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Research Paper

A Comparative Study on the Effectiveness of tDCS[1] and Motivational Interviewing on Self-Control and Craving Reduction in Male Narcotic Addicts

Abstract

Introduction and Objective: This study aims to compare the effectiveness of transcranial direct current stimulation (tDCS) and motivational interviewing in enhancing self-control, and reducing drug craving among men addicted to narcotics.

Research Methodology: This is a quasi-experimental applied research study that was conducted from 2024 to 2025~~o 2025~~. The statistical population consisted of male drug addicts supported by the Imam Khomeini Relief Foundation in Alborz Province, specifically those referred to the Rose Clinic and the Article 16 Addiction Treatment Camp in Kalak, Karaj. A total of 60 participants were selected through convenience sampling and randomly assigned to four groups: 15 received tDCS, 15 underwent sham stimulation, 15 received motivational interviewing, and 15 served as a control group. The research instruments included the Drug Desire Questionnaire (DDQ) and the Self-Control Scale. Data analysis was conducted using descriptive statistics and repeated measures ANOVA via SPSS version 24.

Findings: Both tDCS and motivational interviewing significantly reduced drug craving ($P \leq 0.05$). However, unlike motivational interviewing, tDCS did not show a significant effect on self-control. Follow-up analysis two months later revealed that the effects of motivational interviewing on craving were more enduring than those of tDCS.

Conclusion: Given the longer-lasting impact of motivational interviewing, it is recommended that specialized training programs be developed for psychologists and addiction treatment professionals to enhance their use of motivational interviewing in therapeutic settings.

Keywords:

Addiction, Drug Craving, Motivational Interviewing, Self-Control, Transcranial Direct Current Stimulation (tDCS)

[1] Transcranial Direct Current Stimulation

Introduction

Substance use disorder is increasingly conceptualized as a chronic and relapsing condition in which drug-seeking behavior continues despite harmful psychological, social, and physiological consequences (Zilverstand et al., 2018). Contemporary neurocognitive models suggest that this persistence reflects disruption in reward processing, salience attribution, inhibitory control, and executive functioning rather than merely poor personal choice (Zilverstand & Goldstein, 2020).

According to the impaired Response Inhibition and Salience Attribution model, addiction involves both excessive motivational salience of drug-related cues and weakened capacity to inhibit substance-seeking responses, which directly connects the two major outcomes of the present study: craving and self-control (Zilverstand et al., 2018; Zilverstand & Goldstein, 2020). Self-control refers to the ability to regulate internal responses, interrupt undesired behavioral tendencies, and refrain from acting on impulses. Low self-control has been associated with substance-related problems, including alcohol abuse, heroin addiction, and adolescent and adult substance abuse (Tangney et al., 2004). In addiction, impaired self-control is considered one of the core clinical symptoms alongside craving, negative mood, and increased stress reactivity, and is related to dysfunction in control-related neural systems, including prefrontal, anterior cingulate, and striatal circuits (Tang et al., 2015). Therefore, self-control in substance use disorder should be understood not only as a general personality trait, but also as a clinically relevant regulatory capacity that may influence craving, treatment adherence, and relapse vulnerability.

Craving is a central feature of substance use disorder and refers to a psychological urge to use substances that may be activated by internal states or external drug-related cues (Chan et al., 2024). It is clinically important because it is closely associated with relapse and difficulty maintaining abstinence after treatment (Sinha, 2013). Neurobiological evidence suggests that craving reflects interaction between reward-related pathways and cortical regions involved in cognitive control, especially the dorsolateral prefrontal cortex, anterior cingulate cortex, orbitofrontal cortex, and ventral striatum (Chan et al., 2024). Thus, examining craving together with self-control is consistent with addiction models that emphasize abnormal cue salience and weakened executive regulation (Mehta et al., 2024). Motivational interviewing is relevant to addiction treatment because people with substance dependence often experience ambivalence about quitting, which can interfere with motivation, treatment engagement, and sustained behavioral change. As a client-centered and goal-directed counseling method, MI helps individuals explore ambivalence and strengthen their own reasons for change (Miller, 2023). Evidence suggests that MI may reduce substance use in short-term follow-up, although effects vary across comparison conditions and follow-up periods (Schwenker et al., 2023). More specifically, MI has been shown to improve self-control and self-efficacy while reducing temptation and relapse-related outcomes among clients undergoing substance abuse treatment (Andarz et al., 2025). In an Iranian study, Farhoodi et al. (2014) also reported that MI reduced cognitive impulsivity, motor impulsivity, and non-planning impulsivity among methadone-treated substance users. These findings suggest that MI may improve addiction outcomes by strengthening motivational and self-regulatory processes, not only by reducing substance use directly. Recent MI literature also shows that its clinical value extends to treatment engagement, therapeutic alliance, self-efficacy, cultural responsiveness, and commitment to change. Hurlocker et al. (2023) emphasized the initial intake session as a critical point for disengagement in outpatient addiction treatment and proposed MI at intake as a person-centered strategy for strengthening treatment entry, attendance, and completion. Qualitative evidence indicates that therapist behaviors consistent with the MI spirit, such as collaboration, acceptance, empathy, and evocation, may support therapeutic relationship and self-efficacy for change (Ingesson Hammarberg et al., 2023). In addition, culturally adapted MI can incorporate clients' values, goals, cultural context, and treatment preferences while preserving the core principles of MI (Self et al., 2023). Because client characteristics such as age may also moderate MI outcomes, motivational interventions may not operate uniformly across all clinical groups (Kuerbis et al., 2023). In parallel with psychological interventions, transcranial direct current stimulation has been examined as a non-invasive neuromodulation method that may influence cortical excitability and functional connectivity in brain regions involved in craving and cognitive control (Mehta et al., 2024). The dorsolateral prefrontal cortex is a key target because it contributes to executive control, inhibitory regulation, decision-making, working memory, and top-down regulation of behavior (Klauss et al., 2014; Mehta et al., 2024). Experimental and clinical evidence has shown that DLPFC stimulation can reduce alcohol craving in heavy drinkers and craving in crack-cocaine dependence, although effects are not always consistent across outcomes (Den Uyl et al., 2015; Batista et al., 2015).

