial Direct Current Stimulation:

The intervention in this group was performed as follows: 5 minutes after the application of anodic stimulation at point F4, the time of execution of computer tasks of PARISA inhibitory control rehabilitation program begins and when the duration of 10 minutes of stimulation ends, execution of the program continues until its end; because the effects of stimulation last up to two hours after stimulation. The intervention was performed in 10 individual sessions of 45 minutes and 3 sessions per week. After 10 sessions of intervention with the mentioned protocols, in order to evaluate the effectiveness of the performed interventions, inhibitory control and working memory revalued by the relevant tests including N-BACK and Stroop. Then, 8 weeks after the intervention, in order to follow up the effectiveness and compare the mentioned groups, the subjects were re-evaluated by the above tasks.

Results

In this study, in order to investigate intergroup differences, analysis of covariance of repeated multivariate and univariate factor measures was used, taking into account intragroup (test) and intergroup (group membership) factors. Bonferroni post hoc test is also used for intergroup comparisons. To perform this parametric statistical test, in addition to the spacing of the measurement scale of the variables, confirmation of the hypothesis about normality of the variables distribution (Shapiro-Wilk test results show that the null hypothesis for the normal distribution of scores in the variable dimensions of the Stroop test and its working memory has a normal distribution in three positions of pre-test, post-test, and follow-up of experimental and control groups), homogeneity of variance (Box test for the variable of inhibitory control ($P \geq 0.054$, $F = 1.112$ and BOX = 6868.007) and for working memory variable ($P \geq 0.418$, $F = 1.030$ and BOX = 54.736) was not meaningful. Therefore, the condition of homogeneity of variance / covariance matrices has been properly observed for the variable of dimensions of Stroop accuracy and speed test. Also, based on Levin test and its non-significance for the variables of accuracy and speed of Stroop test in three positions of pre-test, post-test and follow-up, the condition of equality of intergroup variances has been observed. Correlation of dependent variables and Sphericity hypothesis (meaning that there is a moderate and significant relationship between the dimensions of Stroop Test and N-Back working memory and these dimensions can be analyzed in a multivariate model), outlier data (The results of Box-Whisker test showed that outlier data in the upper and lower edge were not observed in the pre-test, post-test and follow-up stages for Stroop and N-Back test, so the assumption of checking the outlier data was correctly observed), linearity (There is a linear relationship between Stroop and N-Back test scores in pre-test and post-test. Therefore, the linearity assumption for the research variables was confirmed using the scatter plot) should be examined. Significant results of Mauchly's test of sphericity were obtained including Mauchly coefficient, its quantity and level for the dimensions of speed and accuracy of Stroop test and N-Back test, correct answer and significant reaction time. It can be stated that the assumption of equality of variances within the subject for the dimensions of speed and accuracy of Stroop test and N-Back test has not been observed. However, this assumption can be ignored because the placement of individuals in the experimental and control groups was random. Therefore, due to the significance of the Mauchly test, the Greenhouse-Geisser test was used to test the hypothesis of the dimensions of speed and accuracy of the Stroop test, which is more conservative with correction in the degrees of freedom of the test compared to the assumed sphericity.

Table 2. Descriptive indicators of Stroop test dimensions (accuracy and speed) in experimental and control groups in three test stages

