

# The effectiveness of transcranial direct current stimulation on the brain-behavioral systems of adolescents with high-risk behaviors

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Received 2024-09-10; Accepted 2024-09-22; Online Published 2025-06-01

## Abstract

**Introduction:** Risky behaviors are destructive behaviors that people commit voluntarily, or without knowing the adverse personal and social consequences, and cause the health and well-being of adolescents to be at risk. The aim of this study was to investigate the effectiveness of transcranial direct current stimulation on the brain-behavioral systems of adolescents with high-risk behaviors.

**Methods:** This research was a quasi-experimental study with pre-test and post-test with the control group, and a follow-up Study. The participants consisted of the research included all male students of the second secondary level with high-risk behaviors in Tabriz city in the academic year of 2019-2020. The research sample included 30 students with high-risk behaviors (15 in the experimental group and 15 in the control group). To collect data, the high-risk behavior questionnaire of Iranian adolescents and brain-behavioral systems were used.

**Results:** Pairwise comparison results showed that direct transcranial current stimulation treatment had an effect on behavioral inhibition ( $P < 0.01$ ) and activation ( $P < 0.01$ ) systems.

**Conclusion:** According to the findings of this research, it was found that transcranial direct current stimulation had an effect on the brain-behavioral systems of students with high-risk behaviors.

**Keywords:** Transcranial direct current stimulation, brain-behavioral systems, high-risk behaviors.

**Citation:** Askarimehrabadi E, Lak Chalsepary GH, Dehghan H, Sharifi Borujerdi M. The effectiveness of transcranial direct current stimulation on the brain-behavioral systems of adolescents with high-risk behaviors. Int J Travel Med Glob Health, 2025;13(2):104-110. doi: 10.30491/ijtmgh.2024.477783.1428

## Introduction

Risky behaviors are behaviors that have adverse effects on the growth and overall health of people that can hinder success and growth, these behaviors can lead to physical injuries or behaviors that have increasing negative effects such as drug abuse <sup>1</sup>. The most common risky behaviors are: Heavy alcohol use, substance abuse, unsafe sex, reckless driving, dangerous sports, gambling, unrestrained and illegal activities. Research shows that the most common occurrence of these behaviors is in the school environment and can lead to high rates of illness and death among students <sup>2</sup>. Most literature on adolescent consequences of risky behaviors focuses on risky behaviors as outcomes, with some studies examining other outcomes such as educational attainment and

employment. Risky behaviors beget other risky behaviors. The fact that adolescent risky behaviors often co-occur makes engaging in any one risky behavior a risk factor for engaging in another <sup>3</sup>.

In examining personality factors effective in high-risk behaviors, it is important to examine the biological-neurological dimension of personality that can be the basis of emotion and behavior. Gray's theory of "reinforcement sensitivity" is a biological approach to personality that has been used more than Eysenck's theory to explain people's uncontrollable passion in high-risk behaviors <sup>4</sup>. According to Gray's theory, three neurocognitive systems determine people's sensitivity to reinforcing events and experiencing different emotions.

The three systems "Behavioral Inhibition System" (BIS), " Behavioral Activation System" (BAS) and " Fight-Flight-Freezing System" (FFFS) are the basis of individual differences and the activity of each of these brain-behavioral systems, emotional reactions It inspires different people <sup>5</sup>. Behavioral Inhibition System (BIS) is sensitive to punishment signs, frustrating signs of lack of reward and exposure to new stimuli, and the output of this system is arousal, passive avoidance, anxiety and inhibition. This system produces inhibition and avoidance responses through the activity of noradrenergic and serotonergic neurotransmitters; Behavioral Activating System (BAS) is another system of personality theory that is sensitive to signs of reward and lack of punishment, this system regulates the desire to be close to rewarding stimuli by means of dopaminergic neurotransmitters, and impulsivity is related to it is the dominance of the activity of this system. The Fight-Flight-Freezing System (FFFS) is also the third brain-behavioral system that invokes avoidance and escape behaviors and fear in the face of annoying conditional and unconditional stimuli <sup>6</sup>. Following the presentation of Gray's theory, various researchers proposed the hypothesis that the dysfunction of the brain-behavioral systems causes psychiatric disorders <sup>7</sup>, for example, the presence of high BAS in people is associated with an increased risk of drug and alcohol abuse <sup>8</sup>. Also, there is a positive relationship between people's sensitivity in BAS and alcohol consumption. Another thing is that the low level of BIS was related to high-risk behaviors <sup>9,10</sup>. Also, reducing the activity of the BAS system causes the stimuli to be unattractive and rewarding for the person, and thus the person is vulnerable to depression symptoms <sup>11,12</sup>.

