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Comparing the effectiveness of Transcranial direct current stimulation (tDCS) and mindfulness on working memory and clinical symptoms of adults with attention-deficit/hyperactivity disorder (ADHD)

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Original Article

Abstract

BACKGROUND: Attention deficit/hyperactivity disorder (ADHD) is one of the most adverse neurological disorders that is associated with multiple defects in cognitive and behavioral dimensions and sometimes continues until adulthood. Due to the side effects of drug therapy, non-drug treatments have been welcomed for this disorder. The purpose of this study was to compare the effects of mindfulness-based cognitive therapy (MBCT) and transcranial direct current stimulation (tDCS) on working memory and clinical symptoms of adults with ADHD.

METHODS: This experimental study had a multi-group pretest/posttest design in which an experimental group was exposed to tDCS (5 sessions of 20-minute interventions of electrical stimulation with the flow of 1 mA) and one other experimental group was exposed to MBCT (8 sessions of 90 minutes, three days a week), and the control group did not receive any intervention. Participants in this study were 45 male subjects (15 in each group), which were selected by the convenience method and online call in social media groups.

RESULTS: The mindfulness and electrical stimulation of the dorsolateral prefrontal cortex (DLPFC) had a significant effect on working memory and clinical symptoms of adults with ADHD.

CONCLUSION: Based on the findings of this study, it is recommended that these methods be used by clinicians and practitioners in neurological clinics and psychological services as a method of intervention and prevention.

KEYWORDS: Transcranial Direct Current Stimulation; Mindfulness; Working Memory; Attention Deficit-Hyperactivity Disorder

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Introduction

Attention deficit/hyperactivity disorder (ADHD) is a common disorder characterized by disproportionate levels of inattention, and/or impulsivity-hyperactivity.[1] The prevalence of this disorder in children is 5.3%. In many cases, it continues into adulthood, and its prevalence in adulthood is 3.4%. Results show that the prevalence of this disorder in Iran is at least 0.95% and at most 17%, with an average of 7.8%; and it seems that this prevalence rate is not significantly different from the global average. According to the results, the prevalence of this disorder in boys is nearly twice in comparison to girls.[2]

Multidisciplinary treatment of ADHD, including psychotherapy, medication, and

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behavioral therapy, is very effective in most patients, but many patients do not get positive results from conventional medical treatments.[3] At best, the moderate effects of behavioral therapy, the high rate of drug withdrawal due to side effects, and the critical attitude of parents toward drug therapy emphasize the urgent need to develop alternative therapeutic strategies.[4] One of the emerging treatments for cognitive and behavioral disorders is mindfulness-based cognitive therapy (MBCT). At first glance, mindfulness and ADHD seem to be a contradictory combination, but considering the key aspects of mindfulness makes it clear how this method is useful for improving the symptoms of the disorder. Mindfulness helps the sufferer by informing the person of what is distracting him or her and helping to restore attention to what was previously focused on, and can be said to be a kind of exercise of attention and excitement.

The results of a study by Rajabian et al. showed that MBCT intervention was effective in the overall composition of working memory.[5] Moreover, findings of Ghorbani and Khalilian indicate the effectiveness of mindfulness-based metacognitive therapy on improving cognitive symptoms in people with ADHD and important points of attention to mindfulness-based therapies in reducing problems with ADHD.[6] Hölzel et al. in a study show changes in the brain during mindfulness training,[7] that these changes lead to a tendency to a non-invasive stimulation method called transcranial direct current stimulation (tDCS).

tDCS is a method by which a weak direct current is applied to the skull and modulates cortical arousal by altering the potential of the resting nerve membrane. Anodic stimulation increases cortical excitation, while cathodal stimulation decreases it at the microscopic level. This method improves the defective parts of executive functions not only in ADHD but also in other disorders consistent with the defective executive function, depending on the target cortical region.[8]

