

Effectiveness of Transcranial Electrical Stimulation in Improving Cognitive Flexibility and Working Memory in Individuals with Obsessive-Compulsive Disorder

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ABSTRACT

Purpose: The present study aimed to determine the effectiveness of transcranial electrical stimulation in improving cognitive flexibility and working memory in individuals with obsessive-compulsive disorder.

Methods and Materials: This study employed a quasi-experimental design with pretest, posttest, and follow-up assessments and a control group. The study population consisted of women aged 20–45 years with obsessive-compulsive disorder who attended treatment clinics in Shiraz. A total of 60 participants were selected using purposive sampling and assigned to two groups: the transcranial electrical stimulation group and the control group, with 30 participants in each group. Cognitive flexibility was assessed using the Wisconsin Card Sorting Test (WCST), and working memory was assessed using the N-back task. The experimental group participated in the transcranial electrical stimulation program, whereas the control group received no intervention. Data were analyzed using multivariate tests, mixed-design analysis of variance with repeated measures, and the Bonferroni post hoc test.

Findings: The effect of the intervention on cognitive flexibility was statistically significant (Wilks' $\lambda = .494$, $F = 11.05$, $p = .001$, $\eta^2 = .506$). The time $\times$ group interaction was significant for the number of categories completed correctly ($F = 15.50$, $p = .001$, $\eta^2 = .211$) and perseverative errors ($F = 8.23$, $p = .004$, $\eta^2 = .124$). The intervention also had a significant effect on working memory (Wilks' $\lambda = .514$, $F = 10.20$, $p = .001$, $\eta^2 = .486$). The time $\times$ group interaction was significant for response time ($F = 23.10$, $p = .001$, $\eta^2 = .285$) and correct responses ($F = 8.10$, $p = .006$, $\eta^2 = .123$). Differences between the posttest and follow-up assessments were not statistically significant for the primary indices, indicating the relative stability of the observed changes.

Conclusion: Transcranial electrical stimulation may be considered a complementary intervention for enhancing cognitive flexibility and working memory in individuals with obsessive-compulsive disorder. Given the limitations related to the sample and the reported details of the stimulation protocol, the generalization of these findings requires caution and replication in more rigorously designed clinical trials.

Keywords: transcranial electrical stimulation, cognitive flexibility, working memory, obsessive-compulsive disorder, executive functions

1. Introduction

Obsessive-compulsive disorder (OCD) is a chronic and frequently disabling psychiatric condition characterized by intrusive, recurrent, and unwanted thoughts, images, or urges, together with repetitive behaviors or mental acts performed to reduce distress or prevent feared outcomes. Beyond the core clinical manifestations of obsessions and compulsions, OCD is increasingly understood as a disorder involving disturbances in multiple cognitive and neuropsychological processes, particularly executive functions, attentional control, response inhibition, cognitive flexibility, working memory, and learning. These impairments are clinically important because they may contribute to the persistence of maladaptive behavioral patterns, difficulty disengaging from threat-related information, repetitive checking, excessive doubt, and reduced ability to modify behavior when environmental contingencies change. Executive dysfunction may therefore represent not merely a secondary consequence of symptom burden but an important component of the cognitive architecture of OCD. Contemporary evidence indicates that executive-function constructs are relevant across anxiety, obsessive-compulsive, trauma-related, and associated disorders, with impairments in cognitive control processes potentially influencing both symptom development and the maintenance of psychopathology (Zainal & Newman, 2022). The clinical relevance of OCD has also become increasingly evident in the context of large-scale societal stressors. A systematic review and meta-analysis examining obsessive-compulsive symptoms during the COVID-19 pandemic documented a substantial worldwide burden of such symptoms, highlighting the sensitivity of obsessive-compulsive phenomena to environmental stress, uncertainty, contamination concerns, and disruption of ordinary behavioral routines (Pozza et al., 2024). These findings reinforce the need for interventions that address not only overt symptom severity but also the cognitive processes underlying rigid, repetitive, and inefficient patterns of information processing.

Cognitive flexibility is one of the executive functions that appears particularly relevant to the psychopathology of OCD. Cognitive flexibility refers to the capacity to adapt thoughts and behavior in response to changing environmental demands, shift between rules or mental sets, abandon previously reinforced but no longer appropriate response patterns, and generate alternative strategies when current approaches prove ineffective. Reduced cognitive

flexibility can manifest as perseveration, difficulty shifting attention or behavioral strategies, and excessive adherence to previously established rules, all of which conceptually overlap with the repetitive and rigid behavioral patterns commonly observed in OCD. One of the most established instruments for assessing cognitive flexibility is the Wisconsin Card Sorting Test (WCST), originally derived from the card-sorting paradigm developed by Grant and Berg. Their foundational work demonstrated how changes in reinforcement contingencies could be used to assess an individual's ability to shift from one response principle to another, thereby providing a behavioral framework for studying adaptive set shifting and perseverative responding (Grant & Berg, 1948). In contemporary neuropsychological assessment, indices such as the number of categories successfully completed and the frequency of perseverative errors are commonly interpreted as indicators of concept formation, rule shifting, feedback utilization, and executive control. A greater number of successfully completed categories generally reflects more efficient adaptation to changing task contingencies, whereas a higher number of perseverative errors suggests difficulty disengaging from a previously learned response strategy. Within OCD, such difficulties may have direct clinical implications, because an impaired ability to flexibly update response patterns could contribute to persistent ritualistic behavior even when individuals recognize that such behavior is excessive or unnecessary.

