ORIGINAL ARTICLE

Comparing the Effectiveness of the Transcranial Alternating Current Stimulation (TACS) and Ritalin on Symptoms of Attention Deficit Hyperactivity Disorder in 7-14-Year-Old Children

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Abstract- Several studies have been conducted on the effect of transcranial direct current stimulation on adult patients. But, in recent years, only a few studies have been carried out in children and teenagers because the aim of the present study was to compare the effectiveness of TACS and Ritalin in the treatment of attention deficit hyperactivity disorder (ADHD) symptoms. This interventional clinical trial study was performed on 62 children with ADHD who were referred to the private psychiatric clinic of children in Tehran. The children were randomly assigned to two coded groups based on a lottery so that they were enrolled in the TACS or the Ritalin group. A questionnaire child syndrome inventory (parental form) and integrated visual and auditory (IVA) test with a pretest and posttest design was used in this study. TACS therapy protocol was employed (3 days a week for eight weeks using alternating current stimulation at 10 Hz over two points on the prefrontal cortex: the anode centered over F3 [the left dorsolateral prefrontal cortex] and the cathode over F4[the right dorsolateral prefrontal cortex]). Results showed that the posttest scores of the TACS-treated group were higher than those of the Ritalin-treated group, and there was a significant difference between the areas of visual attention (visual vigilance, visual focus, Sustained attention visual) and response control visual and auditory prudence ($P<0.05$). Results indicated that TACS was more effective and more durable compared to Ritalin in reducing attention deficit, hyperactivity, and impulsivity.

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Keywords: Attention deficit-hyperactive disorder; Transcranial alternating current stimulation (TACS); Ritalin

Introduction

Attention deficit hyperactive disorder (ADHD) is the most common neurodevelopmental disorder in childhood. ADHD is a challenge for psychiatrists, psychologists, parents, and teachers because the behavioral characteristics of the affected children such as inability to control motor behavior, attention deficit, learning disability, aggression, educational problems, excitation, and restlessness are a major obstacle for parents and school authorities and seriously damage the development of mental talents and socioemotional skills of children. Prevalence of various educational, occupational, and other problems in adulthood is significantly higher in these children than the normal population (1,2).

The standard treatment for ADHD, which is based on scientific evidence, includes treatment with stimulant drugs or behavioral interventions. Drugs used to treat ADHD include stimulants such as Ritalin, tricyclic antidepressants (Imipramine), alpha receptor agonists (Clonidine), and neuroleptics. Ritalin is the most commonly used drug (3,4).

The widespread use of stimulant drugs, including

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Methylphenidate and Dextroamphetamine, to treat ADHD improves behavioral, academic, and social performance in the short term, but not all children respond to these medications (5,6). Many parents are concerned about the side effects of drugs, which include ticks, insomnia, irritability, and drug resistance in long-term use. In addition, some children do not have access to behavioral therapies. Therefore, the inclination to use complementary/alternative therapies has increased dramatically in recent years among parents of children with ADHD6-7 (6,7). In addition, evidence shows that cognitive impairment in ADHD is associated with behavioral and cognitive abnormalities (8). Since 1972, research has increasingly suggested that hyperactivity and executive function deficit are the core problems in ADHD (9).

The impaired motor dimension of inhibitory control is the main defect in people with ADHD. This dimension of inhibitory control has been investigated through tests such as go/no-go and stop signal. The weaker performance of people with ADHD in the stop-signal test significantly differentiates them from the sample group. Therefore, studying the nature of inhibitory deficit in people with ADHD may suggest new perspectives on neuropsychological correlates of inhibitory control (10).

Neurological and neuronal imaging studies show that the right lateral prefrontal cortex, which includes the superior frontal gyrus, the middle frontal gyrus, and, most importantly, the inferior frontal gyrus, plays a key role in motor response inhibition in healthy individuals. These areas are activated by both go/no-go and stop-signal tests. The activity of the right lateral prefrontal cortex is reduced in people with ADHD compared to the control group during these tests (10).

Transcranial Direct Current Stimulation (TDCS) is a neurological therapy that facilitates or inhibits spontaneous neural activity by applying a weak direct current towards the cortical areas (11).

