



Effect of Transcranial Direct Current Stimulation on Food Craving, Attention Bias to Food, and Cognitive Flexibility in People with Binge Eating Disorder

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Abstract

Background and Objective: This study aimed to investigate the effect of transcranial direct current stimulation (tDCS) on food craving, attention bias to food, and cognitive flexibility in people with an eating disorder.

Materials and Methods: This is a pilot study with pre-test and post-test design and a control group. The study population consisted of 40 persons with an eating disorder who were purposefully selected using Binge Eating Scale, General Health Questionnaire, and clinical interview based on DSM-5 criteria. The participants were randomly divided into experimental and control groups. A pre-test was performed using a craving questionnaire, cognitive flexibility questionnaire, and food bias assessment tool based on the dot-prob paradigm. The intervention consisted of 10 sessions of two milliamperes tDCS in the dorsolateral prefrontal cortex (DLPFC) area. Data analysis was conducted using SPSS software (version 23) through multivariate analysis of covariance.

Results: Based on the obtained results, tDCS treatment had a significant effect on food bias, cognitive flexibility, and food craving in people with overeating disorder ($P \leq 0.05$). Moreover, the results remained stable at the 45-day follow-up after the posttest.

Conclusions: Based on the results, the tDCS method along with other major therapeutic and psychological interventions can be effective in binge eating disorder. Therefore, the tDCS method can be promising and helpful as a suitable treatment modality with few side effects along with other major therapeutic interventions for patients with binge eating disorders.

Keywords: Attentional bias, Binge eating disorder, Cognitive flexibility, Food craving, Transcranial direct current stimulation



Background

Binge eating is the most common eating disorder and the most important public health concern around the world [1]. According to the American Psychiatric Association, binge eating disorder (BED) is defined as the recurrent episodes of binge eating that occur on average at least once a week without regular use of compensatory weight control behaviors for three consecutive months [2]. The prevalence of this disorder in the general population is estimated at about 3% [3]. Obesity and BED are common chronic diseases associated with dysfunction, pain, physical and mental illness, and death [4]. However, only a few studies have examined the development of BED [5]. One of the most important factors in BED is attentional bias to food, which refers to capturing of attention by a specific stimulus (i.e. food) when the person is exposed to multiple stimuli at the same time [6]. People with eating disorders have a more

attentional bias to food, are less sensitive to reward, and have changes in brain activity in areas related to impulsivity and compulsive behaviors [7]. It is believed that attentional bias to food is common in obese people [8].

Food craving means an intense desire to eat, which is manifested by excessive consumption of food. Cellular and molecular studies have shown that causative factors of food craving are related to neurobiological systems and pathways in the brain [9]. Research has shown that tDCS treatment reduces food craving [10]. Increasing the activity of the right dorsolateral prefrontal cortex (DLPFC) may strengthen inhibitory control. This inhibitory control is a core component that governs executive self-regulatory processes and goal-oriented eating behavior. It should be noted that tDCS suppresses reward-related activity in the reward-cognition neural circuits that drive food craving and overeating [11].

Cognitive flexibility is one's ability to control unexpected conditions. Prefrontal cortex (PFC) dysfunction leads to impairments in cognitive flexibility [12]. Response inhibition and cognitive flexibility depend on the processing of PFC data [13]. People with eating disorders frequently show inflexible behaviors, including eating-related problems. Most studies have examined the effect of PFC damage on cognitive flexibility and have shown that a decrease in cognitive flexibility is associated with increased damage to PFC [14]. The predominant assumption is that an imbalance in electrical activity in the orbits of the prefrontal cortex and the limbic system may be the main force supporting various aspects of binge eating behaviors [15]. The DLPFC has been recognized as an area in the brain involved in cognitive control and the functional mechanism predicted to suppress food craving in brain stimulation interventions [16].

Many patients are reluctant to use current treatments [17]. The long-term effects of drug therapy and drug discontinuation are not yet clear in BED therapy, and the lack of this information calls into question the safety and effectiveness of drug therapy [18]. Medications are effective in suppressing appetite, however, the effect of the drug can often be observed after a few weeks. Accordingly, it is necessary to use other methods capable of reducing the disturbed behaviors of people with BED in the shortest treatment period with the least negative effect.

The tDCS, as a non-invasive tool, has a high capacity for brain stimulation [19]. The tDCS is a low-cost, non-invasive tool used to alter neural activity and behavior [20]. Research has shown that tDCS is effective in reducing food craving as an electrical brain stimulation technique [16].