Working memory is another central executive function that may be disrupted in individuals with OCD. Working memory refers to the limited-capacity system responsible for temporarily maintaining, updating, and manipulating information in support of ongoing cognitive activity. Efficient working memory is essential for goal-directed behavior, planning, decision-making, problem-solving, monitoring of task-relevant information, and suppression of irrelevant or outdated representations. The N-back paradigm is among the most widely used experimental tasks for examining continuous updating and maintenance within working memory. Its conceptual foundations can be traced to Kirchner's investigation of age-related differences in short-term retention of rapidly changing information, which introduced the sequential matching framework that subsequently became central to N-back methodology (Kirchner, 1958). Performance on N-back tasks is typically evaluated through indices such as response accuracy and response latency, with better performance reflected in a greater number of correct responses and more efficient

response times under controlled task conditions. Evidence suggests that individuals with OCD may exhibit impairments in working-memory processes, although the magnitude and specificity of these deficits may vary according to task characteristics, symptom profile, and cognitive load. Research examining spatial working memory in individuals with OCD has demonstrated meaningful performance differences relative to healthy controls and has also investigated these deficits in unaffected first-degree relatives, thereby raising the possibility that some working-memory abnormalities may reflect broader vulnerability-related neurocognitive characteristics rather than merely the immediate effect of clinical symptoms (Heinzel et al., 2021). More recent syntheses have similarly emphasized that memory abnormalities in OCD extend across several domains and may include disturbances in working memory, episodic memory, metamemory, confidence in memory, and memory monitoring, all of which may interact with compulsive checking and chronic uncertainty (Gurrieri, 2025).

The clinical significance of executive dysfunction in OCD is particularly important because difficulties in cognitive flexibility and working memory may interfere with the capacity to benefit fully from psychological treatment. Cognitive-behavioral interventions, especially exposure-based procedures, require patients to maintain treatment goals, tolerate uncertainty, inhibit habitual avoidance responses, update threat expectations, and incorporate corrective information from new experiences. Deficits in working memory could limit the ability to maintain and manipulate relevant information during therapeutic exercises, while impaired cognitive flexibility may make it more difficult to abandon rigid threat-related rules and adopt alternative behavioral strategies. For this reason, interventions capable of directly modulating neural systems involved in executive functioning have received increasing attention. Noninvasive brain stimulation methods have emerged as promising adjunctive approaches because they allow targeted modulation of cortical excitability and functional connectivity without the risks associated with invasive procedures. Among these methods, transcranial electrical stimulation includes several techniques in which low-intensity electrical currents are applied through scalp electrodes to alter cortical activity. Transcranial direct current stimulation (tDCS), in particular, has been studied as a potential method for modifying neural circuits implicated in cognitive control, affective regulation, learning, and psychiatric symptoms. Depending on electrode placement,

current polarity, stimulation intensity, and individual neurophysiological characteristics, tDCS may influence excitability within prefrontal networks involved in executive processes and may produce effects that persist beyond the stimulation period.

Interest in transcranial electrical stimulation for OCD is supported by converging neurobiological and clinical evidence. OCD has been associated with altered functioning across cortico-striato-thalamo-cortical networks as well as abnormalities in prefrontal systems implicated in inhibitory control, error monitoring, cognitive flexibility, and regulation of learned threat responses. Modulating these networks therefore represents a plausible therapeutic strategy. Ghaffari et al. investigated anodal stimulation of the left dorsolateral prefrontal cortex in individuals with OCD and reported changes toward normalization of brain electrical activity, suggesting that prefrontal stimulation may influence neurophysiological abnormalities associated with the disorder (Ghaffari et al., 2018). Such findings are relevant because the dorsolateral prefrontal cortex plays a major role in working memory, cognitive control, set shifting, and the maintenance of goal-directed representations. Accordingly, stimulation targeting prefrontal regions may have effects extending beyond symptom reduction to the enhancement of executive functioning. Clinical trials have also begun to examine the therapeutic efficacy of tDCS more directly. In a randomized, sham-controlled trial, da Silva et al. evaluated tDCS as an adjunctive treatment for OCD, providing important evidence regarding both the efficacy and safety of noninvasive electrical stimulation in this clinical population (da Silva et al., 2021). Although the therapeutic effects of stimulation may vary across protocols, these findings support continued investigation of tDCS as a complementary intervention for individuals whose symptoms or cognitive impairments remain insufficiently responsive to conventional treatment.