As a non-invasive, inexpensive, and safe alternative method to change the excitability of the cerebral cortex through altering the resting potential of cortical neurons, TDCS has been widely tested in the last decade. This weak direct current stimulates the lower neurons, usually through two opposite electrodes (an anode and a cathode) attached to the various points on the surface of the skull. Stimulation by the cathode and the anode reduces and increases brain excitability, respectively (12). The position of the electrodes is of great importance in determining the effectiveness of stimulation in TDCS. The stimulation intensity of up to 2 mA and a duration of about 22 minutes is nonhazardous and completely safe. There are few and mild side effects during stimulation, including itching under the electrode and mild headache that occur both during stimulation and when the stimulator is off. These effects are seen in different brain regions in healthy subjects and in patients with various neurological disorders (13).

Various studies have confirmed the effectiveness of TDCS in adult patients with stroke, Parkinson’s disease, motor disorders, cognitive, mood, functional memory, and reading comprehension disorders, addiction, acute and chronic pain, depression, epilepsy, post-menopausal vasomotor disorders, cognition, speech and/or conceptual disorders, tinnitus, increased focus and attention in autism, and decreased appetite.

Given its simplicity, TDCS can also be used in children, but factors such as concern about the vulnerability of this population and the ethical aspects involved in employing this technique limit its application in children.

Since children’s brains grow and develop vigorously, intensive studies are underway to determine how TDCS changes cognition, behavior, and other functions. This method can be used as a desirable tool to determine the brain areas that are clearly important at each growth stage (14). In a study by (15), noninvasive cranial stimuli were used as a diagnostic and therapeutic method in children with mental disorders. It was found that these two methods (applying magnetic and electrical stimuli) were reliable, regulated brain plasticity, and created new hopes for the treatment of plasticity disorders. In general, noninvasive stimulation of the brain, along with auxiliary therapies, can be used as an emerging strategy in neurological rehabilitation for promoting neuroplasticity (15).

Bandeira *et al.,* (16) studied the effect of TDCS on children and adolescents with ADHD. TDCS was used in nine males and nine females with a mean age of 11.11 years. The anode was centered over the left dorsolateral prefrontal cortex (F3) and the cathode over the right eyebrow. Results of neurological tests (visual attention, verbal and visual memory, and inhibitory control tests) showed that direct stimulation of the cranial cortex resulted in more efficient processing speed, improved stimulus recognition, and enhanced ability in transitioning between a continuous activity and a new activity. In general, improvement in selective attention and reduction in spectral patterns of attention-deficit were observed in this study. The presented data indicated that TDCS was able to change some parameters of neuropsychological tests in children and adolescents with ADHD (16).

Krishnan *et al.,* (17) assessed the safety of TDCS in children and adolescents in the published studies and found that TDCS could be used in children.

Cachoeira *et al,* (18) investigated the positive effects of TDCS in adult patients with ADHD in a randomized controlled trial. Their results showed that stimulation of the anode over F4 (the right dorsolateral prefrontal cortex (RDLPFC) and of the cathode over F3 (the left dorsolateral prefrontal cortex (LDLPFC) improved the symptoms of ADHD (and the improvement continued even after the stimulation) (18).

In a study on inhibiting excitability of the brain's motor cortex, (19) showed that applying alternating current at the frequency of 15 Hz (TACS) with the electrodes centered over C3 and C4 significantly decreased the amplitude of motor evoked potential and intracortical facilitation (ICF) compared to initial and sham stimulation. These results support the concept that AC stimulation with weak currents can significantly change brain excitability. In this case, the frequency of 15 Hz resulted in a pattern of cortical excitability inhibition. In addition, the results showed that TACS was not associated with any emotional and cognitive complications, nor did it have any potentially significant or harmful effects on motor function. Moreover, there was no relationship between TACS and pain, anxiety, or mood. Therefore, TACS was suggested as a reliable method.

This is the first study to show that TACS is a truly neurological technique. As described in this article, TACS is associated with limited side effects in humans and is a reliable method with effects comparable to those of TDCS (19).

A case report on the successful treatment of obsessive-compulsive disorder with TACS showed that all patients improved significantly after several sessions of TACS, and symptoms decreased in the following months. The electrodes were placed between Fp1-T3 and Fp2-T4, and TDCS was used based on the therapeutic protocol in previous studies (20).

The present study aimed to compare the effects of TACS and Ritalin on symptoms of children with ADHD. Considering the mentioned studies in some of which the anode was centered over F3 and in others over F4, and utilizing the study by (20) on treating obsessive-compulsive disorder in which TACS was used based on the TDCS protocol, the present study applied the TACS method in which alternating current was used. The location of the anode over F3 (where neuronal activity increased by 20 to 40% and blood flow and metabolism also improved under the anode pad) was changed with that of the cathode over F4 (where neuronal activity decreased by 10-30% and blood flow and metabolism also declined under the cathode pad) based on the frequency. For example, if the frequency is 10 Hz, the cathode and the anode change places 10 times, and the brain produces more of any of the adjusted frequencies (whereas the neurons are continuously stimulated in TDCS). The therapeutic protocol of (18) was used in the present study.