Similarly, a narrative review of tDCS for cocaine addiction concluded that right DLPFC stimulation appears promising for reducing craving, while emphasizing the need for further controlled studies (Chmiel et al., 2023). Clinical evidence on tDCS in substance-related disorders has produced promising but variable findings. Repetitive bilateral tDCS over the DLPFC has been reported to reduce relapse probability in severe alcohol dependence, although craving scores did not differ significantly between groups (Klauss et al., 2014). Bifrontal tDCS has also shown greater short-term reduction in alcohol craving than sham stimulation at one-week and four-week follow-ups, but not at eight weeks, suggesting that its craving-reducing effect may be acute rather than stable (Gairola et al., 2024). In opioid dependence, combining tDCS with emotion regulation training produced greater reductions in current drug craving and drug-use thoughts and fantasies than either intervention alone (Kooteh et al., 2020). These findings suggest that tDCS may affect craving and relapse-related outcomes, but its effectiveness may depend on stimulation protocol, substance type, follow-up duration, and whether neuromodulation is combined with psychological intervention. Evidence from nicotine use and behavioral addiction further suggests that transcranial electrical stimulation may influence addiction-related cognitive processes, although these findings should be interpreted cautiously because the target populations differ from narcotic dependence. Gwon et al. (2023) discussed the potential of tDCS for improving nicotine-related outcomes such as craving and smoking behavior and recommended using objective indicators and cognitive variables such as self-regulation in future research. Chen et al. (2024) found that tDCS and exergaming were associated with improvement in executive control and decision-making in smartphone addiction, linking tDCS to inhibitory-control mechanisms relevant to addiction models. In nicotine-dependent individuals, Ghasemi et al. (2023) found that alpha-frequency transcranial alternating current stimulation improved inhibitory control but did not significantly affect impulsivity, highlighting the distinction between inhibitory control, impulsivity, and self-control. The literature on brain stimulation and self-regulation therefore remains mixed. Laskov et al. (2023) examined tDCS effects on inhibitory control in healthy young adults using the Stroop task and did not find clear superiority of active stimulation over sham stimulation. Machado et al. (2024), in a systematic review and meta-analysis, also concluded that current evidence is insufficient to support the clinical use of tDCS or rTMS for reducing impulsivity in individuals with mental disorders, despite some scale-specific trends. These findings suggest that the effects of non-invasive brain stimulation on self-regulatory outcomes may be more variable than its effects on craving, possibly due to differences in stimulation site, number of sessions, sample characteristics, and outcome measurement (Laskov et al., 2023; Machado et al., 2024). Recent evidence has also expanded the possible role of tDCS beyond immediate craving reduction. Neuroimaging findings indicate that tDCS can modify executive-control, default-mode, and salience-network activity implicated in nicotine withdrawal and relapse vulnerability (Aronson Fischell et al., 2020). Meta-analytic evidence suggests that tDCS can produce a moderate reduction in craving in substance addiction, although effects differ according to substance type and stimulation parameters (Chan et al., 2024). Broader reviews of neuromodulation therapies also report medium but variable effects of tDCS on drug use and craving in substance use disorders, indicating that stimulation site, session number, follow-up duration, and clinical condition should be considered when interpreting outcomes (Mehta et al., 2024; Salemi & Sobhi-Gharamaleki, 2024; Trojak et al., 2016). More recently, Salmani et al. (2025) found that repeated prefrontal tDCS improved treatment motivation and cognitive emotion regulation in individuals with substance use disorder during abstinence. Because motivation, emotion regulation, craving, and self-control are closely connected in recovery, comparing tDCS with MI may clarify whether a neuromodulatory or a psychological-motivational intervention produces more stable therapeutic changes over time.

Accordingly, the present study asks whether transcranial direct current stimulation and motivational interviewing differ in their effectiveness in enhancing self-control and reducing drug craving among men with substance dependence.

Methodology

Population, Sample and Sampling Method

This study is applied in nature and employs a quasi-experimental design for data collection which was implemented from 2024 to 2025~~o 2026~~. The target population consisted of male amphetamine and opiate addict individuals under the supervision of the Imam Khomeini Relief Committee in Alborz Province, specifically those referred to the Rose Clinic and the Kalaak Karaj Substance Abuse Treatment Center (Camp of Article 16 of the Anti-Narcotics Law). A total of 60 participants were selected using convenience sampling. Before random assignment, participants’ mental health status was assessed through a clinical interview guided by DSM-V diagnostic criteria (American Psychiatric Association, 2022) and the study inclusion and exclusion criteria. The interview was used to screen for severe psychiatric disorders, acute psychological instability, and psychological conditions that could interfere with participation in the intervention sessions or affect the interpretation of the study outcomes. In addition, participants' general medical history and possible contraindications for tDCS, including a history of seizure, serious head injury, implanted metallic devices, or major neurological conditions, were reviewed based on self-reported medical history. Individuals who met the study criteria and did not present psychological or medical conditions that could compromise intervention safety or outcome interpretation were included in the study.They were randomly assigned into four groups: 15 participants received transcranial direct current stimulation (tDCS), 15 received sham stimulation (electrodes placed without actual stimulation to control for placebo effects), 15 underwent motivational interviewing, and 15 served as a control group with no intervention. Participants were excluded if they expressed unwillingness to continue or experienced physical complications. All participants completed the study.