Variable		Cognitive rehabilitation		Electrical stimulation		hybrid		Control group	
Components	Position	M	SD	M	SD	M	SD	M	SD
Accuracy 1	Pre-test	54.13	6.30	53.93	6.28	53.66	6.74	55.86	6.17
	Post-test	63.13	5.60	67.66	6.87	73.06	4.46	56	7.89
	Follow up	63.60	5.61	68.13	6.94	73.73	4.51	56.20	7.76
Speed 1	Pre-test	113.996	64	11.6216	6.790	109.845	5.314	12.1822	54.14
	Post-test	123.312	5.818	11.1626	8.241	122.267	7.754	12.4123	53.67
	Follow up	123.254	5.069	11.9626	8.321	122.338	7.265	12.5423	53.69
Accuracy 2	Pre-test	53.66	5.51	52.26	6.52	54.73	6.36	54.93	6.60
	Post-test	60.73	5.45	58.33	6.18	62.06	6.75	55.26	6.11
	Follow up	61.33	5.32	58.73	6.08	63	6.46	55.53	6.18
Speed 2	Pre-test	113.922	7.271	11.1626	8.241	111.627	4.387	12.8736	55.76
	Post-test	121.420	6.199	11.8985	7.879	119.426	4.845	12.1037	53.86
	Follow up	121.564	6.979	11.6286	7.639	119.227	4.195	12.3037	53.94
Accuracy 3	Pre-test	51.06	6.18	50.73	6.64	50.13	6.08	51.86	5.85
	Post-test	57.86	5.80	56.26	6.83	57.46	6.59	52.86	6.16
	Follow up	58.40	5.96	56.86	7.20	58.26	6.04	53.20	6.07
Speed 3	Pre-test	114.061	6.294	11.0638	8.070	112.310	47	12.3141	47.68
	Post-test	102.861	6.973	11.7491	7.818	118.635	4.362	12.3342	48.59
	Follow up	120.263	6.133	11.8192	7.188	118.236	4.772	12.3342	48.59
Correct answer	Pre-test	65.06		6.134		62.06		6.263	4.89
	Post-test	70.53		6.868		69.33		6.863	5.92
	Follow up	70.80		6.209		70.06		6.064	5.98
Reaction time	Pre-test	69.331		7.8601		72.262		7.2600	6.676
	Post-test	66.064		6.2678		69.460		6.5397	6.987
	Follow up	6.60064		6.6678		6.20091		6.987	6.5397

The descriptive findings of mean and standard deviation of the Stroop subtests including speed and accuracy and the N-Back test can be seen in Table 2.

Table 3. Results of repeated measures analysis of covariance in the dimensions of inhibitory control test (accuracy and speed of Stroop) and working memory test (N-Back)

Variables	Source of changes	SS	df	MS	F	P	Partial η2	Test power
Accuracy 1	Test	4664.478	*1.050	4442.121	**399.432	P≤0.001	0.877	1
	Group Membership	2826.283	3	942.094	8.614	P≤0.001	0.316	0.991
	Group Membership Test	2040.233	3.150	647.658	58.237	P≤0.001	0.757	1
Speed 1	Test	14341.001	1.004	142831.314	67.333	P≤0.001	0.546	1
	Group Membership	247757.412	3	82585.804	7.803	P≤0.001	0.295	0.984
	Group Membership Test	124487.543	3.012	41328.116	19.483	P≤0.001	0.511	1
Accuracy 2	Test	1208.100	1.339	902.014	624.111	P≤0.001	0.918	1
	Group Membership	597.350	3	199.117	1.786	0.160	0.087	0.440
	Group Membership Test	348.833	4.018	86.818	60.070	P≤0.001	0.763	1
Speed 2	Test	120186.133	1.034	116246.058	636.510	P≤0.001	0.919	1
	Group Membership	143193.997	3	47731.332	3.925	P≤0.05	0.174	0.803
	Group Membership Test	42117.854	3.102	13579.033	74.353	P≤0.001	0.799	1
Accuracy 3	Test	1197.733	1.371	873.840	692.286	P≤0.001	0.925	1
	Group Membership	255.839	3	85.280	0.726	0.541	0.037	0.195
	Group Membership Test	264.044	4.112	64.214	50.871	P≤0.001	0.732	1
Speed 3	Test	83149.479	1.010	82327.636	406.402	P≤0.001	0.879	1
	Group Membership	165920.911	3	55306.970	5.149	P≤0.003	0.126	0.905
	Group Membership Test	27160.058	3.030	8963.870	44.249	P≤0.001	0.703	1
Correct answer	Test	891.144	1.204	740.106	358.965	P≤0.001	0.865	1
	Group Membership	624.950	3	208.317	2.517	P≤0.05	0.120	0.593

	Group Membership Test	255.833	3.612	70.824	34.351	P≤0.001	0.648	1
Reaction time	Test	1788.011	1.023	17481.536	539.475	P≤0.001	0.906	1
	Group Membership	22088.772	3	7362.924	0.387	0.763	0.020	0.122
	Group Membership Test	4844.211	3.069	1578.398	48.709	P≤0.001	0.723	1

* Degrees of freedom are calculated by the software after the necessary correction for the lack of assumption of sphericity.
** Reported F ratio is based on Greenhouse-Geisser index.