Material and Methods

Sample

The current study was a randomized controlled clinical trial. The statistical population consisted of 7-14-year-old children with ADHD visiting a pediatric psychiatry clinic in Tehran.

Sixty four children with ADHD aged 7-14-year-among patients visiting a pediatric psychiatry clinic after a diagnosis of ADHD by a pediatric psychiatry specialist were selected in this study through purposeful sampling. The inclusion criteria were IQ>90, having ADHD, and not taking Ritalin (children who did not consume Ritalin and children whose parents were opposed to taking Ritalin), and the exclusion criterion was being diagnosed with autism spectrum. The children were randomly assigned to two coded groups based on a lottery so that they were enrolled in the TACS or the Ritalin group. Of course, after establishing a relationship and explaining the research importance, the inventory answering method, and the data confidentiality, informed consent was obtained individually from parents. Before the treatment intervention, the parents of each child were first asked to complete the CSI-4 parent form. Then the subjects were evaluated through the IVA test (pretest) in the subscales related to the fields of attention (auditory and visual) inhibition and response (auditory and visual) inhibition. The therapeutic intervention was performed after the pretest, and the subjects were reassessed by the posttest after the intervention. Finally, 32 patients underwent drug intervention for 8 weeks, and 32 underwent TACS 3 days per week for 8 weeks using a Nerotism 2 device placed over two points of the prefrontal cortex at 10 and 20 Hz. The anode was centered over F3 (the left dorsolateral prefrontal cortex) of the small pad and the cathode over F4 (the right dorsolateral prefrontal cortex) of the small pad. The current was set as 1 mA with a rise-fall pattern of 30 seconds at the frequency of 10 Hz for 10-15 minutes.

The effectiveness of TACS and Ritalin was evaluated through the IVA test on the subscales of attention (auditory and visual) and inhibition (auditory and visual). The subjects were reevaluated after three months. Since the participants were from different locations, the follow-up was conducted on six children in the TACS group and 13 children in the Ritalin group. The ethical code (IR.Tums.VCR.REC.1396.4105) was obtained from the Tehran University of Medical Sciences, and the code assigned to the clinical trial was IRCT20150803023478N3.

Instruments

Child syndrome inventory 4 (CSI-4)

This inventory was first developed by Sprafkin and Gadow to perform screening for behavioral and emotional disorders in 5-12-year-old children (2005) with two forms for parents and teachers consisting of 77 and 97 items that are scored based on a 4-point Likert scale. In this study, the parent form was used for screening and evaluating accompanying disorders (21,22).

Integrated visual and auditory (IVA) test

This test was developed in 1994 by Sandford and Turner based on the Diagnostic and Statistical Manual of Mental Disorders V (DSM-V). It is able to diagnose and distinguish different types of ADHD in children over six years of age. The four sections of the test include warm-up, exercise, main test, and cool-down (23). The test requires continuous attention on task and inhibition of impulsive responses, is used to evaluate attention and impulsivity, and is in the form of a computer program consisting of a visual and an auditory part (23,24).

During the test, the person is told to press a key after hearing or seeing the number 1. Answering to the number 2, which is not the target, indicates impulsivity, and answering less frequently to the number 1, which is the target, suggests attention deficit. The test enjoys a proper sensitivity (0.92) and a positive predictive value (0.89) for the diagnosis of ADHD (25). The concurrent validity of this test was calculated by reevaluating the children with ADHD through other diagnostic tools such as the *Test* of *Variables* of *Attention (*TOVA), Gordon Continuous Performance Test, Children's Attention Scale, and ADHD Rating Scale. The agreement was in the 90 to 100% range (25). In another study, the retest coefficient was 0.89, and the validity coefficient using the neurological tool was 60% (26). The AVI subscales evaluated in this study were auditory response control, visual response control, auditory attention, and visual attention.

Nerotism 2 device

This device is designed to provide transcranial electrical stimulation (TES). It has two isolated channels separated from each other to provide various types of TES with a maximum intensity of 4 mA and transmits the electric current from the scalp to the brain through electrodes with different polarities (the anode and the cathode) mounted on

The scalp. The frequency of 10 Hz was used for 15 minutes. The conductive electrodes can be made of carbon. The 5×7 cm electrodes in this study were placed inside a sponge impregnated with 9% sodium chloride in order to prevent heat gain while increasing the conductivity of the electric current. The device can be adjusted with respect to current intensity, electrode size, and stimulation duration.