Psychological therapies, such as cognitive-behavioral therapy, are selective therapies for the entire spectrum of patients with BED [21]; however, this type of treatment requires an appropriate level of education and cognitive processing ability and keeps a wide range of people out of the treatment circle.

Objectives

The present study aimed to evaluate the effectiveness of tDCS on food craving, cognitive flexibility, and attentional bias to food in people with BED.

Materials and Methods

This randomized experimental controlled trial has a pre-test, post-test design, and follow-up stages. The study population consisted of all patients with BED who were referred to the diet and weight management clinics in Omidieh, Khuzestan Province in Iran, between June and July 2019. In total, 85 candidates were selected for the interview

after informed consent was obtained from the participants.

Inclusion criteria included the age range of 20-60 years, a score above 17 on the Binge Eating Scale, the presence of BED based on clinical interviews and following DSM5 diagnosed by a clinical psychologist, and the minimum education of secondary school. However, the exclusion criteria included a history of epilepsy; a history of brain trauma or surgery; use of anticonvulsant or antipsychotic medications or regular use of benzodiazepines in the past month; cognitive impairment or major psychiatric disorder, such as a history of suicide; the existence of metal objects or electronic implants in the body, such as an artificial cardiac pacemaker or cochlear implants; pregnancy; individual or family history of seizures; a history of endocrine or autoimmune disease; and a history of weight-loss drugs or participation in concomitant weight-loss programs during the intervention process. After the interview, 40 people were purposefully selected and randomly assigned to experimental and control groups.

Data collection tools

Food Cravings Questionnaire-Trait (FCQ-T) [22]

This questionnaire consists of 39 items. Kachuei and Ashrafi [23] showed that the Persian version of this scale has suitable validity and reliability for measuring food craving in the Iranian population. In the present study, the reliability of the scale was confirmed by Cronbach's alpha of 0.81.

Binge Eating Scale (BES)

In this 16 items scale, scores below 17 indicated the absence of BED [24]. Mootabi et al. [25] reported Cronbach's alpha of 0.85 for this scale. The sensitivity and specificity of the Persian version of BES were determined at 84.6 and 80.8, respectively, using the cut-off point of 17. In this study, the reliability of this scale was confirmed by Cronbach's alpha of 0.68.

General Health Questionnaire-28 Items (GHQ-28I)

The GHQ-28 measures anxiety, social dysfunction, depression, and physical symptoms. The validity and reliability of this questionnaire have been improved [26]. In this study, the reliability of this scale was confirmed by Cronbach's alpha of 0.72.

Cognitive Flexibility Inventory (CFI)

This 20-item self-report questionnaire was developed by Dennis, Vander Wal [27] and is scored based on a 7-point Likert scale. Dennis, Vander Wal (2010) showed that this questionnaire had a suitable factor structure and convergent and

concurrent validity. In Iran, the test-retest reliability and Cronbach's alpha coefficient for this scale were obtained at 0.71 and 0.90, respectively [28]. In this study, the reliability of this scale was confirmed by Cronbach's alpha of 0.75.

Attentional Bias to Food Test

This tool was developed and validated by researchers using Flash software and dot-probe task. In total, 300 images from different foods and 300 neutral images were selected and homogenized graphically to develop the dot-probe task for attentional bias to food. The content validity of this test was measured using 300 selected images of foodstuffs and non-edible materials which were displayed for 50 students with mental health who did not have BED. Finally, 200 images of emotional stimuli (food) and 200 neutral images were selected based on the scores given to each image.

A task was performed to investigate differential validity for a group (n=60) of individuals with BED based on the BES questionnaire and clinical interview, and another group (n=60) without BED after the task was compiled in a computer format. The results showed a significant power in distinguishing between two groups. The reliability of the task with Cronbach's alpha and test-retest methods was obtained at 0.96 and 0.81, respectively, indicating the appropriate reliability of the task.

Both experimental and control groups answered the BES, Attentional Bias to Food test, and CFI questionnaires. A briefing session was then held for the experimental group to familiarize the participants with the brain stimulation method. After the research units agreed to participate in the intervention, the written informed consent was obtained from the subjects. The tDCS intervention program was implemented individually and with a predetermined schedule in 10 sessions by a clinical psychologist that was trained in tDCS. At the

beginning of each tDCS session, the subject sat on a comfortable chair with the anode and cathode electrodes on the left and right sides of the DLPFC, respectively. Subjects received 2 mA current with 35-cm² electrodes for ten 20-minute sessions three times a week. The proper connection between the electrodes and the skull was maintained by immersing the sponges in a 0.9% saline solution. Sham mode of the device was used for the control (sham/placebo) group which created a feeling of irritation in the subject only in the first and last 30 seconds. The described steps were an accepted routine for the stimulation [10,29]. During the interventions, the final sample size in each group was reduced to 16 due to the lack of proper cooperation of four persons from the intervention group. The post-test was performed after interventions and 45 days follow-up.