Instruments

1. Desire for Drug Questionnaire (DDQ):

Developed by Franken, Hendricks, and Van den Brink (2002), the DDQ assesses current craving as a motivational state. It contains 14 items across three subscales: (1) desire and intention to use, (2) craving and negative reinforcement, and (3) pleasure and loss of control. These subscales are highly correlated. Franken et al. reported Cronbach's alpha coefficients of .85 for the total scale and 0.77, 0.80, and 0.75 for the subscales. In a study by Poorseyed(2012), reliability was reported as 0.82 for the total scale and 0.70, 0.82, and 0.70 for the subscales. Internal consistency was also confirmed for different substance groups: opium (0.86), crack (0.95), smoked heroin (0.94), inhaled heroin (0.94), and injected heroin (0.98).

2. Self-Control Scale:

The second instrument was the Self-Control Scale developed by Grasmick et al. (1993), designed to measure individual differences in self-control. It consists of 24 items rated on a Likert scale and includes six dimensions: impulsivity, preference for simple tasks, risk-seeking, preference for physical activities, self-centeredness, and emotional instability. Reliability was reported at 0.90. In studies by Sarmad et al. (2011) and Imani et al. (2019), Cronbach's alpha exceeded 0.70.

Intervention Procedure

1. Initial Steps:

Participants were briefed on the study protocol and provided informed consent in accordance with the Helsinki Declaration. Eligibility criteria included a history of substance use exceeding one year, current methadone maintenance therapy, and no concurrent psychiatric medication. Exclusion criteria included prior tDCS experience, presence of metal implants or prosthetics in the head or face, psychotic disorders (assessed via clinical interview), No history of seizures or epilepsy, as well as no tumor, heart disease, heart failure.or pacemakers.

2. Pre-Intervention Phase:

Eligible participants were randomly assigned to four groups. Substance use type was matched across groups. Group 1 (n=15) received 10 sessions of active tDCS (30 minutes each). Group 2 (n=15) underwent 8 sessions of motivational interviewing (45–60 minutes each). Group 3 (n=15) received sham tDCS. Group 4 (n=15) served as a no-treatment control. All tDCS sessions were administered by the same technician. One day before treatment, participants completed the DDQ and the Self-Control Scale as pre-tests.

3. Intervention Phase:

In the tDCS group, electrical stimulation was administered by the researcher, who was trained and certified in qEEG, tDCS, and neurofeedback, over 10 sessions, each lasting 30 minutes, while participants were seated in a comfortable position. Electrode placement followed the standard 10–20 EEG system: to enhance self-control, the anode was placed over F3 and the cathode was positioned on the right extracephalic region (RS); for craving reduction, the cathode was placed over F3 and the anode over F4 (Vollstädt-Klein, et al., 2025; Fecteau, et al., 2007; Dedoncker, et al., 2016; Kekic, et al., 2016). In the motivational interviewing group, the intervention was delivered over eight sessions of 45 to 60 minutes, based on the Miller (2013) protocol. The descriptions and titles of the sessions are as follows:

session 1: Getting to know the client better and creating a sense of trust in the client

session 2: Identifying patterns of substance use and explaining treatment
session 3: Expectations from substance use (examining mental and emotional states during use and also hearing the reasons for the need for substances)
session 4: Reaching the client's cognitive contradictions and understanding the need for change (moving from the denial or pre-reflection stage to the pre-reflection to reflection stage), reducing the client's emotions and stress
Session 5: Increasing the motivation to change and trying to get the client to the readiness stage; creating appropriate relationships with others and improving self-esteem
Session 6: Teaching critical thinking, communication, facilitating goal-setting in the client and making them understand the need for planning and goal-setting to enter the action stage
Session 7: Moving towards what the client wants to be (achieving goals) by adopting self-efficacy and creating continuous motivation in the client and using influential people in the family and those around them; having a balanced life.
Session 8: Emphasis on the need to deal with high-risk events and the need to constantly remind the client of goals and contradictions, values and what is most important to the client in such a way that the client is stabilized in the maintenance stage and confronting temptations and impulses of consumption to prevent relapse.

Data Analysis

Descriptive and inferential statistics were used. Descriptive statistics included mean and standard deviation. Inferential analysis was conducted using Repeated measures Anova via SPSS version 24.

Results

In this study, the demographic characteristics of the participants revealed that the average age of men with substance dependence across all groups was approximately 40 to 41 years. In terms of age distribution, most individuals fell within [2]the 25 to 50 age range. Marital status analysis indicated that the majority of participants were married, with a smaller proportion being single. Regarding education, most subjects had a high school diploma or less, and only a small percentage held university degrees. Additionally, employment data showed that most of the men studied had stable jobs, with only a limited number reported as unemployed at the time of the research. Economically, the findings suggested that the majority of participants belonged to lower income deciles and had modest or poor living standards. Overall, the descriptive results indicate that the research sample was relatively homogeneous in terms of age and social background, with most participants characterized by low to moderate economic status, average educational attainment, and married marital status.