Procedure

The present research was an interventional clinical trial and a quasi-experimental study with a two-group pretest-posttest design. Sixty-two children aged 7-14 years with ADHD were randomly selected from patients visiting a child and adolescent psychiatric clinic after they were diagnosed with ADHD by a pediatric psychiatrist and assigned to two coded groups. The inclusion criteria were IQ>90, having ADHD, being 7-14 years of age, and not taking Ritalin (children who did not consume Ritalin and children whose parents were opposed to taking Ritalin). The exclusion criterion was being diagnosed with autism spectrum and taking Ritalin during the intervention. For this purpose, all children were evaluated using the Raven test and CSI-4 (parent form). Prior to the therapeutic intervention, informed consent was obtained from the parents. The children were then randomly assigned to the TACS group (intervention using a Nerotism 2 device) and the Ritalin group. Parent forms of CSI-4 were filled, and the IVA test was performed before the intervention (pretest). This was followed by therapeutic intervention. The subjects were reassessed by posttest after the intervention. Finally, 31 patients underwent drug intervention for eight weeks, and 31 underwent TACS treatment protocol (3 days per week for a total of 20 sessions over two points on the scalp at 10 and 20 Hz. The anode was centered over F3 (the left dorsolateral prefrontal cortex) and the cathode over F4 (the right dorsolateral prefrontal cortex).

Data were analyzed using SPSS 20 and analysis of covariance at the significance level of 0.05 and employing the LSD follow-up test.

Data analysis

In order to analyze the data of the present study, the data were first extracted from the questionnaires and then adjusted in the general information table. Then, all information was analyzed using SPSS20 software in two sections of descriptive and inferential methods. In a descriptive analysis of information, firstly, statistical indices related to the basic variables of the research were calculated. In the section of inferential methods in order to test the research hypotheses, the statistical test of covariance analysis was at the significance level of *P*<0/05 and the LSD follow-up test, the results are presented in separate tables.

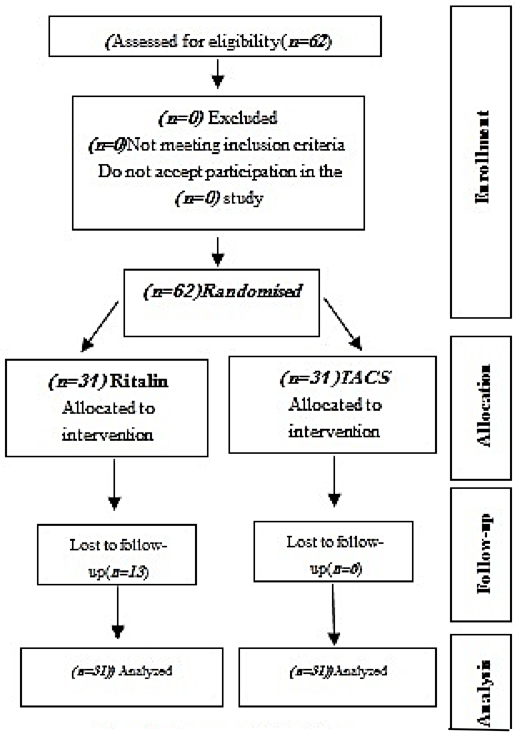

Figure 1. Summary of patient flow diagram

Results

The results of the demographic analysis show that the subjects in the group are 71% of the male and 29% of the girls. So most of the sample is male. Altogether 62% of people under age 10 and 38% of people aged 10 to 14-year-old.

Descriptive analysis results of Table 1 indicate that the mean of subscales of attention and retention of response, the TACS group in the posttest and follow-up stages, is higher than the Ritalin group. It is necessary to note this point is that the increase in scores indicates an increase in the effect. Now, to make a meaningful analysis of these changes, inferential statistics (covariance analysis) are considered. But before presenting the results, the preconditions of the optimal analysis are discussed.

The results of Levine's test for homogeneity of variance tests showed that homogeneity of the variance of the distribution of grades was observed (*P*<0.05). Also, the results of the test Kolmogorov-Smirnov, for the purpose of examining the normal default of the sample distribution, also showed that the default is the sample distribution of data (*P*>0.05). Parametric tests do not face any constraints.