Different studies have shown the effectiveness of transcranial electrical stimulation in improving behavioral and cognitive function and clinical symptoms in children and adults with ADHD.[9] Findings of Castellanos and Proal on ADHD suggested that transcranial electrical stimulation could be useful for ADHD due to its beneficial effect on larger scale networks.[10] Additionally, Brem et al.[8] and Ohn et al.[11] in their work by tDCS concluded that anodic stimulation of dorsolateral prefrontal cortex (DLPFC) by tDCS promoted the working memory of healthy subjects and the patient group. A study by Andrews et al. measured the effect of a transcranial anode stimulation session on the working memory task and observed a significant improvement in the performance of this task.[12] Berryhill and Jones in a study improved working memory by using anodic stimulation on DLPFC in highly educated subjects.[13] Furthermore, researchers (Fregni et al.,[14] Wolkenstein and Plewnia,[15] Loo et al.[16]) observed improvement in working memory after one to several sessions of transcranial electrical stimulation.

This study is directed with the following findings that are the basis of the theoretical logic of the study: 1) people with ADHD show more elimination errors, slower reaction time, and variability of higher reaction time in cognitive tasks compared to the subjects in the control group,[17] 2) lower performance of people with ADHD may be explained by the activity of the prefrontal cortex (PFC), especially the DLPFC identified in neurophysiological and functional magnetic resonance imaging (fMRI) studies,[18] 3) anodal transcranial electrical stimulation of the left lateral dorsal forehead significantly improves cognitive function in healthy subjects as well as patients with depression, Parkinson's disease, and those recovering from stroke,[19] and 4) 1 mA anode stimulation causes a

continuous and significant increase in cortical arousal. Recently, different studies have shown significant effects of electrical stimulation on the left lateral dorsal forehead area on executive functions and attention in children and adolescents with ADHD.[20]

Although stimulant and non-stimulant drugs for this disorder are effective in reducing symptoms, there are also significant deficiencies such as severe side effects that in some cases lead to discontinuation of treatment. Since drugs merely may not be sufficient to reduce the symptoms of the disorder and adherence to conventional therapies (behavioral and pharmacological) decreases in adolescence and is less successful in adulthood, parents and patients seek alternative therapies.[21] Therefore, the overall aim of this study was to compare the effectiveness of two new treatments, namely tDCS and MBCT on working memory and clinical symptoms in adults with ADHD.

Methods

This was an experimental study with 3 groups (15 people in each group) with a pretest-posttest design. The statistical population included all men with ADHD in Rasht City, Iran, in 2020. Participants were selected by convenience method and also through an online call (social media groups) based on the initial diagnosis of a psychologist, clinical interview of the researcher, and diagnostic test. This study was conducted in a medical clinic in Rasht City, and in a while, participants did not follow any treatment. The inclusion criteria in this study were: the presence of ADHD syndrome since childhood and also a psychological diagnosis of ADHD. Exclusion criteria were: a history of epilepsy, implantation, or migraine and using medication or other behavioral treatments. The Conners' Adult ADHD Rating Scale-Self-report (CAARS-S) and Working Memory Questionnaire (WMQ) were implemented for all 3 groups before the classification of participants. Of the participants, only 45 were eligible to participate in the study (only men/18-40 years old). The main experimental group received 5 sessions of 20-minute transcranial electrical stimulation with a current of 1 mA by the corresponding author under the supervision of a professional psychologist, which was performed on the left DLPFC in a physician's office in order to prevent possible side effects. The other experimental group participated in MBCT interventions based on the treatment program of Mitchell et al.[25] This program included eight 90-minute sessions, and 45-minute homework three days a week that works for reducing stress and is a kind of psychotherapy in which individuals are taught to mentally represent objects in life that are beyond their immediate control through breathing and thinking. In fact, this therapy is a combination of relaxation and mindfulness.[25] The control group did not have any intervention. The post-test was held for all members of the three groups after the intervention sessions to investigate the possible changes. A follow-up session was performed after three months to evaluate the durability of the intervention methods. Ultimately, repeated measures analysis of variance (ANOVA) of data was done by SPSS (version 22, IBM Corporation, Armonk, NY) software.