Table 1: Descriptive Statistics of Research Variables in Male Drug Addicts Assessed in Three Phases

Variables	Groups	Pretest		Posttest		Follow-up	
		M	SD	M	SD	M	SD
Self-control	tDCS	54.93	6.5	57.73	9.28	55.4	5.7
	MI	52.33	4.9	76	10.18	75.73	5.18
	Sham tDCS	58	6.16	57.66	5.97	57.46	6.32
	Control	55.81	7.32	62.58	11.16	62.35	10.71
Drug craving	tDCS	52.13	9.7	25.6	6.2	57.13	9.7
	MI	45.93	3.35	30.53	3.87	32.8	4.87
	Sham tDCS	36	16.23	36.33	16.83	36.06	17.24
	Control	37.93	14.13	37.93	13.61	38.26	13.94

able 1 presents the mean scores of the evaluated variables among men with substance dependence across the tDCS, motivational interviewing, sham tDCS, and control groups at the pre-test, post-test, and follow-up stages. Based on the analysis of data obtained from questionnaires and statistical tests, all assumptions required for conducting ANCOVA and repeated measures ANOVA were met. Initially, given the nature of the Likert scale, all research variables were considered quantitative and measured at the interval level. The normality of data distribution was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests, which confirmed that the distributions of the two main variables—self-control and substance craving—followed a normal pattern, satisfying the normality assumption. Additionally, Levene’s test results indicated homogeneity of variances across the experimental and control groups, confirming the assumption of equal variances. The homogeneity of regression slopes test further showed that the interaction between the independent variable and covariates was not significant for any of the variables, thereby validating this assumption as well. Finally, Pearson correlation analysis revealed that the correlation coefficients among covariates were below 0.8, satisfying the assumption of low multicollinearity. Accordingly, all prerequisites for applying parametric tests in this study were fulfilled, and the data were deemed suitable for inferential analysis. Based on these conditions, the study proceeded to test its hypotheses regarding the comparative effectiveness of transcranial direct current stimulation (tDCS) and motivational interviewing on self-control and substance craving.

a)Comparing the Effectiveness of Transcranial Direct Current Stimulation (tDCS) and Motivational Interviewing on Self-Control

Initially, the effectiveness of two therapeutic interventions—transcranial direct current stimulation (tDCS) and motivational interviewing—was compared in improving self-control among men with substance dependence. To control for placebo and suggestibility effects, a sham tDCS group was also included, in which participants experienced the initial sensation of stimulation without the delivery of an effective electrical current.

Table 2: Results of One Way ANCOVA Examining Between Group Effects on Self Control among Male Drug Addicts

Type of Intervention	Sum of Squares	df	Mean Square	F	Sig.	η^2_p
tDCS	17.75	1	17.75	2.41	0.132	0.082
MI	3232.27	1	3232.27	66.83	0.001	0.712
Sham tDCS	12.03	1	12.03	2.95	0.097	0.099

The results of the univariate analysis of covariance (ANCOVA) indicated that only the motivational interviewing intervention led to a statistically significant improvement in participants’ self-control scores ($P < 0.01$). In contrast, no significant differences were observed in self-control scores within the tDCS and sham tDCS groups ($P > 0.05$). Therefore, motivational interviewing was deemed statistically effective and practically beneficial. Moreover, based on the eta squared value ($\eta^2 = 0.71$), motivational interviewing accounted for approximately 71% of the variance in self-control changes, reflecting a strong and clinically meaningful effect size. In comparison, the effect sizes for the tDCS and sham tDCS interventions were weak and reported as ineffective. To examine the persistence of therapeutic effects, a repeated measures ANOVA was conducted, revealing significant effects of time and time × group interaction on the self-control variable ($P < 0.01$). The findings showed that in the motivational interviewing group, self-control scores increased significantly from pre-test to post-test and this improvement was sustained through the follow-up phase, whereas no such change was observed in the tDCS group.

Subsequently, to compare the effectiveness of the two interventions—transcranial direct current stimulation (tDCS) and motivational interviewing (MI)—on the self-control variable, a series of supplementary analyses were conducted. First, to control for the influence of pre-test scores, analysis of covariance (ANCOVA) was employed to ensure that any observed differences in later stages were attributable to the interventions rather than pre-existing group differences. Next, to examine changes in self-control scores over time within each group, repeated measures ANOVA was applied. In cases where the main effect of time or the time × group interaction was significant, Bonferroni-corrected pairwise comparisons were used to precisely identify differences between the pre-test, post-test, and follow-up stages. Subsequently, to assess differences between the two interventions at the post-test and follow-up stages, separate between-group ANOVAs were conducted. These analyses enabled a final comparison of the effectiveness of tDCS and MI and clarified the statistical significance of the observed differences at the specified time points. The results of these analyses served as the basis for the final interpretation of the interventions’ effects on self-control.

Table 3: Results of Mauchly's Test of Sphericity for Repeated-Measures ANOVA on Self-Control

Evaluated Variable	Mauchly's W	Approx. Chi-Square	df	Sig.
Self-control	0.669	10.85	2	0.004

Table 4: Results of Repeated Measures ANOVA to Determine the Effect of Motivational Interviewing on Self Control among Male Drug Addicts

Source		Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	3235.40	2	1617.70	73.00	0.001
	Greenhouse-Geisser	3235.40	1.50	2153.22	73.00	0.001
TIME × GROUP	Sphericity Assumed	2364.28	2	1182.14	53.34	0.001
	Greenhouse-Geisser	2364.28	1.50	1573.48	53.34	0.001

Table 5: Results of Bonferroni Post Hoc Test for Pairwise Comparison of Self Control Scores Across Three Measurement Phases in the MI Group

Type of Intervention	Phases Compared	Mean Difference	Std. Error	Sig.
MI	Pretest – Posttest	−12.30	1.25	0.001
	Pretest – Follow-up	−13.10	0.84	0.001
	Posttest – Follow-up	−0.80	1.47	1.000