The results of analysis of covariances mixed with repeated measures of the effect of time (from post-test to follow-up) on the dimensions of accuracy and speed of the Stroop test are significant. As can be seen, the effect of the group on the accuracy score 1 (P <0.001, F = 8.614 (3 and 56)), speed 1 (P <0.001, 7.803 (3 and 56) F), speed 2 (P <0.05, F = 3.925 (3 and 56) and speed 3 (P <0.001, F (3 and 56) = 5.149) is significant. The effect of time by Greenhouse-Geisser test and by modifying the degrees of freedom of accuracy score 1 (P <0.001, F (1.050 and 58.803) = 2332/239), speed 1 (P <0.001, F (1.004 and 56/227) = 67/333), accuracy 2 (P <0.001, F (1.339 and 753.003) = 604/050), speed 2 (P <0.001, F (1.034 and 57/898) = 636/510), accuracy 3 (P <0.005, F (1.371 and 76.757) = 692.268) and speed 3 (P <0.001, F (1/010 and 56/559) = 406 / 402) is significant. Also, the effect of interaction between time and group by Greenhouse-Geisser test and by modifying the degrees of freedom of accuracy 1 (P <0.001, F (3.150 and 112) = 58.237), speed 1 (P <0.001) , F (3.012 and 112) =19.483), accuracy 2 (P <0.001, F (4.018 and 112) = 60.070), speed 2 (P <0.001, F(3.102 and 112) =74/353), accuracy 3 (P <0.005, F (4.112 and 112) = 50.871) and speed 3 (P <0.001, F(3.030 and 112) =44.249) is significant. Therefore, it can be said that the difference between the mean scores of the dimensions of the accuracy and speed of the Stroop test at different times is different according to the variable levels in the experimental group. As can be seen in Table 3, the effect of intra-subjects (time) also affects the scores of the accuracy and speed dimensions of the Stroop test. Therefore, it can be concluded that regardless of the time of measurement, there is a significant difference between the mean scores of the experimental group in the post-test and follow-up.

As can be seen in Table 3, the effect of group on correct response score (P <0.001, F (3 and 56) = 2.517) is significant. The effect of time by Greenhouse-Geisser test and by modifying the degrees of freedom of the correct response score (P <0.001, F (1.204 and 67.428) = 358.965) and reaction time (P <0.001, F (1.023 and 1856.444) = 539.475) is significant. Also the effect of interaction between time and group by Greenhouse-Geisser test and by correcting the degrees of freedom of correct response (P <0.001, F (3.612 and 112) = 70.824) and reaction time (P <0.001) F (3.069 and 112) = 1578.398) is significant. The effect of intra-subjects (time) also affects the scores of the dimensions of correct answer test and the reaction time. Therefore, it can be concluded that regardless of the time of measurement, there is a significant difference between the mean scores of the experimental group in the post-test and follow-up.

Table 4. Results of Bonferroni test to compare the means of groups in the dimensions of accuracy and speed of Stroop and N-Back test

Variable	Group (I)	Group (J)	Mean difference	SD	P
Accuracy 1	Cognitive rehabilitation	Electrical stimulation	-2.95	2.20	1
	Cognitive rehabilitation	Hybrid	-6.53	2.20	0.05
	Cognitive rehabilitation	Control	4.26	2.20	0.348
	Electrical stimulation	Hybrid	-3.57	2.20	0.661
	Electrical stimulation	Control	7.222	2.20	0.05
	Hybrid	Control	10.800	2.20	0.001
Speed 1	Cognitive rehabilitation	Electrical stimulation	77.94	21.68	0.004
	Cognitive rehabilitation	Hybrid	17.37	21.68	1
	Cognitive rehabilitation	Control	-21.86	21.68	1
	Electrical stimulation	Hybrid	-60.566	21.68	0.05
	Electrical stimulation	Control	-99.80	21.68	0.001
	Hybrid	Control	-39.23	21.68	0.455
Accuracy 2	Cognitive rehabilitation	Electrical stimulation	2.13	2.22	0.455
	Cognitive rehabilitation	Hybrid	-1.35	2.22	1
	Cognitive rehabilitation	Control	3.33	2.22	0.839
	TDCS	Hybrid	-3.488	2.22	0.736
	TDCS	Control	1.200	2.22	1
	Hybrid	Control	4.688	2.22	0.238
Speed 2	Cognitive rehabilitation	TDCS	19.74	23.24	1
	Cognitive rehabilitation	Hybrid	15.54	23.24	1
	Cognitive rehabilitation	Control	-51.12	23.24	0.192
	TDCS	Hybrid	4.200	23.24	1
	TDCS	Control	70.86	23.24	0.05
	Hybrid	Control	-66.66	23.24	0.05
Accuracy 3	Cognitive rehabilitation	TDCS	1.15	2.28	1
	Cognitive rehabilitation	Hybrid	0.488	2.28	1
	Cognitive rehabilitation	Control	3.13	2.28	1
	TDCS	Hybrid	-0.677	2.28	1