Beyond symptom reduction, transcranial electrical stimulation may influence learning and memory processes that are highly relevant to OCD. Adams et al. examined tDCS targeting the medial prefrontal cortex and found that stimulation modulated functional connectivity and enhanced safety learning in individuals with OCD (Adams et al., 2022). Safety learning is especially relevant to the disorder because individuals with OCD often struggle to update maladaptive threat predictions despite repeated evidence that feared consequences do not occur. The ability to learn that previously threatening cues are safe depends on flexible updating of internal representations, integration of feedback,

and coordination among prefrontal and limbic systems. Therefore, stimulation-related improvements in safety learning provide indirect support for the hypothesis that noninvasive electrical stimulation may enhance cognitive mechanisms involved in adaptive updating and behavioral flexibility. Similarly, individualized transcranial alternating current stimulation (tACS) has recently been examined as a treatment strategy for OCD. Preliminary findings from a randomized, sham-controlled clinical trial indicated that home-based individualized alpha-frequency tACS was associated with improvement in obsessive-compulsive symptoms, suggesting that modulation of oscillatory neural activity may represent another promising direction within the broader field of transcranial electrical stimulation (Perera et al., 2023). Although tACS and tDCS operate through partially different physiological mechanisms, evidence from both approaches strengthens the general rationale for targeting dysfunctional neural dynamics in OCD through noninvasive electrical stimulation.

The potential effects of transcranial electrical stimulation on memory-related cognitive functions have also been investigated beyond OCD. This broader literature is important because cognitive outcomes may not always parallel reductions in clinical symptom severity, and direct evaluation of neuropsychological performance is therefore necessary. Fernández et al. examined the effectiveness of tDCS for improving episodic memory in young adults, contributing to evidence that externally modulating cortical activity may influence memory encoding and retrieval processes under certain stimulation conditions (Fernández et al., 2021). Similarly, cognitive rehabilitation studies have explored whether combining structured cognitive tasks with tDCS can enhance working-memory outcomes. In a study involving patients with stroke, Amini Masuleh et al. compared computer-based cognitive rehabilitation protocols delivered with and without tDCS and found evidence relevant to the potential value of combining cognitive training with brain stimulation for improving working memory (Amini Masuleh et al., 2022). Although findings from neurological populations cannot be directly generalized to OCD, they provide mechanistic support for the possibility that tDCS can facilitate plasticity within neural systems involved in working-memory performance. This possibility is especially important because working memory depends heavily on prefrontal cortical functioning, and prefrontal areas are among the most frequently targeted regions in noninvasive stimulation protocols. Enhancement of working memory may, in turn, contribute to improved

capacity for maintaining task goals, updating information, resisting interference, and regulating behavior in accordance with changing contextual demands.

At the same time, the existing literature suggests that the effects of transcranial electrical stimulation are not uniform and may depend on a wide range of methodological and individual factors. Stimulation outcomes can be influenced by electrode montage, targeted cortical region, current intensity, session duration, total number of sessions, interval between sessions, baseline cortical excitability, medication status, symptom severity, age, and structural or functional characteristics of the brain. The cognitive domain being assessed is also important, because improvements in one executive function cannot necessarily be assumed to generalize to another. Furthermore, a considerable proportion of the OCD stimulation literature has focused primarily on changes in clinical symptoms rather than objective neurocognitive outcomes. This creates a meaningful gap because symptom improvement and cognitive enhancement represent related but distinguishable treatment targets. A patient may experience some reduction in obsessive-compulsive symptoms without substantial improvement in the executive deficits that contribute to functional impairment, while enhancement of specific cognitive processes may occur even when changes in symptom scales are modest. The growing literature on the executive-function profile of OCD underscores the importance of evaluating distinct cognitive constructs rather than treating cognition as a unitary domain (Zainal & Newman, 2022). Likewise, accumulating evidence regarding memory dysfunction in OCD indicates that memory difficulties are heterogeneous and may involve not only objective performance but also confidence, monitoring, retrieval, and updating processes (Gurrieri, 2025). Consequently, studies that simultaneously examine multiple objective cognitive indices can provide a more informative account of the potential neurocognitive benefits of stimulation.

Another unresolved issue concerns the durability of stimulation-induced cognitive changes. Immediate post-intervention improvements may reflect short-term modulation of cortical excitability, practice effects, or transient changes in attention and arousal, whereas clinically meaningful neurocognitive enhancement requires some degree of maintenance over time. Repeated stimulation sessions are theoretically capable of inducing cumulative neuroplastic changes, but persistence of benefit must be demonstrated empirically through follow-up assessment. In

OCD, this issue is particularly important because the disorder typically follows a chronic or recurrent course, and interventions with only transient cognitive effects may have limited functional value. Existing studies provide encouraging evidence that repeated noninvasive stimulation can alter neural activity, functional connectivity, safety learning, and symptom expression (Adams et al., 2022; Ghaffari et al., 2018; Perera et al., 2023), while randomized clinical evidence supports continued evaluation of stimulation as an adjunctive therapeutic modality (da Silva et al., 2021). Nevertheless, fewer studies have examined whether improvements in specific executive functions such as cognitive flexibility and working memory persist beyond the immediate post-intervention period. The use of repeated-measures designs incorporating pretest, posttest, and follow-up assessments can therefore provide important information regarding both treatment response and maintenance of cognitive change.