Table 6: Results of ANOVA Comparing the Effectiveness of the Two Intervention Methods

Type of Intervention Comparison	Phase	Mean Difference	Std. Error	Sig.
tDCS vs MI	Posttest	−18.26	2.98	0.001
	Follow-up	−20.33	2.65	0.001

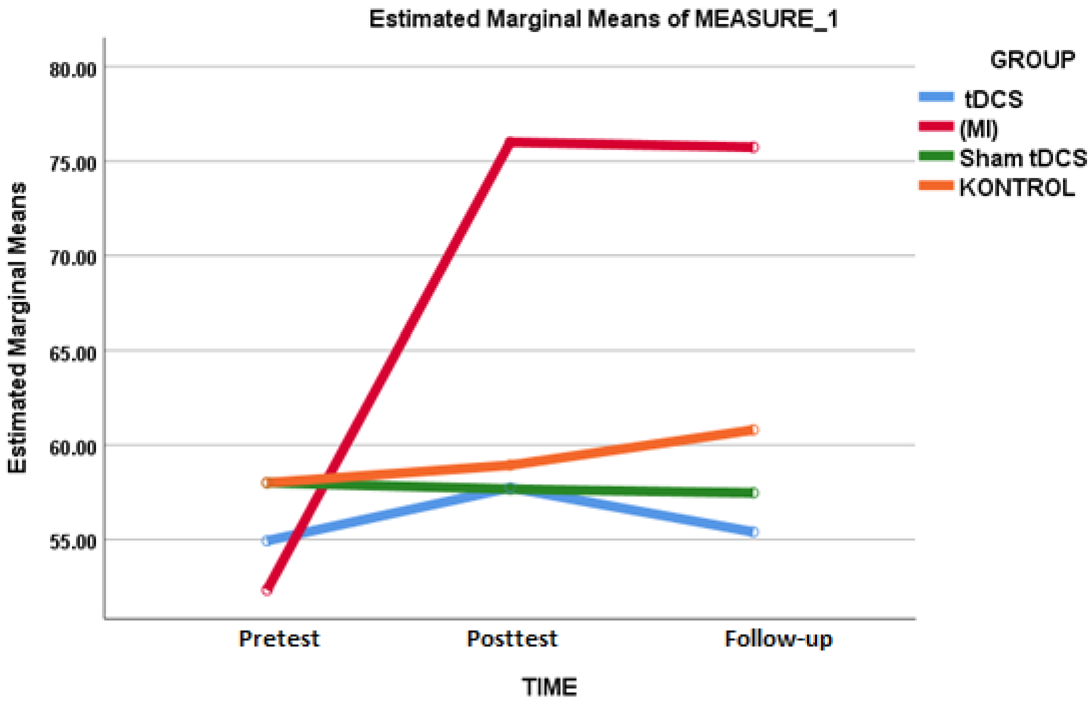

Figure 1: Trends of Self-Control across Pretest, Posttest, and Follow-up Phases by Intervention Type

The results of the repeated measures ANOVA (RM ANOVA) indicated that both the main effect of time and the time × group interaction were statistically significant ($P < 0.01$). Bonferroni-corrected within-group analyses revealed that the mean self-control scores in the motivational interviewing (MI) group increased significantly from pre-test to post-test and follow-up ($P < 0.01$), whereas no significant changes were observed in the tDCS and control groups ($P > 0.05$). To further examine differences between the two interventions at the post-test and follow-up stages, separate between-group ANOVAs were conducted. The results showed that at both time points, the mean self-control scores in the MI group were significantly higher than those in the tDCS group ($P < 0.01$). The effect size ($\eta^2 = 0.71$) indicated a very strong impact. Therefore, based on the between-group analyses at post-test and follow-up, it was concluded that motivational interviewing had a more substantial and sustained effect on enhancing self-control compared to transcranial direct current stimulation.

b) Comparing the Effectiveness of Transcranial Direct Current Stimulation (tDCS) and Motivational Interviewing (MI) in Reducing Substance Craving

In this hypothesis as well, the sham tDCS group was retained to control for non-specific stimulation effects, allowing for an unbiased comparison between the actual impact of electrical current and the cognitive-motivational effects of the intervention.

Table 7 : Results of One-Way ANCOVA Examining Between-Group Effects on Drug Craving among Male Drug Addicts

Type of Intervention	Sum of Squares	df	Mean Square	F	Sig.	η^2_p
tDCS	3008.18	1	3008.18	138.05	0.001	0.836
Motivational Interviewing (MI)	1450.01	1	1450.01	293.07	0.001	0.916
Sham tDCS	0.78	1	0.78	0.143	0.709	0.005

The results of the ANCOVA revealed a statistically significant difference among the three groups ($P < 0.01$), with the greatest reduction in substance craving observed in the motivational interviewing group. The eta squared value ($\eta^2 = 0.68$) indicated that the motivational intervention accounted for 68% of the variance in craving reduction, demonstrating a strong and clinically meaningful effect. In contrast, the effect size for tDCS was limited and statistically non-significant ($P > 0.05$).
To assess changes in craving across the pre-test, post-test, and follow-up stages, repeated measures ANOVA (RM ANOVA) was conducted. When a significant time effect was detected, the pattern of change was examined using Bonferroni-corrected within-group comparisons. Finally, to directly compare the two interventions at the post-test and follow-up stages, separate between-group ANOVAs were performed. These analyses clarified the extent to which the effectiveness of each method in reducing substance craving was sustained over time.