Considering neurodevelopmental etiology and cognitive and neuropsychological variables involved in high-risk behaviors, it seems that one of the treatments that can affect the prevention and reduction of high-risk behaviors is transcranial direct current stimulation (tDCS) <sup>13</sup>. Transcranial direct current stimulation intervention is one of the non-invasive methods that are established to stimulate the function of neurons in the brain based on the ability of the magnetic field to pass through the skull and brain membranes and as a result induce electric current in the brain tissue. In the transcranial direct current stimulation method, anode is used to increase cerebral cortex excitation and cathode is used to reduce it <sup>14</sup>. In other words, in this method, using large electrodes that are placed on the person's head, a continuous and mild electric current is passed through the head <sup>15</sup>. The effectiveness of transcranial direct current stimulation depends on the direction of the current current; anodal stimulation increases brain activity and arousal, and

cathodal stimulation, on the contrary, decreases activity<sup>16</sup>. This current is provided by a direct current generator caused by a battery, and by using it, long-term changes in the polarity of the cerebral cortex are created following the depolarization and hyperpolarization of neurons and the effect on neuroreceptors. There are studies that indicate the possible effectiveness of this type of non-psychological treatment method on various emotional cognitive functions (for example <sup>17,18</sup>). Hassani and Sepahmansoor showed in a research that treatment of tDCS on behavioral inhibition students with A personality type and active behaviour making students with behavioral type B meaningful impact <sup>19</sup>. Sergiou et al showed in a research that treatment of tDCS reduced impulsivity and aggressive behaviors in subjects <sup>20</sup>. The study of Gilmore et al. showed that tDCS treatment reduced risk-taking behavior in veterans with clinically relevant impulsivity <sup>21</sup>. In a study, Khalifa et al showed that tDCS treatment led to a reduction in impulsivity and aggression in adults with mild intellectual disabilities <sup>22</sup>. On the other hand, it seems that there is a research gap in the research literature related to the effectiveness of this type of intervention, therefore, special research attention is needed. Therefore, based on research statistics, the treatment of transcranial direct current stimulation has been done very little in the case of disorders such as high-risk behaviors, which is still a deep gap. Finally, it can be acknowledged that considering that the direct stimulation method is a painless, cost-effective, safe and effective method that can be easily used <sup>23</sup>. It is noteworthy that risky behaviors have an intensifying or strengthening effect on each other and in many cases they occur together. For example, in most cases, addiction is associated with violence, smoking, and high-risk sexual behaviors <sup>24,25</sup>. Therefore, according to the mentioned cases, the aim of the present study was the effectiveness of transcranial direct current stimulation on the brain-behavioral systems of adolescents with high-risk behaviors.

## Materials and Methods

This research was a quasi-experimental study with pre-test and post-test with the control group, and a follow-up group. The participants consisted included all high school boys with high-risk behaviors in Tabriz city (East Azerbaijan province, Iran). 30 adolescents were selected from among the adolescents with high-risk behaviors who were screened based on the risk-taking questionnaire and signed the informed consent form to participate in the research and were replaced in two experimental and control groups (15 people in each group) using Inclusion criteria and Exclusion criteria. Data Collection tools:

### 1. Iranian Adolescents Risk-taking Scale (IARS):

To measure high-risk behaviors, the Persian version of the high-risk behavior scale for youth and adolescents, which was designed and adjusted by adapting the high-risk behavior questionnaire of the American Center for Disease Control, was used. The version used in this research has 38 items and was designed and standardized by Zadeh Mohammadi et al. in 2010. This questionnaire includes seven subscales of drug addiction, alcohol addiction, smoking addiction, violence addiction, sexual behavior addiction, opposite sex addiction, and dangerous driving addiction. The results indicate that the reliability of the risk-taking questionnaire and its subscales is at an appropriate and desirable level, so that Cronbach's alpha for the overall scale is 0.941, dangerous driving 0.746, violence 0.784, smoking 931. 0, drug use 0.90, alcohol use 0.909, sexual relationship and behavior 0.876, and friendship with the opposite sex 0.83 have been obtained <sup>26</sup>. It should be noted that the reliability of the above instrument was obtained using Cronbach's alpha of 0.75.