This research was approved by Guilan University of Medical Sciences, Rasht, with ethics ID IR.GUMS.REC.1399.160 and can be viewed on the website of the National Ethics Committee.

Research tools

CAARS-S: This diagnostic questionnaire is a tool with appropriate validity and reliability, including 26 items that are scored from zero to 3, and has subscales including inattention/memory problems, hyperactivity/restlessness, impulsivity/emotional lability, and problems with self-concept. The results of Mokhtari et al.'s analysis showed that the

validity coefficient obtained from the test halving method was equal to 0.70 and its reliability using the test-retest method was higher than 0.60.[22]

WMQ: The working memory capacity test consists of 27 sentences that are divided into six sections, from two-sentence to seven-sentence sections. The main feature of the working memory capacity test is the simultaneous measurement of two parts of working memory (processing and storage). The validity and reliability of this questionnaire based on Arjmandnia and Rafikhah[23] study were 0.88 and 0.85, respectively.

Results

According to table 1, the mean of pretest, posttest, and follow-up of working memory in the mindfulness group were 76.80, 70.13, and 68.67 with standard deviations (SDs) of 2.30, 2.66, and 1.63, respectively. Moreover, the mean of working memory scores in the pretest, posttest, and follow-up in the tDCS group was equal to 75.47, 64.13, and 63.33 with SDs of 2.13, 1.40, and 1.29, respectively. The mean of the pretest, posttest, and follow-up in the control group was equal to 76.00, 75.75, and 73.67, respectively, with SDs of 3.74, 3.26, and 1.63. Further, the skewness and elongation of the working memory variable were in the range of 1 and -1 (or close to this range), which indicates that the working memory variable had a normal distribution in all three groups.

As is shown in table 2, the Levene's test was used to investigate the assumption of the equality of variances, and considering the non-significance of the Levene's test, it can be concluded that the assumption of homogeneity of variance of error for research variables is established in all stages of the research ($P > 0.01$).

Based on table 3, posttest and follow-up scores of working memory and clinical symptoms in the electrical stimulation group decreased compared to the pretest ($P < 0.01$), while in the control group, there was no significant difference in the three stages of the test ($P > 0.05$). Therefore, electrical stimulation treatment has been effective in improving working memory and clinical symptoms in the posttest and follow-up stages. In the mindfulness group, posttest and follow-up scores of working memory and clinical symptoms decreased compared to the pretest ($P < 0.01$), while in the control group, there was no significant difference in the three stages of the test ($P > 0.05$). Therefore, mindfulness therapy has been effective in improving working memory and clinical symptoms in the posttest and follow-up stages.

According to table 4, the mean of clinical symptoms between the groups of mindfulness and electrical stimulation was equal to -0.33 with a standard error of 0.39 ($P > 0.05$) and this means that there was no significant difference in clinical symptoms between the two groups in terms of effectiveness on inhibition control and selective attention. The difference in the average working memory score between the two groups was equal to 4.22 with a standard error of 0.63 ($P < 0.01$), which means that there was a significant difference between the two groups in terms of effectiveness on memory, and the difference between the means in the electrical stimulation group of the brain compared to the mindfulness group in the posttest stages was more than the pretest and indicates that electrical brain therapy was more effective on working memory.

Discussion

The present study shows that tDCS improves working memory and clinical symptoms in adults with ADHD. One hypothesis could be that brain stimulation improves excitability in the external posterior cortex of the forehead, which may be due to increased glutamate levels. This finding is consistent with previous findings of Andrews et al.,[12] Berryhill and Jones,[13] and Loo et al.[16] on improving working memory by tDCS.