Taken together, theoretical models of executive dysfunction in OCD, evidence of impaired working-memory performance, the established role of cognitive flexibility in adaptive behavior, and emerging findings from noninvasive brain-stimulation research provide a coherent rationale for examining the cognitive effects of transcranial electrical stimulation in individuals with OCD. The WCST offers a well-established behavioral approach to assessing set shifting and perseverative responding based on the foundational framework introduced by Grant and Berg (Grant & Berg, 1948), while the N-back paradigm provides a theoretically grounded method for examining the continuous maintenance and updating of rapidly changing information based on the experimental tradition initiated by Kirchner (Kirchner, 1958). At the clinical level, increasing attention to the prevalence and burden of obsessive-compulsive symptoms (Pozza et al., 2024), combined with evidence of executive and memory dysfunction in OCD (Gurrieri, 2025; Heinzel et al., 2021; Zainal & Newman, 2022), highlights the need for interventions that address cognitive as well as symptomatic dimensions of the disorder. At the neurostimulation level, studies demonstrating changes in brain electrical activity, clinical symptoms, functional connectivity, safety learning, and memory-related performance following transcranial electrical stimulation provide a plausible empirical foundation for such an approach (Adams et al., 2022; Amini Masuleh et al., 2022; da Silva et al., 2021; Fernández et al., 2021; Ghaffari et al., 2018; Perera et al., 2023). Therefore, the present study aimed to determine the effectiveness of transcranial electrical

stimulation in improving cognitive flexibility and working memory in individuals with obsessive-compulsive disorder.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quasi-experimental design with pretest, posttest, and follow-up assessments and a control group. The statistical population consisted of women aged 20–45 years residing in Shiraz who had attended treatment clinics and had been diagnosed with obsessive-compulsive disorder based on diagnostic criteria. A total of 60 eligible participants were selected using purposive sampling and assigned to two groups, the transcranial electrical stimulation group and the control group, each comprising 30 participants. At baseline, the two groups were compared in terms of the main demographic variables, and no significant differences were reported in age, educational level, marital status, or occupational status.

The inclusion criteria were being female and within the age range of 20–45 years, having a confirmed diagnosis of obsessive-compulsive disorder based on clinical assessment, obtaining a high score on the Maudsley Obsessive-Compulsive Inventory, having no severe psychiatric disorders such as psychosis, schizophrenia, or bipolar disorder, and providing written informed consent to participate in the study. The exclusion criteria included absence from more than two intervention sessions, a substantial change in pharmacological or psychotherapeutic treatment during the study period, and the emergence of physical or psychological conditions preventing continued participation.

After identifying eligible individuals and obtaining written informed consent, the pretest assessment was conducted. The experimental group then received the transcranial electrical stimulation intervention, whereas the control group was assessed during the study period without receiving the intervention. Following completion of the intervention, the cognitive tests were administered again, and the assessments were repeated at the follow-up stage to examine the maintenance of the effects. Participants were informed about the purpose and procedures of the study, their right to withdraw, and the confidentiality of their information, and the data were stored in coded form. The study was conducted under the supervision of the university ethics committee, and the principles of informed consent, confidentiality, voluntary participation, and the right to withdraw throughout the study were observed.

2.2. Instruments

Cognitive flexibility was assessed using the computerized version of the Wisconsin Card Sorting Test (WCST). This test, originally developed by Grant and Berg, assesses set-shifting ability, problem-solving, and functions associated with the prefrontal cortex. In the version used in the present study, four stimulus cards are displayed at the top of the screen, and the participant is required to classify the presented cards according to a rule that must be inferred from “correct/incorrect” feedback. Once the correct criterion is achieved, the classification rule changes, and the participant must use the feedback to identify the new rule. The two primary indices used in the present study were the “number of correctly completed categories” and “perseverative errors.” An increase in the number of correctly completed categories and a decrease in perseverative errors indicate better cognitive flexibility.

Working memory was assessed using a computerized N-back task. Visual stimuli appeared sequentially on the screen, and participants were required to respond according to whether the current stimulus matched or did not match the preceding stimulus. This task requires short-term maintenance of information, continuous updating of content, and attentional control. Performance was assessed using two indices, “response time” and “number of correct responses”; reduced response time and an increased number of correct responses were considered indicators of improved working memory.

The Maudsley Obsessive-Compulsive Inventory (MOCI) was used to assess and screen the severity of obsessive-compulsive symptoms. The scale consists of 30 yes/no items and assesses domains such as checking, cleaning, repetition, and doubting. Higher scores indicate greater symptom severity. In the study documentation, test-retest reliability and internal consistency of approximately .80 were reported for this scale, while an overall reliability coefficient of .84 was reported for the Iranian version. Its convergent validity with the Yale-Brown Obsessive Compulsive Scale was also reported to be .87.

2.3. Intervention

The experimental group participated in the transcranial electrical stimulation program. The intervention was implemented over 10 sessions in a controlled clinical setting. Participants in the control group did not receive transcranial electrical stimulation during the corresponding period. The intervention and assessments were conducted for participants according to the same sequence of pretest, intervention, posttest, and follow-up stages.

2.4. Data Analysis

Descriptive statistics, including the mean and standard deviation, were first calculated. The assumptions underlying the analyses were evaluated using the Shapiro-Wilk test, Box’s M test, Levene’s test, assessment of the homogeneity of regression slopes, and examination of linearity. Given the significant result of Mauchly’s test of sphericity, the Greenhouse-Geisser correction was applied to within-subject effects. Multivariate tests and mixed-design analysis of variance with repeated measures were used to examine the intervention effects, and the Bonferroni post hoc test was used for pairwise comparisons across the assessment stages. The significance level was set at .05.