Based on the results of Table 2, we can conclude that considering the scores of pretest in the subscales, the difference between the performance of the two groups TACS with Ritalin in the treatment, taking into account the Eta squared, can be said that the total effect of the modified corrected in the Attention Auditory Vigilance 1.5 % Attention Auditory Focus 4.5%, Attention Auditory Speed 0.8%, Attention Visual Vigilance 13.3%, Attention Visual Focus 7.7%, Attention Visual Speed 2.6%, Response Control Auditory Prudence 6.5%, Response Control Auditory Consistency 5.4%, Response Control Auditory Stamina, 2.8%, Response Control Visual Prudence 7.5%, Response Control Visual Consistency 6%, Response Control Visual Stamina 1%, Sustained Attention Auditory 5.1%, and Sustained Attention Visual 8.4%, which is due to the effect of independent variable (intervention) The LSD post hoc test was used to clarify the comparison of changes between treatment drowning.

Table 1. Comparison of the scores of attention and inhibition of Response areas in the pre-test, post-test, and follow-up stages by groups

Dependent Variable		Ritalin		tACS	
		Mean	Std. Error	Mean	Std. Error
.Attention Auditory Vigilance	pre-test	45.19	37.35	73.1	37.28
	post-test	57.71	45.53	90.32	31.97
	follow-up	78.61	31.54	91.8	22.32
.Attention Auditory Focus	pre-test	68.94	46.84	92.84	13.87
	post-test	85.45	36.87	103.32	12.52
	follow-up	97.33	26.97	103.64	12.43
.Attention Auditory Speed	pre-test	62.23	42.98	93.74	21.64
	post-test	80.32	34.96	95.58	18.29
	follow-up	87.33	25.23	96.4	19.47
Sustained Attenstion Auditory	pre-test	39.65	37.41	65.65	36.8
	post-test	60.42	44.24	91.65	33.84
	follow-up	74.44	44.97	103.8	15.51
.Attention Visual Vigilance	pre-test	50.58	43.65	77.06	35.04
	post-test	70.68	36.96	100.48	16.22
	follow-up	75.06	43.9	104.76	9.72
.Attention Visual Focus	pre-test	58.9	46.57	86.13	26.46
	post-test	78.94	37.74	103.29	15.58
	follow-up	72.44	44.06	102.88	11.46
.Attention Visual Speed	pre-test	59.35	46.63	94.16	31.78
	post-test	82.74	39.5	106.42	19.39
	follow-up	76.28	43.65	105.12	20.29
Sustained Attention Visual	pre-test	46.03	44.63	75.74	34.29
	post-test	71.13	41.16	101.6	22.38
	follow-up	79	35.13	91.36	22.39
.Response Control Auditory Prudence	pre-test	67.29	46.63	89.58	24.12
	post-test	88.84	37.03	107.52	12.01
	follow-up	99.89	28.89	99.16	13.67
.Response Control Auditory Consistency	pre-test	64	43.61	90.42	14.27
	post-test	81.29	35.55	101.48	14.77
	follow-up	91.61	25.49	105.48	15.03
.Response Control Auditory Stamina	pre-test	71.19	47.22	104.45	16.67
	post-test	88.23	37.81	102.9	13.18
	follow-up	94.28	27.47	108.4	12.06
.Response Control Visual Prudence	pre-test	63.48	49.27	79.81	34.59
	post-test	79.45	38.67	99.19	16.78
	follow-up	82.61	47.03	99	23.61
.Response Control Visual Consistency	pre-test	60.52	46.81	87.03	26.72
	post-test	81.74	38.68	104.45	13.42
	follow-up	77.83	45.38	104.08	13.8
.Response Control Visual Stamina	pre-test	61.32	47.76	88.52	27.02
	post-test	81	38.5	94.81	12.62
	follow-up	72.61	42.41	100.64	27.29

Table 2.The results of the intergroup covariance analysis for comparing the pretest, posttest, and follow-up scores of the subscale of attention and response deterrence (visual-auditory)