Results

The demographic characteristics of participants are presented in Table 1. There is no significant difference in demographic variables between the two groups and the experimental and control groups were homogeneous in terms of demographic profile (Table 1).

The mean and standard deviation of all main research variables in both experimental and control groups are presented in Table 2.

The ANCOVA method was used to investigate the effect of the intervention on post-test scores after its assumptions were fulfilled. The results are presented in Tables 3 and 4.

There is a significant difference in at least one of the dependent variables (craving, attentional bias to food, and cognitive flexibility) between the two groups in the post-test phase (Table 3). The one-way ANCOVA in the MANCOVA environment was performed on the dependent variables to investigate the cut-off point.

Table 1. Demographic characteristics

Group	Gender (N)		Education level (N)			Weight M (SD)	Height M (SD)	Age M (SD)
	Female	Male	Diploma	Associate	Bachelor			
TDCS	10	6	4	5	7	81.56 (19.14)	162.62 (9.03)	30.25 (6.45)
Control	10	6	3	3	10	82.19 (9.55)	165.56 (9.98)	32.25 (8.97)
P	0.06		0.15			0.90	0.39	0.47

Table 2. Descriptive findings of research variables

Group	Craving M (SD)			Attention bias M (SD)			Cognitive flexibility M (SD)		
	Pre-test	Post test	Follow-up	Pre-test	Post-test	Follow	Pre-test	Post-test	Follow-up
TDCS	151.38 (19.06)	131.94 (36.09)	135.63 (30.59)	7.56 (21.80)	-1.44 (20.02)	-0.50 (18.63)	91.06 (17.78)	98 (16.96)	96.50 (17.01)
Control	154.56 (28.28)	154.19 (28.17)	154.38 (28.35)	9.56 (22.54)	10.88 (21.66)	10.69 (20.85)	89.06 (17.10)	89.25 (17.92)	88.88 (17.59)

Table 3. Multivariate analysis of covariance (MANCOVA) results

Test	Value	F	df	Error df	Sig	Eta
Pillai's Trace	0.33	4.27	3	25	0.01	0.33
Wilk's lambda	0.66	4.27	3	25	0.01	0.33
Hotelling's trace	0.51	4.27	3	25	0.01	0.33
Roy's largest root	0.51	4.27	3	25	0.01	0.33

Table 4. Results of one-way analysis of covariance

Variable	Sum of squares	df	Mean squares	F	Sig	Eta
Craving	3086.78	1	3086.78	4.58	0.041	0.14
Attention bias	994.59	1	994.59	5.62	0.025	0.17
Cognitive flexibility	397.03	1	397.03	6.14	0.020	0.18

Table 5. Multivariate analysis of covariance results in the follow-up stage

Test	Value	F	df	Error DF	Sig	Eta
Pill's Trace	0.31	3.87	3	25	0.02	0.31
Wilk's Lambda	0.68	3.87	3	25	0.02	0.31
Hotelling's Trace	0.46	3.87	3	25	0.02	0.31
Roy's Largest Root	0.46	3.87	3	25	0.02	0.31

Table 6. Results of one-way analysis of covariance in the follow-up stage

Variable	Sum of squares	df	Mean squares	F	Sig	Eta
Craving	1985.27	1	1985.27	4.05	0.05	0.13
Attention bias	818.89	1	818.89	5.85	0.02	0.17
Cognitive flexibility	273.68	1	273.68	5.09	0.03	0.15

There is a significant difference in the post-test scores in terms of the dependent variable of craving ($F=4.85$; $P=0.041$), cognitive flexibility ($F=6.14$; $P=0.020$), and attentional bias to food ($F=5.62$; $P=0.025$) between the two experimental and control groups (Table 4).

The ANCOVA test was performed on the follow-up phase to determine the persistence of the outcomes in the follow-up phase, the results of which are listed in Tables 5 and 6.