Table 8:Test of Sphericity for Repeated-Measures ANOVA on Drug Craving

Evaluated Variable	Mauchly's W	Approx. Chi-Square	df	Sig.
Drug Craving	0.887	6.60	2	0.037

Table 9: Results of Repeated-Measures ANOVA for the Effects of tDCS and Motivational Interviewing on Drug Craving among Male Drug Addicts

Source		Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	3162.63	2	1581.31	154.59	0.001
	Greenhouse-Geisser	3162.63	1.79	1760.32	154.59	0.001
TIME × GROUP	Sphericity Assumed	5493.05	6	915.50	89.50	0.001
	Greenhouse-Geisser	5493.05	5.39	1019.14	89.50	0.001

Table 10: Bonferroni Post-Hoc Test Comparing Drug Craving Scores across Three Phases in the Two Intervention Groups

Type of Intervention	Phase Comparison	Mean Difference	Std. Error	Sig.
tDCS	Pre test – Post test	12.33	0.86	0.001
	Pre test – Follow-up	−1.10	1.07	0.942
	Post test – Follow-up	−13.43	1.07	0.001
MI	Pre test – Posttest	7.70	0.41	0.001
	Pre test – Follow-up	6.40	0.74	0.001

Type of Intervention	Phase Comparison	Mean Difference	Std. Error	Sig.
	Post test – Follow-up	−1.30	0.69	0.206

Table 11: Results of ANOVA Comparing Drug Craving between the Two Intervention Methods (tDCS vs. Motivational Interviewing)

Type of Intervention Comparison	**Phase**	**Mean Difference**	**Std. Error**	**Sig.**
tDCS vs MI	Post test	−4.93	4.17	1.000
	Follow-up	19.33	4.50	0.001

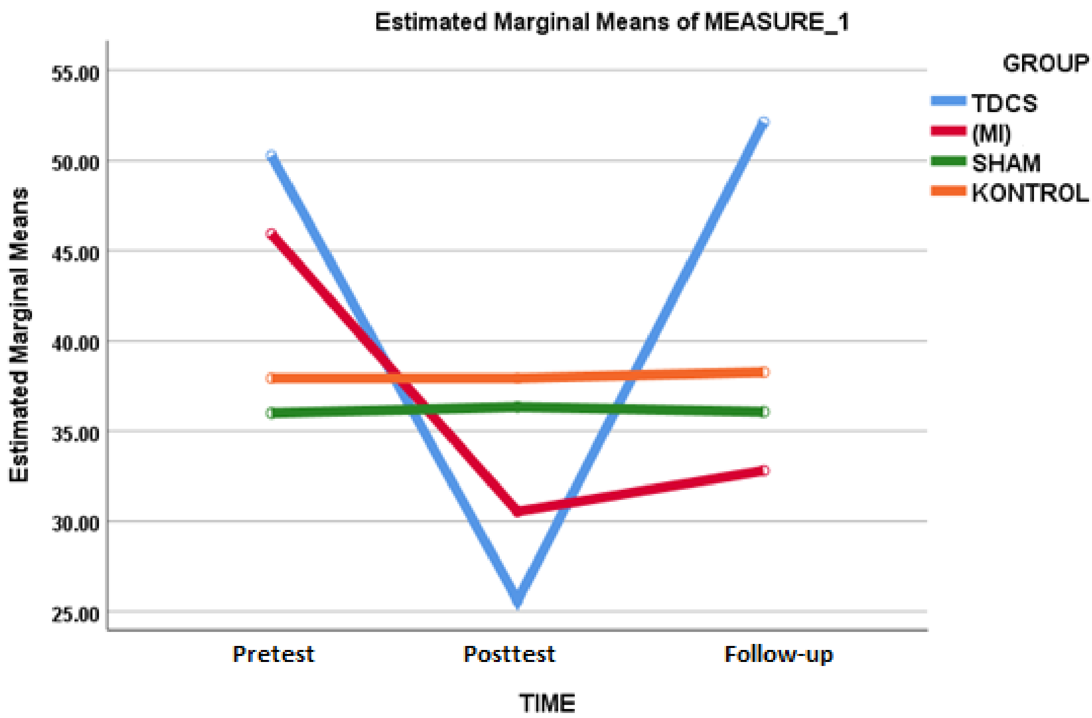

Figure 2: Trends of Drug Craving across Pretest, Post test, and Follow-up Phases by Intervention Type

To examine changes in substance craving across different time points, repeated measures ANOVA (RM ANOVA) was conducted. The results revealed a significant main effect of time as well as a significant time × group interaction ($P < 0.01$). Bonferroni-adjusted within-group comparisons showed that the mean craving scores in the motivational interviewing (MI) group decreased significantly from pre-test to post-test and follow-up ($P < 0.01$), whereas no significant changes were observed in the tDCS group ($P > 0.05$). To clarify the differences between the two treatment groups, between-group ANOVAs were performed at the post-test and follow-up stages. The findings indicated that the mean craving scores in the MI group were significantly lower than those in the tDCS group at both time points ($P < 0.01$). The effect size ($\eta^2 = 0.68$) reflected a very strong and sustained impact of MI in reducing substance craving. Based on the results of the between-group analyses, it can be concluded that motivational interviewing is more effective than transcranial electrical stimulation in reducing and maintaining control over substance craving.