### 2. Behavioral Inhibition/ Activation Systems Scale:

The main form of these scales are scales with 20 questions, which consist of two general factors of inhibition (7 questions) and activator (5 questions). In this form, the activation factor is composed of three subscales: reward (5 questions), motivation (4 questions) and search (4 questions) <sup>27</sup>. Behavioral inhibition refers to the expected level of sensitivity to anxiety when a person is under the influence of punishment cues (for example, I feel anxious when I feel that I have done something incompletely). Reward-based responding indicates the extent of the reward's effect in creating energy and positive emotions (for example, when I get what I need, I feel full of energy). Traction dimensions mean a person's active orientation towards attractive goals (for example, when I feel I need something, I try with all my might to achieve it). The search-based response subscale means the tendency to search for new stimuli and engaging in rewarding activities (for example, I look for new and exciting situations). The behavioral activation subscale has thirteen items, which measures the sensitivity of the

behavior activation system, and the minimum score in this subscale is 13 and the maximum is 52. In this tool, each statement has a four-point response scale ranging from completely disagree (score 1) to completely agree (score 4). Cronbach's alpha was reported as 0.74 for inhibition scale, 0.73 for activation scale, 0.76 for incentive reward, and 0.66 for search (27). In Atri Fard et al.'s study, the internal consistency of the behavioral inhibition scale is equal to 0.47 and the internal consistency of the behavioral activation system scale is 0.47 and its subscales, i.e. drive, response to reward and entertainment seeking, respectively, are 0.60, 0.73 and 0.18 has been obtained <sup>28</sup>. It should be noted that the reliability of the above instrument was obtained using Cronbach's alpha of 0.81.

### Treatment protocol

The participants sat on a comfortable chair in a quiet room without other sensory stimuli and received current brain stimulation with a tDCS device (Mind A Life device made in Canada) for 20 minutes with a constant current between 1.5 and 2 mA (intensity according to the patient's tolerance) was induced to teenagers. The sessions were done every other day and in the number of 20 sessions, using a pair of rubber electrodes 5 x 5 cm square covered with synthetic sponge soaked in normal salt water solution and placed in the desired areas. It should be noted that cathodal and anodic stimulation were placed in the left dorsolateral prefrontal brain region (DLPFC1). Analysis of variance with repeated measurements and SPSS-23 software were used for data analysis. The intervention was carried out by the researcher (PhD student of psychology) under the supervision of Dr. Tabatabai with expertise in Neuroscience and at Bozorgmehr Counseling Center in Tabriz.

### Results

The mean and standard deviation of age in the experimental group was  $16.800 \pm 1.146$  and the mean and standard deviation of age in the control group was  $17.00 \pm 1.195$ .

**Table 1.** Mean and standard deviation of research variables.

Variable	Group	Experimental		Control		Shapiro-Wilk
		M	SD	M	SD	P
Behavioral Inhibition System	Pre- test	12.133	3.335	11.933	3.453	0.42
	Post-test	19.733	4.267	12.133	522.3	0.40
	Follow up	21.200	3.405	14.466	3.542	0.07
Behavioral Activation System	Pre- test	37.333	8.474	37.600	9.006	0.82
	Post-test	24.333	7.668	35.133	7.936	0.96
	Follow up	20.667	5.094	34.733	8.639	0.11

As can be seen in [table 1](#), the mean and standard deviation of the research variables in the pre-test, post-test and follow-up are reported in the experimental and control groups. Repeated measurement variance analysis was used to determine the difference in measurements

and intra- group and inter-group comparison, before which assumptions related to this analysis are examined. All repeated measurement assumptions such as normality of data, homogeneity of variances, etc. were checked and confirmed.

**Table 2:** Results of repeated measures analysis of variance for research variables.

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	P	Partial Eta Squared
Behavioral Inhibition System	371.28	2	185.64	18.85	0.001	1.00
Behavioral Inhibition System* Group	357.42	2	178.71	18.15	0.001	1.00
Behavioral Activation System	1089.86	2	544.93	11.61	0.001	0.99
Behavioral Activation System* Group	962.48	2	481.24	10.25	0.001	0.98

According to the [table 2](#), it can be said that the effect of time factor on inhibitory components ( $F=18.85$ ;  $F=0.01$ ) and activation ( $F=11.61$ ;  $0.001$ ) were significant. In other words, their pre -test levels until follow-up have significant changes. Also the effect of time and group interaction indicates that inhibition scores (Partial  $\eta^2=0.39$ ;  $F=18.15$ ;  $P=<0.01$ ), Activation (Partial  $\eta^2=0.29$ ;  $F=10.25$ ;  $P=<0.01$ ) There is a difference in two groups.