Dependent (Ritalin &tACS)		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Attention Auditory Vigilance							
Post	**pre-test**	30955.19	1	30955.19	29.51	0	0.333
	group	3307.78	1	3307.78	3.15	0.08	0.051
Follow-up	**post**	10863.41	1	10863.41	24.14	0	0.38
	group	36.7	1	36.7	0.08	0.78	0
Attention Auditory Focus							
Post	**pre-test**	4561.43	1	4561.43	6.58	0.01	0.1
	group	1932.76	1	1932.76	2.79	0.1	0.045
Follow-up	**post**	3635.5	1	3635.5	11.69	0	0.23
	group	4.72	1	4.72	0.02	0.9	0
Attention Auditory Speed							
Post	**pre-test**	7153.09	1	7153.09	10.68	0	0.153
	group	335.85	1	335.85	0.5	0.48	0.008
Follow-up	**post**	7260.84	1	7260.84	22.93	0	0.36
	group	62.36	1	62.36	0.2	0.66	0.01
Attention Visual Vigilance							
Post	**pre-test**	13638.06	1	13638.06	22.83	0	0.279
	group	5401.89	1	5401.89	9.04	0	0.133
Follow-up	**post**	20379.34	1	20379.34	55.61	0	0.58
	group	66.3	1	66.3	0.18	0.67	0.01
Attention Visual Focus							
Post	**pre-test**	8246.54	1	8246.54	11.65	0	0.165
	group	3469.21	1	3469.21	4.9	0.03	0.077
Follow-up	**post**	17735.22	1	17735.22	38.53	0	0.49
	group	296.29	1	296.29	0.64	0.43	0.02
Attention Visual Speed							
Post	**pre-test**	16269.06	1	16269.06	22.96	0	0.28
	group	1123.5	1	1123.5	1.59	0.21	0.026
Follow-up	**post**	29878.49	1	29878.49	96.38	0	0.71
	group	43.73	1	43.73	0.14	0.71	0
Response Control Auditory Prudence							
Post	**pre-test**	3045.93	1	3045.93	4.24	0.04	0.067
	group	2939.94	1	2939.94	4.09	0.05	0.065
Follow-up	**post**	3751.88	1	3751.88	10.06	0	0.2
	group	656.2	1	656.2	1.76	0.19	0.04
Response Control Auditory Consistency							
Post	**pre-test**	4422.26	1	4422.26	6.52	0.01	0.099
	group	2306.59	1	2306.59	3.4	0.07	0.054
Follow-up	**post**	2457.35	1	2457.35	7.01	0.01	0.15
	group	561.43	1	561.43	1.6	0.21	0.04
Response Control Auditory Stamina							
Post	**pre-test**	1245.47	1	1245.47	1.57	0.22	0.026
	group	1364.9	1	1364.9	1.72	0.2	0.028
Follow-up	**post**	3889.73	1	3889.73	12.52	0	0.24
	group	369.87	1	369.87	1.19	0.28	0.03
Response Control Visual Prudence							
Post	**pre-test**	5475.87	1	5475.87	6.76	0.01	0.103
	group	3860.67	1	3860.67	4.76	0.03	0.075
Follow-up	**post**	34149.26	1	34149.26	81.21	0	0.67
	group	672.37	1	672.37	1.6	0.21	0.04
Response Control Visual Consistency							
Post	**pre-test**	10282.49	1	10282.49	15.17	0	0.204
	group	2548.76	1	2548.76	3.76	0.06	0.06
Follow-up	**post**	21188.91	1	21188.91	46.06	0	0.54
	group	51.98	1	51.98	0.11	0.74	0

Continuance of Table 2

Response Control Visual Stamina							
post	**pre-test**	8313.43	1	8313.43	11.98	0	0.169
	group	424.78	1	424.78	0.61	0.44	0.01
follow-up	**post**	18226.6	1	18226.6	24.12	0	0.38
	group	1506.87	1	1506.87	1.99	0.17	0.05
Sustained Attention Auditory							
post	**pre-test**	28871.74	1	28871.74	26.54	0	0.31
	group	3457.61	1	3457.61	3.18	0.08	0.051
follow-up	**post**	10535.29	1	10535.29	14.23	0	0.26
	group	3762.64	1	3762.64	5.08	0.03	0.11
Sustained Attention Visual							
post	**pre-test**	21886.81	1	21886.81	29.37	0	0.332
	group	4037.62	1	4037.62	5.42	0.02	0.084
follow-up	**post**	8926.53	1	8926.53	14.83	0	0.27
	group	108.41	1	108.41	0.18	0.67	0

Based on the results of Table 3, the results show that in all areas, the attention and response rate of TACS treatment was more effective than Ritalin, and there was a significant difference between the areas of visual attention and response control visual and auditory prudence.