Discussion and Conclusion

Transcranial Direct Current Stimulation (tDCS) and Motivational Interviewing both showed beneficial effects on drug craving among men with substance dependence; however, the pattern of change differed between the two interventions. The findings indicated that tDCS produced a clear reduction in craving immediately after the intervention, but this effect was not maintained at follow-up. In contrast, Motivational Interviewing produced a more stable reduction in craving across time. Moreover, regarding self-control, the findings showed that Motivational Interviewing had a significant and sustained effect, whereas tDCS did not produce a statistically significant or lasting improvement. Therefore, the results suggest that tDCS may have a more immediate effect on craving-related processes, while Motivational Interviewing may produce deeper and more durable changes by targeting motivational, cognitive, emotional, and self-regulatory mechanisms.

Regarding the effect of tDCS on craving, the present findings are generally consistent with previous evidence suggesting that stimulation of prefrontal regions may reduce craving-related outcomes in substance-related disorders, although the durability of these effects is variable. Gairola et al. (2024) reported that bifrontal tDCS reduced alcohol craving in the short term, but this effect was not maintained in later follow-up. Similarly, Chmiel et al. (2023), in a narrative review of tDCS for cocaine addiction, concluded that stimulation of the right dorsolateral prefrontal cortex appears promising for reducing cocaine craving, although further controlled studies are still needed. Experimental and clinical studies have also shown that DLPFC stimulation may reduce alcohol craving in heavy drinkers and craving among patients with crack-cocaine dependence (Den Uyl et al., 2015; Batista et al., 2015). In addition, Klauss et al. (2014) reported that repetitive bilateral tDCS over the dorsolateral prefrontal cortex reduced relapse probability in patients with alcohol dependence, although between-group changes in craving scores were not significant. Taken together, these findings support the present result that tDCS may reduce craving in the short term, but they also suggest that its long-term effectiveness may depend on stimulation protocol, target region, number of sessions, substance type, and follow-up duration.

This interpretation is further supported by Kooteh et al. (2020), who showed that combining tDCS with self-control and emotion regulation training reduced craving and relapse-related outcomes in opioid-dependent patients. Aronson et al. (2020) also showed that tDCS applied to prefrontal regions can modify cognitive circuits involved in nicotine withdrawal and relapse vulnerability. Trojak et al. (2016), Den Uyl et al. (2015), Klauss et al. (2014), and Batista et al. (2015) similarly reported that tDCS may influence alcohol- or cocaine-related craving outcomes, although the strength and stability of these effects varied across studies. Therefore, the present findings do not contradict the tDCS literature; rather, they suggest that tDCS may be more effective for immediate craving reduction than for maintaining long-term change.

In this context, tDCS is considered a non-invasive brain stimulation technique that uses low-intensity electrical currents to modulate activity in specific brain regions (Chen et al., 2024).
It is increasingly being explored as a potential treatment for a wide range of neurological and psychiatric disorders, including substance use disorders. Side effects are generally mild and transient, typically including headache, tingling, and itching at the stimulation site (Chmiel et al., 2023). Alternating current transcranial stimulation, which involves applying weak electrical currents through electrodes placed on the scalp, alters neuronal excitability.

This stimulation can lead to changes in brain activity and improve the functioning of regions involved in emotion regulation and stress control. One of the key target areas in tDCS is the dorsolateral prefrontal cortex, which plays a crucial role in emotional regulation and executive control (Gairola et al., 2024). By modulating activity in brain regions associated with emotional regulation and reducing neural excitability, tDCS may help improve psychological states. Moreover, transcranial stimulation can be used as an adjunctive therapy alongside other substance abuse treatments, such as cognitive behavioral therapy (Gwon et al., 2023).

Despite a slight increase in post-test mean scores, the effect of tDCS on self-control was not statistically significant and did not persist over time.
In line with these findings, Ghasemi et al. (2023) examined the effectiveness of alpha-frequency transcranial alternating current stimulation on inhibitory control and impulsivity in nicotine-dependent individuals. They reported that alpha-tACS improved inhibitory control, whereas no significant effect was observed on impulsivity. Therefore, although their findings partly support the potential role of transcranial electrical stimulation in inhibitory control, they also suggest that its effects on broader self-regulatory traits such as impulsivity may be limited. Previous research on non-invasive brain stimulation and self-regulatory processes has produced mixed findings. For example, Laskov et al. (2023) reported that tDCS may influence inhibitory control in healthy young adults, whereas Machado et al. (2024), in a systematic review and meta-analysis, concluded that there is currently insufficient evidence to support the clinical use of rTMS or tDCS for reducing impulsivity in individuals with mental disorders. These inconsistencies may be related to differences in stimulation protocols, target populations,

outcome measures, and whether self-control is assessed as a behavioral task, impulsivity-related construct, or broader psychological traitThese researchers reported that anodal stimulation over the right dorsolateral prefrontal cortex (DLPFC) can significantly enhance attention control, response inhibition, and logical decision-making.

The discrepancy between these findings and the present study may be attributed to several factors:

1. Differences in stimulation protocols: In the current study, a 2 mA current was applied for 20 minutes, whereas other studies used different intensities and electrode placements.
2. Differences in target populations: Most tDCS-related studies have been conducted on healthy individuals or patients with depression, not on men with substance dependence.
3. Combination of treatments: In many studies reporting positive outcomes, tDCS was administered alongside other cognitive or behavioral interventions, rather than as a standalone treatment.
4. Follow-up duration: While tDCS effects are often reported as short-term and transient, the present study found that its effects did not persist during a two-month follow-up period.
5. Use of alternative questionnaires: Many assessment tools measure aggression or impulsivity instead of self-control (Farhodi et al., 2014), which may appear similar at first glance but differ significantly upon closer examination. Self-control is a high-level cortical and complex brain process that requires comprehensive processing across multiple neural networks. In contrast, impulsivity and aggression may arise from various causes, particularly mood disorders such as depression, or dysfunction in specific neuro-organic pathways like the limbic system.