3. Findings and Results

A total of 60 participants were included in the final analysis, with 30 participants in the transcranial electrical stimulation group and 30 in the control group. The mean age of participants in the intervention group was 33.4 years (SD = 8.29), whereas the mean age in the control group was 34.4 years (SD = 7.32). The difference in age between the two groups was not statistically significant, $t = 0.478$, $p = .634$. Furthermore, the two groups did not differ significantly in educational level, marital status, or occupational status (all $p > .05$), indicating baseline comparability between the groups with respect to the main demographic characteristics.

Table 1

Descriptive Statistics for Cognitive Flexibility and Working Memory Across the Three Assessment Stages

Variable	Group	Pretest, M (SD)	Posttest, M (SD)	Follow-up, M (SD)
Correctly completed categories	Transcranial electrical stimulation	1.41 (0.567)	3.06 (1.005)	2.96 (1.007)
Correctly completed categories	Control	1.70 (0.758)	2.16 (0.767)	2.17 (0.780)
Perseverative errors	Transcranial electrical stimulation	37.50 (10.40)	31.06 (10.20)	32.20 (10.10)
Perseverative errors	Control	35.30 (10.60)	35.80 (8.49)	35.70 (8.51)

Response time	Transcranial electrical stimulation	753.70 (134.40)	546.60 (111.00)	546.50 (111.10)
Response time	Control	737.30 (103.10)	738.40 (137.40)	738.70 (137.30)
Correct responses	Transcranial electrical stimulation	42.20 (13.10)	57.90 (12.10)	57.90 (11.90)
Correct responses	Control	42.70 (15.10)	46.10 (10.05)	45.80 (9.87)

As shown in Table 1, the two groups demonstrated relatively similar scores on the cognitive flexibility and working memory indices at pretest. Following the intervention, the mean number of correctly completed categories in the transcranial electrical stimulation group increased from 1.41 at pretest to 3.06 at posttest and remained at 2.96 at follow-up. In contrast, the corresponding increase in the control group was smaller, from 1.70 to 2.16 and 2.17, respectively. Perseverative errors in the intervention group decreased from 37.50 at pretest to 31.06 at posttest and remained relatively stable at 32.20 at follow-up, whereas little change was observed in the control group. With respect to working memory, mean response time in the intervention group decreased markedly from 753.70 at pretest to 546.60 at posttest and remained essentially unchanged at 546.50 at follow-up. The mean number of correct responses in this group increased from 42.20 to 57.90 and remained at 57.90 at follow-up. By comparison, response time remained nearly unchanged in the control group, and the increase in correct responses was more limited.

Table 2

Results of Mixed-Design Analysis of Variance for Cognitive Flexibility and Working Memory

Variable	Effect	F	p	Partial η^2	Statistical Power
Correctly completed categories	Time	50.30	.001	.465	1.000
Correctly completed categories	Group	8.13	.006	.123	.801
Correctly completed categories	Time $\times$ Group	15.50	.001	.211	.973
Perseverative errors	Time	6.24	.010	.097	.736
Perseverative errors	Group	3.71	.029	.080	.714
Perseverative errors	Time $\times$ Group	8.23	.004	.124	.847
Response time	Time	22.50	.001	.280	.997
Response time	Group	25.20	.001	.303	.999
Response time	Time $\times$ Group	23.10	.001	.285	.997
Correct responses	Time	18.90	.001	.246	.990
Correct responses	Group	10.70	.002	.157	.898
Correct responses	Time $\times$ Group	8.10	.006	.123	.801

The multivariate test for cognitive flexibility was statistically significant, Wilks' $\lambda = .494$, $F = 11.05$, $p = .001$, $\eta^2 = .506$, with a statistical power of 1.00. As presented in Table 2, significant effects of time, group, and the time $\times$ group interaction were found for both correctly completed categories and perseverative errors. For correctly completed

The assumptions underlying the inferential analyses were examined prior to hypothesis testing. The results of the Shapiro-Wilk test, together with skewness and kurtosis indices, indicated acceptable distributions for the study variables. Box's M test was nonsignificant for correctly completed categories ($F = 1.551$, $p = .064$), perseverative errors ($F = 1.485$, $p = .084$), response time ($F = 1.421$, $p = .099$), and correct responses ($F = 1.355$, $p = .121$), supporting the assumption of homogeneity of covariance matrices. Levene's tests were also nonsignificant at the pretest, posttest, and follow-up stages, indicating homogeneity of error variances. In addition, the pretest $\times$ group interaction was nonsignificant for correctly completed categories ($F = 1.295$, $p = .286$), perseverative errors ($F = 0.442$, $p = .646$), response time ($F = 3.330$, $p = .051$), and correct responses ($F = 1.969$, $p = .088$), confirming the homogeneity of regression slopes. However, Mauchly's test of sphericity was significant; therefore, the Greenhouse-Geisser correction was applied to the within-subject effects.

categories, the time $\times$ group interaction was significant, $F = 15.50$, $p = .001$, partial $\eta^2 = .211$, indicating that the pattern of change over time differed between the intervention and control groups. A significant time $\times$ group interaction was also observed for perseverative errors, $F = 8.23$, $p = .004$, partial $\eta^2 = .124$. The multivariate test for working memory

was likewise significant, Wilks' $\lambda = .514$, $F = 10.20$, $p = .001$, $\eta^2 = .486$, with a statistical power of 1.00. For response time, the effects of time, group, and time $\times$ group were statistically significant, with the interaction effect reaching $F = 23.10$, $p = .001$, partial $\eta^2 = .285$. Similarly, significant effects of time, group, and their interaction were found for

correct responses, with a significant time $\times$ group interaction, $F = 8.10$, $p = .006$, partial $\eta^2 = .123$. Overall, these findings indicate that changes in both cognitive flexibility and working memory across the assessment stages differed significantly between the transcranial electrical stimulation and control groups.