	TDCS	Control	1.97	2.28	1
	Hybrid	Control	2.64	2.28	1
Speed 3	Cognitive rehabilitation	TDCS	7.85	21.84	1
	Cognitive rehabilitation	Hybrid	18.006	21.84	1
	Cognitive rehabilitation	Control	-59.92	21.84	0.05
	TDCS	Hybrid	10.14	21.84	1
	TDCS	Control	-67.78	21.84	0.05
	Hybrid	Control	-77.93	21.84	0.004
Correct answer	Cognitive rehabilitation	TDCS	1.400	1.918	1
	Cognitive rehabilitation	Hybrid	1.644	1.918	1
	Cognitive rehabilitation	Control	5.067	1.918	0.05
	TDCS	Hybrid	0.244	1.918	1
	TDCS	Control	3.667	1.918	0.366
	Hybrid	Control	3.422	1.918	0.479
Reaction time	Cognitive rehabilitation	TDCS	-12.93	29.09	1
	Cognitive rehabilitation	Hybrid	-29.97	29.09	1
	Cognitive rehabilitation	Control	-25.11	29.09	1
	TDCS	Hybrid	-15.14	29.09	1
	TDCS	Control	-12.17	29.09	1
	Hybrid	Control	-2.86	29.09	1

The results show that intergroup differences in the dimensions of accuracy 1 between inhibitory cognitive rehabilitation and hybrid therapy, tDCS and control, and hybrid therapy and control are significant ($P \geq 0.01$). There is a significant difference in speed 1 of cognitive rehabilitation and, tDCS and hybrid stimulation, tDCS and control ($P \geq 0.01$). At speed 2, there is a difference between tDCS and control, and hybrid and control ($P \geq 0.01$). At speed 3 there is a significant difference between cognitive rehabilitation, tDCS and hybrid therapy with the control group ($P \geq 0.01$). Also, the results in Table 4 for the N-BacK test show that the intergroup differences are significant only in the correct response between inhibitory cognitive rehabilitation and the control group ($P \geq 0.01$).

Discussion

The aim of this study was to compare the effectiveness of cognitive rehabilitation of inhibitory control, transcranial direct current stimulation and the combination of inhibitory control and transcranial direct current stimulation on executive functions of children with attention deficit hyperactivity disorder. The results showed that cognitive rehabilitation of inhibitory control, transcranial direct current stimulation and the combination of inhibitory control rehabilitation and transcranial direct current stimulation increased the inhibitory control of children in the experimental group compared to the control group, so the first hypothesis of this study is confirmed. These results are in line with the findings of other studies, for example (Lamber et al., 2020; Renault & Devin, 2019; Nejati, 2020; West et al., 2021; Lipka et al., 2020) and accordingly students who have received cognitive rehabilitation inhibitory control, transcranial direct current stimulation, and a combination of rehabilitation inhibitory control and transcranial direct current stimulation programs benefited from higher inhibitory control than their peers.

In explaining these results, it can be said that transcranial direct current stimulation is a non-invasive method that inhibits or stimulates the activity of neurons by creating a magnetic field in the stimulated area and affects the function of neural networks in that area and surrounding areas (Kim et al., 2012). The observed results are in line with previous studies and accordingly repeated transcranial direct current stimulation in the dorsolateral prefrontal cortex has led to improved performance of individuals in the inhibitory control process. The observed improvement supports the hypothesis that the left dorsolateral prefrontal cortex plays an important role in inhibitory control by actively exercising and maintaining attention to task-related stimuli and ignoring non-task-related stimuli (Harrison et al., 2005). Regarding the neural correlations of individuals' performance in Stroop task, recent studies have shown that each of the right and left dorsolateral prefrontal cortex is involved in different aspects of cognitive control function (Vanderhasselt et al., 2009). However, the way that transcranial direct current stimulation affects the functions of biological neurons that lead to cognitive-functional changes in individuals is complex and largely unknown (Guse et al., 2010). However, to explain the research findings, it can be said that these changes are due to the facilitation of the activity of neural networks that support the targeted function or due to the suppression of the activity of neural networks that simultaneously inhibit the targeted function. According to Clark, Kaufman, Trumbo, and Gasparovik (2011), magnetic resonance spectroscopy studies have shown that the transcranial stimulation method of the brain alters the glutamatergic activity of the stimulated areas; therefore, the observed effects can be attributed to changes in glutamatergic activity and, consequently, because of irritability changes in some areas of the forehead that play a role in inhibitory control. Abedanzade and Albogbeish (2016) observed in their study that there is a significant difference between the consistent and inconsistent efforts of the Stroop task in healthy individuals; so that inconsistent stimuli have a longer response time than consistent stimuli. It can be said that people in the inconsistent stimulus position spend more time to analyze or check their response to ensure the accuracy of the answer.