There is a significant difference between the two groups in the follow-up phase at least in terms of one of the dependent variables including craving, attentional bias to food, and cognitive flexibility (Table 5). One-way ANCOVA in MANCOVA environment was performed on the dependent variables to investigate the cut-off point.

There is a significant difference in the follow-up scores in terms of the dependent variable ($F=4.05$; $P=0.05$) of cognitive flexibility ($F=5.85$; $P=0.02$) and attentional bias to food ($F=5.09$; $P=0.03$) between the two experimental and control groups (Table 6).

Discussion

This study aimed to investigate the effectiveness of tDCS on food craving, attentional bias to food, and cognitive flexibility in people with BED. The findings showed that tDCS significantly reduced food craving and attentional bias to food and increased cognitive flexibility in people with BED. Attained results are consistent with the other results

in this field [30-33].

The attentional bias causes people with BED to selectively focus on eating stimuli and ignore other stimuli. This selective attention ultimately directs one's responses to the relevant stimuli [34]. People with eating disorders were less reward sensitive and had changes in brain activity in the areas (striatum and insular cortex, prefrontal cortex, and impulse-control networks) related to impulsivity and compulsive behavior [7], resulting in an attentional bias toward food. Impulsivity reflects decisions that occur with limited anticipation, and a tendency to act hastily indicates an enhanced reward-related drive. In contrast, compulsivity is characterized by repetitive and continuous actions that are not related to an overall goal or reward and can continue despite adverse consequences [7,35]. Factors that cause food cravings are associated with neurobiological systems and pathways in the brain. Direct electrical stimulation from the skull reduces the food craving [10]. Neuroimaging in relation to obesity revealed that an imbalance in the electrical activity in the orbits of the prefrontal cortex and the limbic system is the main driving force for binge eating behaviors [15]. Therefore, the changes and stimuli caused by tDCS can change the performance of the reward system and play a role in attention control in these patients.

Three main mechanisms involved in craving control include 1) a system consisting of the brainstem, hypothalamus, and autonomic nerves that interact with gastrointestinal hormones to create a sense of

hunger or satiety; 2) a stimulus system that works with the elements involved in memory and learning to create a desire to eat food, and 3) the self-regulatory system that regulates appetite based on the person's living conditions [36]. The DLPFC is involved in eating disorders and its decreased activity can lead to eating disorders [37]. In addition, stimulation of glutamatergic neurons can alter the dopaminergic sensitivity of the reward pathway which in turn reduces the patient's craving for certain foods [30]. Apart from changes in cravings, stimulation of the limbic system can play a role in controlling the symptoms of these patients by increasing cognitive control [16] and decreasing appetite [30]. Stimulation of these regions by tDCS improves their neuronal function due to the fact that the tDCS optimizes the function and structure of neurons.

Cognitive flexibility refers to one's ability to change thoughts or think in several different ways at the same time. This concept refers to a person's mental ability to adjust his/her attention or thinking in response to changes in environmental stimuli. The DLPFC plays a key role in this shift process [38]. Therefore, stimulation of this region can force the nervous system to learn new patterns at the cost of losing previous patterns and improve cognitive flexibility as a result [14]. Moreover, it should be noted that tDCS is effective in the reduction of stress [39], since, the factors such as stress act as triggers for BED behavior in people with this disorder.

The findings of this study are inconsistent with the results of some similar studies. However, the literature review revealed that a single therapy session might be considered as an intervention in these studies and that studies holding several therapy sessions reported the effectiveness of this method on obesity and eating disorders [30]. In addition, inconsistencies in outcomes may be justified by the fact that different regions of the brain were stimulated in different studies [40].

Regarding the limitations of the present study, one can refer to the poor collaboration of some subjects and the specific age range of the participants which might have affected the study results. Future studies are recommended to measure variables such as the weight and age of the individuals in the long run to determine the persistence of outcomes.

Conclusion

Based on the obtained results, tDCS can improve the function of certain regions of the brain involved in the development of eating disorders. Therefore, the use of this treatment is recommended to therapists active in the field of eating disorders.

Compliance with ethical guidelines

The participants were informed about the study purpose and the stages at the beginning of the study. The informed consent was obtained from the participants and they were assured of the confidentiality of their information. Moreover, the participation in the study was based on willingness and the participants were free to withdraw from the study at any time.

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Authors' contributions

The first, second, and corresponding author designed the study and wrote the protocol. The third author conducted the literature review and managed the data gathering stage. R. A and P. E conducted the statistical analysis. The corresponding author wrote the first draft of the manuscript and all the authors approved the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest regarding the publication of this study.

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