Table 3

Bonferroni Pairwise Comparisons Across Assessment Stages

Variable	Comparison	Mean Difference	p
Correctly completed categories	Pretest – Posttest	-1.05	.001
Correctly completed categories	Pretest – Follow-up	-1.01	.001
Correctly completed categories	Posttest – Follow-up	0.04	.146
Perseverative errors	Pretest – Posttest	3.89	.010
Perseverative errors	Pretest – Follow-up	2.76	.010
Perseverative errors	Posttest – Follow-up	1.12	.126
Response time	Pretest – Posttest	103.02	.001
Response time	Pretest – Follow-up	102.90	.001
Response time	Posttest – Follow-up	-0.12	1.000
Correct responses	Pretest – Posttest	-9.55	.001
Correct responses	Pretest – Follow-up	-9.38	.001
Correct responses	Posttest – Follow-up	0.172	.584

The Bonferroni pairwise comparisons presented in Table 3 showed that the number of correctly completed categories increased significantly from pretest to posttest (mean difference = -1.05, $p = .001$) and from pretest to follow-up (mean difference = -1.01, $p = .001$), whereas the difference between posttest and follow-up was not statistically significant ($p = .146$). Perseverative errors decreased significantly from pretest to posttest (mean difference = 3.89, $p = .010$) and from pretest to follow-up (mean difference = 2.76, $p = .010$), while the posttest-to-follow-up difference was nonsignificant ($p = .126$). Similarly, response time decreased significantly from pretest to posttest (mean difference = 103.02, $p = .001$) and from pretest to follow-up (mean difference = 102.90, $p = .001$), with no significant difference between posttest and follow-up ($p = 1.000$). The number of correct responses also increased significantly from pretest to posttest (mean difference = -9.55, $p = .001$) and from pretest to follow-up (mean difference = -9.38, $p = .001$), whereas the difference between posttest and follow-up was not significant ($p = .584$). Collectively, the absence of significant differences between the posttest and follow-up assessments across all four indices indicates that the improvements in cognitive flexibility and working memory were largely maintained during the follow-up period.

4. Discussion and Conclusion

The present study examined the effectiveness of transcranial electrical stimulation in improving cognitive flexibility and working memory among individuals with obsessive-compulsive disorder (OCD). The findings indicated that the intervention produced significant improvements in both domains. With respect to cognitive flexibility, the number of correctly completed categories increased significantly from pretest to posttest and remained higher at follow-up, whereas perseverative errors decreased significantly following the intervention and remained lower at follow-up. The significant time $\times$ group interactions for both indices indicated that these changes were greater in the transcranial electrical stimulation group than in the control group. Similarly, working-memory performance improved following the intervention, as reflected by a significant reduction in response time and a significant increase in the number of correct responses. Again, the significant time $\times$ group interactions demonstrated that the temporal pattern of improvement differed significantly between the intervention and control groups. Importantly, no significant differences were observed between posttest and follow-up scores across the principal outcome measures, suggesting that the cognitive improvements induced by the intervention were relatively stable during the follow-up period. Overall, the

results support the effectiveness of transcranial electrical stimulation as a potentially useful intervention for enhancing executive functions that are frequently compromised in individuals with OCD.

The improvement observed in cognitive flexibility is theoretically consistent with the executive-function profile reported in OCD. Cognitive flexibility requires the ability to shift attentional sets, abandon previously reinforced response patterns, modify behavior according to changing environmental contingencies, and use feedback efficiently. These processes are highly dependent on prefrontal cortical systems and their interactions with subcortical networks. OCD is frequently associated with rigid cognitive and behavioral patterns, persistent repetition, and difficulty disengaging from previously established rules or threat-related representations. Zainal and Newman emphasized the importance of executive-function abnormalities across obsessive-compulsive and related disorders and identified cognitive control and set-shifting deficits as relevant mechanisms underlying persistent maladaptive behavior (Zainal & Newman, 2022). The present reduction in perseverative errors is therefore particularly important, because perseveration reflects difficulty changing an established response strategy even when feedback indicates that the strategy is no longer appropriate. Improvement in this index suggests that transcranial electrical stimulation may have enhanced the participants' capacity to update behavioral responses and shift flexibly between competing cognitive rules.