Table 1. Descriptive information on working memory and clinical symptoms

Groups	Pretest			Posttest			Follow-up		
Working memory	Mean ± SD	Skewness	Elongation	Mean ± SD	Skewness	Elongation	Mean ± SD	Skewness	Elongation
Mindfulness	76.80 ± 2.30	0.64	-0.58	70.13 ± 2.66	0.53	-0.52	68.67 ± 1.63	-0.51	0.33
tDCS	75.47 ± 2.13	0.96	0.03	64.13 ± 1.40	-0.44	1.52	63.33 ± 1.29	0.19	0.12
Control	76.00 ± 3.74	0.29	0.66	75.40 ± 3.26	0.69	1.14	73.67 ± 1.63	-0.96	0.58
Clinical symptoms									
Mindfulness	85.00 ± 1.69	-0.20	-0.64	47.70 ± 1.54	-0.91	0.07	46.60 ± 1.24	-0.65	-0.32
tDCS	58.73 ± 1.90	-0.62	1.89	47.20 ± 1.78	0.35	-0.19	47.07 ± 1.62	-0.46	0.50
Control	58.33 ± 0.65	-0.62	-0.65	58.40 ± 1.72	0.24	0.75	58.27 ± 1.48	-0.22	0.65

tDCS: Transcranial direct current stimulation; SD: Standard deviation

Table 2. Descriptive information on working memory and clinical symptoms

Variable	Phase	F	Df1	Df2	P
Working memory	Pretest	1.82	2	42	0.17
	Posttest	3.15	2	42	0.06
	Follow-up	0.37	2	42	0.68
Clinical symptoms	Pretest	2.83	2	42	0.07
	Posttest	0.10	2	42	0.90
	Follow-up	0.08	2	42	0.91

df: Degree of freedom

Table 3. Repeated measures analysis of variance (ANOVA) for mindfulness and transcranial direct current stimulation (tDCS) groups

Variable	Teste	Phase	Mindfulness			tDCS			Control		
			Mean difference	SD	P	Mean difference	SD	P	Mean difference	SD	P
Working memory	Pre-test	Post-test	6.66	0.61	> 0.01	11.33	0.65	> 0.01	0.60	0.28	> 0.05
		Follow-up	8.13	0.76	> 0.01	12.13	0.54	> 0.01	2.33	1.09	> 0.05
	Post-test	Follow-up	1.46	0.81	> 0.05	0.80	0.22	> 0.01	1.73	0.97	> 0.05
Clinical symptoms	Pre-test	Post-test	10.60	0.61	> 0.01	11.53	0.66	> 0.01	-0.06	0.50	> 0.05
		Follow-up	11.40	0.55	> 0.01	11.66	0.65	> 0.01	0.06	0.44	> 0.05
	Post-test	Follow-up	0.80	0.10	> 0.05	0.13	0.35	> 0.05	0.13	0.32	> 0.05

tDCS: Transcranial direct current stimulation; SD: Standard deviation

Table 4. The difference in effectiveness between the two groups (mindfulness and electrical stimulation)

Variable	Groups		Mean difference	Standard error	P
Working memory	Mindfulness	tDCS	4.22	0.63	< 0.001
Clinical symptoms	Mindfulness	tDCS	-0.33	0.39	0.040

tDCS: Transcranial direct current stimulation

Application of tDCS to the DLPFC for 5 consecutive days could cause long-term improvements in neuropsychological function and the clinical course of ADHD. This hypothesis was confirmed in the present study and is in line with previous studies such as Soff et al.[9] and Castellanos and Proal[10] that have applied anodal stimulation to this area. Previous studies have suggested that hyperactivity syndrome in patients with ADHD may be due to increased arousal and decreased inhibition in the motor network. Since the activity of the motion network is affected by DLPFC, it can be argued that stimulation of the DLPFC region improves network efficiency and reduces hyperactivity.[10]

According to the results, mindfulness activities play a particularly important role in increasing the relevant mental abilities and working memory. This finding is in line with the results of Rajabian et al.,[5] and Ghorbani and Khalilian[6] which showed the effectiveness of mindfulness-based metacognitive therapy in improving cognitive symptoms in people with ADHD. The reason is that working memory is a multi-component system responsible for actively storing information. In line with the study of Gilbert et al.,[24] results of this study showed that mindfulness could be used to reduce the symptoms of ADHD in adolescents and youth. Mindfulness training and tDCS in the context of Iranian culture also have a positive effect on people with ADHD and by identifying these people, these therapies can be used as an innovative treatment in this area.