To explain the effectiveness of inhibitory cognitive rehabilitation education, children with attention deficit/ hyperactivity disorder are incapable of controlling their responses and offering it without thinking, which is why these children are defective in the duties that need attention and focus. To explain this recovery, it can be said that the brain always counteracts the injured circuit and that individual's performance improves after the damage, which may occur due to changes in nervous organization in response to damage (Kolb & Wbishaw, 2016; Translated by Ali Pour, Agah Harris, Mansouri Rad and Mohammadi, 2015). The degree of recovery seen in students with attention deficit impairment and extensive brain hyperactivity indicates that changes occur in the nervous system. Sensory inputs and skill practice can affect the flexibility of the brain. Post -traumatic practice i.e. re -learning of mental actions and processes is a vital stimulus to create new or effective performance communication in residual tissue (Ansari & Naghdi, 2013). Studies show that post -cognitive rehabilitation improvement of working memory is due to the flexibility of training in working memory neuronal networks (Klingberg, 2010). In addition to these studies, brain imaging has also shown that grey matter of the Frontoparietal region (Takuchi et al., 2010) and the activities of the prefrontal and parietal areas increase after cognitive rehabilitation (Olesen, Westerberg & Clinberg, 2004). As a result, the Cognitive Rehabilitation Program used in this study due to the nature of practice and repetition of specific working memory tasks that re-learn mental functions and, based on brain flexibility, improve working memory and inhibitory control in people with attention deficit disorder and hyperactivity disorder. Because after the use of cognitive function sessions including attention, planning, organizing and flexibility in the form of software to improve and regenerate the activities of frontal lobes in these individuals, can be useful compared to their peers in the control group. Therefore, in the post-test, we observed an increase in the Stroop test score of individuals.

Regarding the effectiveness of the hybrid rehabilitation method of inhibitory control and transcranial direct current stimulation can be said; selected attention and inhibitory control is closely related to working memory. According to the Posner model, which stated in 1992, the selective attention is processed in the posterior and parietal parts of the brain which refers to the zonal overlap between working memory and attention. Since the results of this study showed that cognitive rehabilitation and transcranial direct current stimulation have shown changes in inhibitory control, memory, and selective attention that may be due to the change in the function of the synapses and the brain areas associated with it, and due to the overlap of areas involved in working memory and selected attention, it can be concluded that hybrid treatment and transcranial direct current stimulation improve inhibitory control. Because it creates a similar involvement and improvement in the brain area, which can be seen in the data obtained from the Stroop test. On the other hand, it can be said that the use of cognitive rehabilitation principles and skills that emphasize control and inhibition and simultaneously applying Transcranial Direct Current Stimulation and increasing surface stimulation in prefrontal cortex led to reduced GABA nervous transmission and increased dopamine in the left dorsolateral prefrontal cortex in people with attention deficit/ hyperactivity disorder. The intervention indicates the effects of improving inhibitory control in child with attention deficit/ hyperactivity impairment, which increases their performance in simple Stroop test in post-test and follow -up. As a result, this method can improve inhibitory control performance in students with attention deficit/ hyperactivity disorder (West et al., 2021). The results showed that cognitive rehabilitation of inhibitory control, transcranial direct current stimulation, and hybrid treatment increased the working memory of the experimental group compared to the control group, so the second main hypothesis of this study is confirmed. These results are consistent with other research findings, for example (Lamber et al., 2020; Renault & Devin, 2019, Nejati, 2020; West et al., 2021; Lipka et al., 2020) and accordingly students who had received educational programs of Cognitive rehabilitation inhibitory control, transcranial direct current stimulation, and hybrid treatment had higher working memory than their peers.

Research findings are consistent in correct answer factor with the findings of study by Akerlund et al. (2013), who studied cognitive practices after cognitive rehabilitation by BNIS app, and reported positive results.