The findings concerning cognitive flexibility can also be interpreted in light of the neural systems targeted by transcranial electrical stimulation. The dorsolateral and medial prefrontal cortices are involved in executive control, rule updating, working memory, inhibition, and flexible adaptation to changing task demands. Ghaffari et al. reported that anodal stimulation of the left dorsolateral prefrontal cortex in individuals with OCD was associated with normalization of brain electrical activity, suggesting that stimulation of prefrontal regions may modify neurophysiological abnormalities related to the disorder (Ghaffari et al., 2018). This provides a plausible neurophysiological explanation for the improvement in cognitive flexibility observed in the present study. By modulating excitability within prefrontal control networks, stimulation may increase the efficiency of neural mechanisms responsible for shifting between mental sets, monitoring feedback, inhibiting perseverative responses, and selecting alternative response strategies. The Wisconsin

Card Sorting Test is particularly sensitive to these processes and was originally developed to assess the capacity to modify responses when reinforcement contingencies change (Grant & Berg, 1948). The increase in correctly completed categories observed in the intervention group therefore suggests that participants became more effective at discovering, maintaining, and shifting classification rules in response to changing task demands.

The present findings are also compatible with clinical studies showing beneficial effects of noninvasive electrical stimulation in OCD. Da Silva et al., in a randomized sham-controlled trial, evaluated transcranial direct current stimulation as an adjunctive intervention for OCD and provided evidence regarding its efficacy and safety in this population (da Silva et al., 2021). Although that study focused primarily on clinical symptoms, its findings support the broader proposition that modulation of cortical activity through tDCS can alter neural processes involved in OCD. Similarly, Perera et al. reported preliminary evidence that individualized alpha transcranial alternating current stimulation may improve obsessive-compulsive symptoms (Perera et al., 2023). These results, together with the present findings, suggest that different forms of transcranial electrical stimulation may influence both symptomatic and cognitive dimensions of OCD. The current results extend this literature by focusing directly on neurocognitive outcomes and showing that executive functions such as cognitive flexibility may improve in parallel with neural modulation.

The significant improvement in working memory is another important finding of the present study. Working memory enables individuals to temporarily retain, manipulate, and update information while performing ongoing cognitive activities. It plays a central role in planning, decision-making, attentional control, problem-solving, and the maintenance of goal-relevant representations. The significant decrease in response time and increase in correct responses observed after the intervention indicate that participants became both faster and more accurate on the N-back task. This pattern is especially meaningful because working-memory deficits have been repeatedly documented in individuals with OCD. Heinzel et al. reported impaired spatial working-memory performance in individuals with OCD and also investigated such deficits in unaffected first-degree relatives, suggesting that working-memory dysfunction may represent a broader neurocognitive vulnerability marker rather than merely a secondary consequence of symptom severity (Heinzel et al.,

2021). More recent work has similarly emphasized the importance of memory dysfunction in OCD and has described abnormalities across working memory, episodic memory, metamemory, and confidence in memory performance (Gurrieri, 2025). Accordingly, the improvement found in the present study may represent a meaningful modification of a core cognitive vulnerability associated with the disorder.

The working-memory findings can also be interpreted in relation to the neurocognitive effects of transcranial direct current stimulation reported in other populations. Amini Masuleh et al. compared cognitive rehabilitation with and without tDCS in patients with stroke and found evidence supporting the potential usefulness of brain stimulation for improving working memory (Amini Masuleh et al., 2022). Although the clinical characteristics of stroke differ substantially from those of OCD, the relevance of this finding lies in the capacity of tDCS to influence neural plasticity in networks supporting executive functioning. Similarly, Fernández et al. investigated the effects of tDCS on episodic memory and provided evidence that noninvasive electrical stimulation may modify memory performance under appropriate stimulation conditions (Fernández et al., 2021). Together, these findings suggest that electrical stimulation may not be restricted to symptom reduction but may influence fundamental cognitive operations involved in encoding, maintenance, retrieval, and updating of information.

The reduction in response time observed in the present study may indicate improved processing efficiency within working-memory networks. The N-back paradigm requires continuous monitoring of sequential stimuli and comparison of current information with previously presented material. Its conceptual basis originates from early experimental work on short-term retention of rapidly changing information (Kirchner, 1958). Successful performance requires sustained attention, active maintenance, rapid updating, and inhibition of irrelevant information. In OCD, these processes may be disrupted by intrusive thoughts, excessive internal monitoring, and competition from symptom-related cognitive content. Transcranial electrical stimulation may have enhanced the efficiency of prefrontal systems responsible for maintaining task goals and updating working-memory representations, thereby reducing the cognitive resources required to make correct responses. The simultaneous increase in response accuracy and decrease in response latency observed in the intervention group suggests

that the improvement cannot be explained simply by a speed-accuracy trade-off.

The present results are also consistent with evidence that transcranial electrical stimulation may enhance learning processes that depend on adaptive updating of internal representations. Adams et al. found that stimulation targeting the medial prefrontal cortex modulated functional connectivity and enhanced safety learning in individuals with OCD (Adams et al., 2022). Safety learning requires individuals to revise previously learned threat associations in light of new evidence and therefore depends on flexible updating, working memory, and cognitive control. The findings of Adams et al. provide a particularly relevant framework for interpreting the present improvements in both cognitive flexibility and working memory. If stimulation facilitates the integration of corrective information and strengthens prefrontal regulation of maladaptive threat-related networks, improvements may emerge not only in explicit learning paradigms but also in broader executive functions. The current results may therefore reflect enhanced prefrontal efficiency across multiple interrelated cognitive processes.