It is worth noting that according to the neuroimaging study of Mitchell et al., structural changes occur in the forehead brain areas during mindfulness exercises.[25] In fact, mindfulness itself can increase the cognitive control mechanisms of the forehead area and it raises the issue of overlap between the mechanism of action of intervention methods and the reinforcement of results. This means that mindfulness and transcranial electrical stimulation both strengthen the common areas of the frontal cortex. Therefore, the simultaneous effectiveness of these two methods on the studied variables can be due to the fact that common cortical regions are manipulated in both methods. The results and evidence of this study are contradictory to this issue in the other study stating that cross-sectional and short-term training is not possible to change neural and biological structures.

The present study had limitations such as small sample size, convenience sampling method, sample selection just from men, and not controlling the intelligence variable. Further, due to the long duration of the MBCT, the fatigue of the learners can be seen. Due to the fact that the selected sample is related to Rasht City, the generalization of the results to other parts of the country should be done with caution.

Conclusion

The current findings indicate that tDCS and even mindfulness can somewhat adjust the regions of the brain that are affected by ADHD, and therefore enhance the performance of memory. Thus, these new and innovative treatment methods could be used by psychiatrists, psychologists, and psychotherapists in psychiatric clinics and psychological service centers as a method of intervention and prevention.

Conflict of Interests

Authors have no conflict of interests.