These findings suggest that the physiological nature of tDCS leads to rapid stimulation of neurotransmitters within one or two neural circuits, and thus, it may not be effective on its own in enhancing higher-order cognitive functions that require engagement of broader neural networks. In the absence of deeper cognitive and motivational changes, this intervention may prove ineffective or, like many medications, produce only temporary effects. On the other hand, Motivational Interviewing—by emphasizing value internalization, cognitive restructuring, and engaging multiple neural circuits within the prefrontal cortex—gradually enhances and stabilizes self-control skills over time. Kuerbis et al. (2023) found that Motivational Interviewing helps individuals enhance their motivation for change by exploring ambivalence and strengthening commitment to reducing alcohol consumption. Similarly, Ingesson et al. (2023), in a study titled "Patients' Experiences of Receiving Motivational Enhancement Therapy at a Specialized Addiction Treatment Center in Sweden", reported that many patients felt Motivational Interviewing helped them develop stronger motivation to change their addictive behaviors.

The techniques used in Motivational Interviewing made them feel more in control of their lives. Many patients also reported that the positive effects of Motivational Interviewing persisted even after the treatment sessions had ended. These effects included improvements in family and social relationships, as well as increased life satisfaction.

Motivational Interviewing (MI) is a counseling approach designed to enhance individuals' intrinsic motivation to change unhealthy behaviors. There are several mechanisms that may explain its effectiveness in reducing substance craving. MI helps individuals recognize their own capacity to cope with addiction and related psychological challenges (Hurlocker et al., 2023).

An increase in self-efficacy can lead to a reduction in negative emotions and psychological distress (Ingesson et al., 2023). Therapists using MI create a supportive and empathetic environment that helps patients feel less isolated and helpless. MI encourages individuals to focus on their personal values and goals, and to identify practical ways to achieve them. This approach can improve one's outlook on life and enhance self-control over time (Self et al., 2023).

Overall, the findings suggest that MI can effectively boost motivation and self-confidence in men with substance use disorders, enabling them to gain greater control over their lives.

These results highlight the importance of incorporating MI as a complementary method in addiction treatment programs.Therefore, it can be concluded that Motivational Interviewing is more effective and enduring than transcranial direct current stimulation (tDCS) in improving self-control among men with substance dependence.

Moreover, based on the findings, the lasting effectiveness of Motivational Interviewing (MI) surpasses that of transcranial direct current stimulation (tDCS). This can be explained by the fact that MI addresses the psychological, emotional, and motivational dimensions of patients, emphasizing the individual's role in mastering their own impulses. As a result, MI tends to produce deeper and more enduring effects. By fostering a supportive and empathetic environment, MI helps reduce patients' focus on substance use and enhances their self-confidence, thereby improving self-control. Through increasing patients' sense of self-efficacy, MI empowers them to feel more in control of their behaviors and to cope more effectively with addiction-related challenges.

Overall, the findings of this study indicate that, unlike the variable of self-control—on which transcranial direct current stimulation (tDCS) did not yield statistically significant effects—Motivational Interviewing (MI) had a positive impact on enhancing self-control, with its effects proving to be more enduring over time.

On the other hand, both tDCS and MI were effective in reducing substance craving among men with addiction, but MI demonstrated greater overall efficacy and longer-lasting outcomes.

Limitations: all participants were men with substance dependence; therefore, the results should be generalized to women with caution, as hormonal, neurobiological, emotional-regulation, and psychosocial differences may influence craving, impulse control, relapse vulnerability, and response to motivational interviewing or tDCS. Second, participants were recruited from a specific treatment setting and geographic region; therefore, local cultural, social, and economic characteristics may have affected treatment engagement, stigma, family support, readiness for change, and access to care. Third, the use of convenience sampling may have introduced selection bias, because individuals who were available and willing to participate may differ from those who refused treatment or had more severe clinical conditions. Fourth, the relatively short follow-up period limits conclusions about the long-term stability of changes in self-control and craving. Fifth, self-control and craving were assessed through self-report measures, which may be affected by social desirability, memory bias, temporary emotional states, or willingness to report craving accurately. Finally, this study did not include objective indicators of substance use or relapse, such as toxicological screening or independently verified relapse records, and did not directly assess neurocognitive or neurobiological mechanisms.

Suggestions for Future Research:

The novelty of the present study does not lie in examining tDCS or motivational interviewing separately, as both interventions have already been investigated in substance-related conditions. Rather, the main contribution of this study is the direct comparison of a neuromodulatory intervention with a psychological-motivational intervention on two clinically important outcomes, namely self-control and drug craving, among men with substance dependence. This comparative design may help clarify whether the therapeutic changes produced by motivational interviewing remain more stable during follow-up than those produced by tDCS. Nevertheless, future studies are recommended to replicate this comparison in more diverse samples, include both male and female participants, extend the follow-up period, and use objective indicators of substance use and relapse. Future research should also include direct measures of executive control or brain activity to clarify the neurocognitive and neurobiological mechanisms underlying changes in self-control and craving.

Ethical Considerations

his study complies with all ethical standards, including participant education, awareness of research objectives, and obtaining informed consent. It has been approved by the Research Ethics Committee of Islamic Azad University, Karaj Branch, and has received official endorsement from the Ministry of Health and Medical Education under the ethics approval code IR.IAU.K.REC.1403.072. On the other hand, my research project has been approved in the Ministry of Health's clinical trial system with membership number 67950 and clinical trial code IRCT20251110067950N1.

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Conflict of Interest

The authors of this article declare that they have no conflict of interest.

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