The durability of the observed changes is another noteworthy aspect of the findings. None of the major cognitive indices differed significantly between posttest and follow-up, suggesting that the improvements achieved after stimulation were largely maintained. This pattern may indicate that repeated stimulation produced effects extending beyond transient modulation of cortical excitability. Repeated noninvasive stimulation has been proposed to induce cumulative changes in synaptic efficiency and functional connectivity, and such mechanisms may contribute to the persistence of cognitive benefits after the intervention period. The results of Adams et al., who reported modulation of functional connectivity following prefrontal stimulation in OCD, are compatible with this interpretation (Adams et al., 2022). Likewise, the neurophysiological findings reported by Ghaffari et al. suggest that repeated stimulation may influence brain electrical activity in a manner potentially relevant to longer-lasting changes in cognitive control (Ghaffari et al., 2018). Although the present study did not directly measure neural plasticity, the stability of post-intervention cognitive performance at follow-up is consistent with the possibility that repeated stimulation induced more sustained functional changes within executive networks.

The clinical relevance of these findings should also be considered in relation to the broader burden of OCD.

Obsessive-compulsive symptoms can substantially impair daily functioning, and their prevalence may increase under conditions characterized by heightened uncertainty, contamination concerns, and psychological stress. Pozza et al. documented a considerable worldwide prevalence of obsessive-compulsive symptoms during the COVID-19 pandemic, highlighting the sensitivity of obsessive-compulsive phenomena to environmental and contextual pressures (Pozza et al., 2024). This broader burden emphasizes the importance of developing interventions that target not only symptomatic distress but also the cognitive processes that may maintain dysfunctional behavior. Improving cognitive flexibility may help individuals disengage from rigid routines and repetitive behavioral patterns, while enhancing working memory may strengthen the ability to retain therapeutic instructions, update threat expectations, and maintain goal-directed behavior. Such cognitive changes could potentially complement established psychological treatments by improving the underlying capacities required for successful behavioral adaptation.

The findings also support a multidimensional conceptualization of treatment response in OCD. Symptom severity remains a central clinical outcome, but improvement in executive functioning may represent an independent and clinically meaningful treatment target. Zainal and Newman noted that executive dysfunction cuts across anxiety and obsessive-compulsive spectrum conditions and may affect emotional regulation and adaptive behavior (Zainal & Newman, 2022). Similarly, Gurrieri emphasized that memory dysfunction in OCD involves several distinct processes rather than a single generalized memory deficit (Gurrieri, 2025). The present study extends this perspective by demonstrating simultaneous improvement in two separate executive domains: cognitive flexibility and working memory. The fact that both behavioral indices of flexibility and both indices of working memory improved suggests that the intervention may have influenced a broader cognitive-control system rather than a single isolated task-specific process.

Several limitations should be considered when interpreting the findings. First, the sample consisted only of women aged 20 to 45 years from treatment clinics in Shiraz, which limits the generalizability of the findings to men, other age groups, community samples, and individuals from different cultural or clinical settings. Second, the relatively modest sample size may reduce the precision of effect-size estimates and limit the ability to examine potentially important moderators such as baseline symptom severity,

medication status, duration of illness, or comorbid conditions. Third, although the study included a control group, the absence of a sham-stimulation condition may have allowed expectancy or nonspecific treatment effects to contribute to the observed changes. In addition, the available description of the stimulation protocol did not provide detailed information regarding electrode montage, current intensity, session duration, or precise cortical targets, which limits reproducibility and makes comparison with other stimulation studies more difficult. Finally, the follow-up period provided evidence of short-term maintenance, but longer-term durability could not be established.

Future research should employ larger and more heterogeneous samples that include both women and men across broader age ranges and different clinical settings. Randomized, double-blind, sham-controlled trials would provide stronger evidence regarding the specific effects of transcranial electrical stimulation and would help distinguish neurophysiological effects from expectancy and placebo-related influences. Future studies should report stimulation parameters comprehensively and systematically compare different electrode montages, current intensities, session numbers, and cortical targets. Incorporating neurophysiological and neuroimaging measures alongside cognitive outcomes would also help clarify the mechanisms through which stimulation affects executive functioning. Researchers should additionally examine whether baseline cognitive impairment, symptom severity, medication use, or psychiatric comorbidity moderates treatment response. Longer follow-up intervals are needed to determine whether gains in cognitive flexibility and working memory persist over several months and whether booster sessions are required to maintain therapeutic effects.

From a practical perspective, transcranial electrical stimulation may be considered as a complementary intervention within multidisciplinary treatment programs for individuals with OCD, particularly when executive-function deficits interfere with daily functioning or treatment engagement. Clinicians may benefit from assessing cognitive flexibility and working memory in addition to conventional symptom severity, because these domains may influence the individual's ability to respond adaptively to changing situations and to benefit from cognitive-behavioral interventions. Brain stimulation should be implemented by trained professionals within controlled clinical settings and according to standardized safety procedures. Its use may be especially valuable when combined with cognitive rehabilitation, exposure-based treatment, or other

interventions that require active learning and behavioral updating. Nevertheless, clinical application should remain individualized, and treatment decisions should take into account symptom profile, cognitive status, concurrent treatments, and the availability of appropriately trained personnel.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the study and participated in the research with informed consent.

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