Table 3. The LSD post hoc test results the difference between the auditory and visual subscale scores of tACS in ritalin pretest-posttest

group	A	B	Mean Difference (A-B)	Std. Error	.Sig	.Confidence Interval for955% Difference: Lower Bound	Upper Bound
Attention Auditory Vigilance	tACS	Ritalin	15.63	8.8	0.08	-1.98	33.24
Attention Auditory Focus	tACS	Ritalin	11.84	7.09	0.1	-2.35	26.03
Attention Auditory Speed	tACS	Ritalin	5.15	7.27	0.48	-9.4	19.69
Attention Visual Vigilance	tACS	Ritalin	19.718*	6.56	0	6.6	32.84
Attention Visual Focus	tACS	Ritalin	15.928*	7.2	0.03	1.53	30.32
Attention Visual Speed	tACS	Ritalin	9.31	7.4	0.21	-5.49	24.11
Sustained Attention Auditory	tACS	Ritalin	15.86	8.89	0.08	-1.94	33.65
Sustained Attention Visual	tACS	Ritalin	17.121*	7.36	0.02	2.4	31.84
Response Control Auditory Prudence	tACS	Ritalin	14.399*	7.12	0.05	0.15	28.65
Response Control Auditory Consistency	tACS	Ritalin	13.2	7.16	0.07	-1.13	27.53
Response Control Auditory Stamina	tACS	Ritalin	10.4	7.93	0.2	-5.47	26.27
Response Control Visual Prudence	tACS	Ritalin	16.079*	7.37	0.03	1.34	30.82
Response Control Visual Consistency	tACS	Ritalin	13.6	7.02	0.06	-0.44	27.64
Response Control Visual Stamina	tACS	Ritalin	5.56	7.1	0.44	-8.65	19.77

Discussion

The findings of this study in Table 1 indicated the effectiveness of TACS in improving the symptoms of attention-deficit and hyperactivity-impulsivity in patients with ADHD; this improvement was achieved by increasing the posttest scores in the subscales of attention and the subscales related to inhibition in the IVA test. Many studies, including those (10,13,14,16,18,19,27-33), demonstrated the effect of electrical stimulation of the brain cortex on improving attention deficit and hyperactivity-impulsivity in patients with ADHD. The findings of the present research were consistent with those of the mentioned studies.

ADHD is one of the most common psychiatric diseases in childhood. Symptoms usually appear before elementary school but become completely marked at about nine years of age. Early diagnosis and treatment of this disease will reduce the educational problems of children and improve their psychosocial development. Given the heterogeneous symptoms and complexity of the disease, a single treatment method is not usually effective. Multi-interventional methods such as pharmacotherapy together with psychotherapy and behavioral therapy can be effective (34,35).

Moreover, the results of research by (18) showed the positive effects of TCDS on adult patients with ADHD. The anode and cathode stimulation centered over F4 (RDLPFC) and F3 (LDLPFC) improves ADHD symptoms, and this improvement remains after the stimulation. In the present study, the alternative current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Although both groups have improved in the subscales of attention and response inhibition (auditory and visual) but based on Table 3, The effect of tACS in visual vigilance, visual focus, sustained attention visually, and response control visual and auditory prudence was a significant effect. These results are in agreement with those of the research mentioned above.

Results of the research by (27) showed that TCDS of the brain cortex with the anode centered over F3 (the left dorsolateral prefrontal cortex) and the cathode over the vertex with the center of CZ improved clinical symptoms in adolescents with ADHD and reduced ADHD symptoms and improved neuropsychological function in adolescents, and was a treatment method for ADHD (27). In the present study, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 2,3 indicated improvement in areas related to focus and attention in the subscales (visual vigilance, visual focus, sustained attention visual and response control visual and auditory prudence as a result of the TACS intervention. These results are consistent with those of the mentioned research.

The impaired motor dimension of inhibitory control is the main defect in people with ADHD.

Consequently, studying the nature of inhibition impairment in people with ADHD may suggest new perspectives on neuropsychiatric correlates in the area of inhibitory control (10).

Neuronal imaging studies show that the right lateral prefrontal cortex, which includes the superior gyrus, middle gyrus, and, most importantly, the inferior frontal gyrus, plays a key role in inhibiting motor responses in healthy individuals. In contrast, the activity of the right lateral prefrontal cortex decreases in people with ADHD compared to the control group during these two tests (10).

In the case of areas involved in inhibitory control, results of neuroimaging studies have shown that the right inferior frontal gyrus is activated during activation of inhibitory control.

Structural magnetic resonance imaging, functional magnetic resonance imaging, and electroencephalography studies have provided strong evidence that defect in the right frontal area (especially in the prefrontal area) forms the basis for the impairment of inhibitory control (28,36).