That is, the interventional effect of direct stimulation of the transcendental stimulation has made significant changes on inhibition and activation components, however comparing the couples in the following [table](#) shows a more accurate inference from the effectiveness of each interventions and their stability in their sustainability.

**Table 3:** Summary of Bonferroni Multiple Comparison Test for Groups.

Variable	Group	Evaluation (I)	Evaluation (J)	Mean difference (I_J)	standard error	P
Behavioral Inhibition System	Experimental	Pre- test	Post-test	-6.93	0.97	0.001
			Follow up	-9.53	1.24	0.001
		Post-test-	Pre- test	6.93	1.97	0.001
			Follow up	2.60	1.00	0.064
	Control	Pre- test	Post-test	-0.13	1.24	1.000
			Follow up	-0.06	1.42	1.000
		Post-test	Pre- test	0.13	1.24	1.000
			Follow up	0.06	0.87	1.000
Behavioral Activation System	Experimental	Pre- test	Post-test	12.73	1.56	0.001
			Follow up	15.33	2.60	0.001
		Post-test	Pre- test	-12.73	1.56	0.001
			Follow up	2.60	1.79	0.508
	Control	Pre- test	Post-test	-0.86	2.03	1.000
			Follow up	1.20	3.33	1.000
		Post-test	Pre- test	0.86	2.03	1.000
			Follow up	2.06	3.13	1.000

As can be seen in [table 3](#), the pairwise comparison between the dependent variables "inhibition" (I-J=6.93;  $P<0.001$ ) and "activation" (I-J=12.73;  $P<0.017$ ) from pre-test to post-test in the treatment group (tDCS) has a significant difference in contrast to the control group.

## Discussion

The aim of the present study was to investigate the effectiveness of transcranial direct current stimulation on the brain-behavioral systems of adolescents with high-risk behaviors. Based on the pairwise comparison between the dependent variables "inhibition" and "activation" from pre-test to post-test, there is a significant difference in the treatment group (tDCS) as opposed to the control group. Also, the examination of the stability of treatment from post-test to follow-up also shows that there is no significance between the averages from post-test to follow-up, that is, the treatment effect was not different between post-test and follow-up, as a result, the treatment was stable. This finding is in line with the results of Sergiou et al. [20](#), Bettis et al. [29](#) and Alaei et al. [30](#). Sergiou et al. [20](#) showed in a research that transcranial direct stimulation reduces aggressive behaviors in people. Shahmohammadi Kaleybar et al. showed in a research that direct transcranial current stimulation caused an increase in response inhibition in patients with obsessive-compulsive disorder [31](#). The effectiveness of transcranial direct electrical stimulation depends on the direction of the electrical current; Anodic stimulation increases brain activity and arousal, and condylar stimulation, on the contrary, decreases activity [16](#). Vaghef et al. in a research entitled the effectiveness of transcranial direct current stimulation on risky decision reaction time and selective attention in people with symptoms of depression showed that transcranial direct current stimulation reduces risky decision making in students [32](#). In this regard, Brunoni et al. In a research, showed that the direct transcranial current stimulation reduced depression, increased cognitive control, and reduced risky behaviors [33](#).

Following the Gary theory, in the form of (brain-behavioral systems theory) focuses on the existence of a relationship between personality dimensions and brain processes and points to the role of biological-neural factors to explain individual differences [34,35](#). In this regard, activity considers the establishment and dominance of brain-behavioral systems in people as the factor that causes individual differences in the attention and selection of stimuli and the emergence of behavior. For example, the behavioral activating system (BAS), is the neurophysiological basis of impulsivity and is associated with positive emotions and is activated by positive stimuli. High activity of this system leads to behavioral and bipolar disorders. While the behavioral inhibition system (BIS) is the neurophysiological basis of anxiety and is related to negative emotions and stimuli. Excessive activity of this system causes anxiety disorders