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References

1. American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-5™. 5th ed. Arlington, VA: American Psychiatric Publishing; 2013.
2. Hassan zadeh S, Amraei K, Samad zadeh S. A meta-analysis of attention deficit/hyperactivity disorder prevalence in Iran. Empow Except Children. 2019; 10(2): 165-77. [In Persian].
3. Clavenna A, Bonati M. Safety of medicines used for ADHD in children: a review of published prospective clinical trials. Arch Dis Child. 2014; 99(9): 866-72.
4. Zahmatkesh YZ, Dortaj F, Sobhi Gharamaleki N, Kiamanesh AR. The effectiveness of mindfulness training on increasing working memory capacity and academic self-efficacy of girl students. J Res Educ Syst. 2018; 12: 13-26. [In Persian].
5. Rajabian A, Asghari M, bigdeli A. The effectiveness of mindfulness-based cognitive therapy in improving working memory, inhibition, and cognitive flexibility in people with generalized anxiety disorder. [Thesis]. Mashhad, Iran: Ferdowsi University; 2017. [In Persian].
6. Ghorbani M, Khalilian R. Effects of mindfulness training on working memory and behavioral inhibition for adults with attention deficit/hyperactivity. Adv Cogn Sci. 2016; 18(3): 90-100. [In Persian].
7. Hölzel BK, Carmody J, Vangel M, Congleton C, Yerramsetti SM, Gard T, et al. Mindfulness practice leads to increases in regional brain gray matter density. Psychiatry Res: Neuroimaging. 2011; 191(1): 36-43.
8. Brem S, Grünblatt E, Drechsler R, Riederer P, Walitza S. The neurobiological link between OCD and ADHD. Atten Defic Hyperact Disord. 2014; 6(3): 175-202.
9. Soff C, Sotnikova A, Christiansen H, Becker K, Siniatchkin M. Transcranial direct current stimulation improves clinical symptoms in adolescents with attention deficit hyperactivity disorder. J Neural Transm (Vienna). 2017; 124(1): 133-44.
10. Castellanos FX, Proal E. Large-scale brain systems in ADHD: beyond the prefrontal-striatal model. Trends Cogn Sci. 2012; 16(1): 17-26.
11. Ohn SH, Park CI, Yoo WK, Ko MH, Choi KP, Kim GM, et al. Time-dependent effect of transcranial direct current stimulation on the enhancement of working memory. Neuroreport. 2008; 19(1): 43-7.
12. Andrews SC, Hoy KE, Enticott PG, Daskalakis ZJ, Fitzgerald PB. Improving working memory: the effect of combining cognitive activity and anodal transcranial direct current stimulation to the left dorsolateral prefrontal cortex. Brain Stimul. 2011; 4(2): 84-9.
13. Berryhill ME, Jones KT. TDCS selectively improves working memory in older adults with more education. Neurosci Lett. 2012; 521(2): 148-51.
14. Fregni F, Boggio PS, Nitsche MA, Marcolin MA, Rigonatti SP, Pascual-Leone A. Treatment of major depression with transcranial direct current stimulation. Bipolar Disord. 2006; 8(2): 203-4.
15. Wolkenstein L, Plewnia C. Amelioration of cognitive control in depression by transcranial direct current stimulation. Biol Psychiatry. 2013; 73(7): 646-51.
16. Loo CK, Alonzo A, Martin D, Mitchell PB, Galvez V, Sachdev P. Transcranial direct current stimulation for depression: 3-week, randomised, sham-controlled trial. Br J Psychiatry. 2012; 200(1): 52-9.
17. Chamberlain SR, Robbins TW, Winder-Rhodes S, Müller U, Sahakian BJ, Blackwell AD, et al. Translational approaches to frontostriatal dysfunction in attention-deficit/hyperactivity disorder using a computerized neuropsychological battery. Biol Psychiatry. 2011; 69(12): 1192-203.
18. Bédard AC, Newcorn JH, Clerkin SM, Krone B, Fan J, Halperin JM, et al. Reduced prefrontal efficiency for visuospatial working memory in attention-deficit/hyperactivity disorder. J Am Acad Child Adolesc Psychiatry. 2014; 53(9): 1020-30.e6.
19. Hill AT, Fitzgerald PB, Hoy KE. Effects of anodal transcranial direct current stimulation on working memory: A systematic review and meta-analysis of findings from healthy and neuropsychiatric populations. Brain Stimul. 2016; 9(2): 197-208.
20. Bandeira ID, Guimarães RS, Jagersbacher JG, Barretto TL, de Jesus-Silva JR, Santos SN, et al. Transcranial direct current stimulation in children and adolescents with attention-deficit/hyperactivity disorder (ADHD): A pilot study. J Child Neurol. 2016; 31(7): 918-24.
21. Halperin JM, Healey DM. The influences of environmental enrichment, cognitive enhancement,

and physical exercise on brain development: can we alter the developmental trajectory of ADHD? Neurosci Biobehav Rev. 2011; 35(3): 621-34.
22. Mokhtari H, Rabiei M, Salimi SH. Psychometric properties of the Persian version of adult attention-deficit/hyperactivity disorder self-report scale. Iran J Psychiatry Clin Psychol. 2015; 21(3): 244-53. [In Persian].
23. Arjmandnia AA, Rafikhah M. The role of working memory on the performance of executive functions in students with learning disabilities. Shenakht J Psychol Psychiatr. 2015; 1(3): 31-43. [In Persian].
24. Gilbert DL, Isaacs KM, Augusta M, Macneil LK, Mostofsky SH. Motor cortex inhibition: a marker of ADHD behavior and motor development in children. Neurology. 2011; 76(7): 615-21.
25. Mitchell JT, Zylowska L, Kollins SH. Mindfulness meditation training for attention-deficit/hyperactivity disorder in adulthood: current empirical support, treatment overview, and future directions. Cogn Behav Pract. 2015; 22(2): 172-91.