All the mentioned studies showed a reduction in prefrontal cortex activity and inhibition impairment in people with ADHD. In the present study, prefrontal cortex activity was increased through applying alternating current instead of a direct current centered above F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 2,3 showed improvement in inhibitory subscales (response control visual and auditory prudence). These results are consistent with those of the mentioned research.

Studies that evaluated the effectiveness of TDCS on cognitive functions showed its inhibition and facilitation effects. For example, anodic stimulation of dorsolateral prefrontal cortex (DLPFC) improved performance accuracy in patients with Parkinson’s disease, and the digit span test in patients with major depression indicated its improvement after five stimulation sessions (13), enlander. In the present study, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 2,3 showed improvement of inhibition subscales that were consistent with findings of the mentioned studies.

In a study about the effects of TDCS on improving inhibition in people with ADHD (29), showed that anodic stimulation in the frontal gyrus area significantly increased the accuracy of the go/no-go test compared to stimulation-like conditions. In the present study, alternating current was used instead of a direct current centered over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 2,3 showed improvement in visual vigilance, visual focus, sustained attention visual and response control visual and auditory prudence subscales. These results were in agreement with those of the research mentioned above.

In addition (30), showed that those who had been diagnosed with ADHD in childhood and whose behavioral symptoms had persisted exhibited a significant pattern of parietal and striated frontal malfunction during inhibitory control tasks. In this study also, evaluation of subscales in the visual response inhibition showed malfunction of inhibitory control, and increased inhibitory control was observed after the therapeutic intervention.

Cosmo *et al.*, (31) used anode stimulation centered over LDLPFC (F3) to examine the effectiveness of TDCS in modulating inhibitory control in adults with ADHD. They showed that anodic stimulation over F3 did not improve inhibitory control in children with ADHD. However, in the present study, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 3 showed improvement in visual vigilance, visual focus, sustained attention visual and response control visual and auditory prudence subscales. These results did not conform to those of the research mentioned above.

In a study by (32), it was shown that stimulation of the brain cortex in the right middle frontal gyrus with the anode in TDCS led to behavioral inhibition. In the present study, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 3 showed improvement in visual vigilance, visual focus, sustained attention visual and response control visual and auditory prudence subscales. These results were in line with those of the study mentioned above.

Results of the research by (33) showed that direct electrical stimulation with the anode centered over the right inferior frontal cortex and the cathode over the left eyebrow improved interference control in people with ADHD. In the present study, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. Results of Table 2,3 showed improvement in visual vigilance, visual focus, sustained attention visual and response control visual and auditory prudence subscales. These results conformed to those of the study mentioned above.

Zaghi & *et al*., (19) showed that TACS of the motor cortex at the frequency of 15 Hz with the electrodes at C3 and C4 considerably reduced the range of motor potential and intracortical facilitation (ICF). These results support the concept that TACS with weak currents at the frequency of 15Hz leads to a pattern of inhibition of cortical excitability. In the present study also, alternating current was used instead of direct current over F3 and F4 with the frequency of 10 Hz for 15 minutes. The results of Table 2,3 showed that TACS was effective in improving visual vigilance, visual focus, sustained attention, visual and response control visual and auditory prudence. These results were in agreement with those of the study mentioned above.

Most of the mentioned studies applied direct stimulation of the cerebral cortex in ADHD patients, some of which only focused on attention deficit and some on inhibition. In addition, patients consumed Ritalin in these studies. However, in the present research, alternating current stimulation was used over F3 and F4 on the scalp, and the subscales of attention (auditory and visual) and response inhibition (auditory and visual) were evaluated in children with no Ritalin consumption who had IQ >90 using the IVA test version 2015. Results showed that the TACS treatment intervention improved the symptoms of ADHD, and this improvement persisted in the follow-up. No research was found in which all the variables explored accurately in this study were investigated. Therefore, it was impossible to comprehensively compare the findings of the present research with those of other studies. However, it can be argued that some results of the present research are consistent with some of the findings in domestic and foreign studies. In general, parents of most children were satisfied with the intervention in the present study. Therefore, it is suggested that further studies be carried out on larger sample sizes and over other points. The results of this research can be used as a guide for curriculum planners and educational authorities of psychology and psychiatry faculties. In addition, the Ministry of Education and the Exceptional Children Association can use them to improve the academic progress of children with ADHD and help them and their families.

The limitations of this study included its novelty, unfamiliarity of parents with this treatment, the fact that the children came from different parts of Iran, the transportation problem, considerable sample attrition, and non-uniformity of subjects in terms of economic, cultural, educational, and nutritional status.

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