in childhood, and defects in its activity are associated with ADHD and risky behaviors [36](#). Decreasing the activity of the BAS system causes the stimuli to be unattractive and rewarding for the person, and thus the person becomes vulnerable to depression symptoms [37](#). Researches have shown that when the sensitivity of the behavioral inhibition system is low, the person does not react to the signs of punishment, and this increases the probability of antisocial behavior [38,39](#). In the explanation above, it can be stated that as long as the activity of the behavioral inhibition system in adolescents improves through anodic stimulation that increases the level of activity and arousal of the brain; It causes the behavioral inhibition system to keep a person aware of the possibility of danger or punishment and facilitate avoidance behavior. On the other hand, cathodal stimulation reduces the activity of the behavioral activation system, which is active in relation to reward signs and engages the person in tendency behaviors, which in turn reduces the activity of the behavioral activation system and thus prevents the occurrence of risky behaviors in the person [40](#). On the other hand, transcranial direct current stimulation through the effect on GABA and dopamine causes a change in the inhibitory and activating behaviors of the brain. Increasing inhibition and decreasing activation of behavior causes people to turn to risky behaviors.

## Conclusion

Pairwise comparison results showed that direct transcranial current stimulation treatment had an effect on behavioral inhibition ( $P<0.01$ ) and activation ( $P<0.01$ ) systems. According to the findings of this research, it was found that transcranial direct current stimulation had an effect on the brain-behavioral systems of students with high-risk behaviors.

One of the major limitations of this research is the lack of control of other factors affecting high-risk behaviors (life history, family conditions, social and economic class, or the level of social support of individuals). Due to the time limitations of implementing the techniques and using the educational techniques needed for other problems of the participants after the end of the treatment period and also the lack of continuity of proper communication of the majority of the participants with the therapists, other psychological states of the people involved in the problem were not investigated during the treatment period. Therefore, the mentioned conditions face the generalization of the results with caution. Considering the limitations of intergroup research methods (experimental research), it is suggested that researchers use single-subject experimental designs to investigate the effectiveness of transcranial direct current stimulation in the future. It is suggested to apply intervention methods by different experts to increase the credibility of this treatment method and their generalizability.

**Highlights****What Is Already Known?**

Research shows that transcranial direct current stimulation increases excitability in target brain areas, and increased excitability in specific brain areas causes changes in cognitive and behavioral performance in individuals. A review of intervention studies shows that this type of treatment can be used as a promising method in the treatment of various psychological disorders at young and old ages. On the other hand, studies indicate that the research literature on the effectiveness of this new type of intervention has a research gap; a gap that requires research attention. For example, some studies have only studied the effectiveness of working memory; because it is believed that working memory is more often associated with learning problems compared to other cognitive skills; therefore, according to research statistics, transcranial direct current stimulation treatment has been used very little for disorders such as self-injurious behaviors, which is still a deep gap.

**What Does This Study Add?**

The results showed that as long as the activity of the behavioral inhibition system in adolescents is improved through anodic stimulation that increases the level of brain activity and arousal, this causes the behavioral inhibition system to keep the individual alert to the possibility of danger or punishment and facilitates avoidance behavior. On the other hand, Cathodic stimulation reduces the activity of the behavioral activation system that is active towards reward cues and engages the individual in propensity behaviors, which in turn reduces the activity of the behavioral activation system and, as a result, prevents the occurrence of self-injurious behaviors in the individual. On the other hand, this effect of transcranial direct electrical stimulation on behavioral brain systems can be due to the effect on neurotransmitters and neuroplasticity of nerve cells. Transcranial direct current stimulation causes changes in inhibitory and activating behaviors of the brain through its effect on GABA and dopamine. Increasing inhibition and decreasing behavioral activation reduce individuals' tendency to engage in self-injurious behaviors.

**Authors' Contributions**

Study design and data analysis: All authors. Investigation and drafting the manuscript: All authors; Final. Approval: All authors.

**Acknowledgements**

We are extremely grateful to all the participants in this research, it should be noted that the data of this research has been registered under the ethics code number: IR.IAU.TABRIZ.REC.1399.146 in the Faculty of Medicine of Tabriz University of Medical Sciences.

**Conflicts of Interest Disclosures**

The authors declared no conflict of interest.

**Consent For Publication**

not applicable

**Ethics approval**

not applicable

**Funding/Support**

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

**The extent of AI use**

not applicable

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