Regarding the effectiveness of transcranial direct current stimulation on the memory of children with attention deficit hyperactivity disorder; the role of dopamine in cognitive processes of prefrontal area (Poon, 2018) and the presence of disorders in the dopaminergic system of children with attention deficit / hyperactivity disorder should be considered (American Psychiatric Association, 2013). It may be suggested that one of the effective factors in the development of executive dysfunction in children with attention deficit/hyperactivity disorder is a defect in the dopaminergic system. The ability to inhibit response is considered as one of the most important executive functions and is directly related to self-regulatory goal-oriented behaviors; but children with Attention Deficit / Hyperactivity Disorder have difficulty with restraint and cannot ignore the information they need. Inadequate control and inhibition of executive functions can also affect working memory and lead to the deterioration of working memory of these children (Poon, 2018). Attention Deficit / Hyperactivity Disorder also delays the growth of executive functions. In other words, this disorder delays the growth of what the executive functions are built based on that. Thus, the disorder puts the sufferer in control of external events, people around him, the present, and the immediate consequences (Hobson, Scott, & Rubia, 2011). A study by Pilli (2013) also showed that Transcranial Direct Current Stimulation in the left dorsolateral prefrontal cortex stimulates neurotransmitters in that area and increases dopamine. This will lead to better performance in executable (memory) functions. These observations are consistent with the results of studies by Ruf, Fallgatter, and Plewnia (2017) in increasing cognitive function and improving attention in hyperactive people with TDCS. Left lateral frontal cortex anode stimulation (the same area stimulated to improve attention therapy) has shown the improvement of task efficiency across a number of cognitive-behavioral tasks utilizing higher levels of cognitive functions, such as inhibitory control and memory.

Regarding the effectiveness of the hybrid method of inhibitory control rehabilitation and transcranial direct current stimulation can be said; this method is a special and unique type of treatment due to the cognitive processes involved in ADHD, the inhibitory cognitive rehabilitation program and tDCS, which focuses primarily on improving cognitive abilities (executive functions). Cognitive training computer programs provide tools that can be used to help improve basic mental processes that are important in high-level learning. Computer games increase cognitive function in people with ADHD because they require a significant amount of cognitive energy to complete the game (Barlett et al., 2009). The computer cognitive rehabilitation program significantly increased processing speed, cognitive flexibility, verbal and visual cognitive memory scores, and also played a significant role in increasing prefrontal cortex activity (Salehinejad et al., 2020).

Conclusion

Therefore, it can be said that by reducing the ability of attention in individuals, what initially declines is the response to the inconsistent stimulus, which makes the response selection process more complex and longer. Based on the results of the present study and similar studies, it can be concluded that since the response to consistent stimuli requires less attention control than to inconsistent stimuli, it seems that the rate of recurrent transcranial direct current stimulation in the present study, makes it possible to improve the attention control of individuals in response to consonant stimuli. To observe improvement in response to inconsistent stimuli that are more complex and therefore require more attention control, larger cortical stimulation can increase the likelihood of observing improvement. Thus, although studies in the field of inhibitory cognitive rehabilitation, transcranial direct current stimulation, and the combination of these two therapies have so far shown many advantages, including non-invasiveness, safety, and ease of use; however, the results of research on the effectiveness of these methods of inhibitory cognitive rehabilitation and transcranial direct current stimulation is heterogeneous on cognitive domain changes. Further studies with larger samples are needed to confirm recurrent transcranial direct current stimulation as a safe and effective way to promote neural function and, consequently, cognitive function in children with ADHD. This research was associated with several limitations, some of which are as follows: The specificity of the study to the children of Arak city, which limits the generalizations of the findings to other areas, time limitation in performing cognitive rehabilitation, inhibition, electrical stimulation training of the brain, and a combination of these two methods. Another limitation of this study was the lack of control over the variables threatening internal validity, spatial dispersion of subjects and the lack of a single place to conduct research and the lack of standard evaluation of the impact of interventions on the quality of life of ADHD children. For more generalizability of the results, this research should be repeated in other cities with subcultures and minorities in Iranian society. Based on the experiences and findings obtained, repeating similar studies on a larger number with higher homogeneity and following these people at specific intervals and for longer periods of time, can provide stronger results and more practical solutions to improve inhibitory control, working memory and reduce the problems of these children. It is suggested that in future research, the effectiveness of these treatments will be considered in improving problems including learning disabilities, Oppositional Defiant Disorder and conduct disorders in children with ADHD.

Disclosure Statement

No conflict of interest has been reported by the authors.

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