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Systematical review and Meta-analysis

Effects of single and multiple Transcranial Direct Current Stimulation sessions targeting the dorsolateral prefrontal cortex on binge-eating symptoms: a systematic review

MILENA ARTIFON[1] | NATHÁLIA GRIEBLER[1] | GABRIEL M. TOSSI[1] | EDUARDA BLANCO-RAMBO[1] | MARCELO BANDEIRA-GUIMARÃES[1] | PEDRO SCHESTATSKY[2] | CAROLINE PIETTA-DIAS[1]

[1] Exercise Research Laboratory, School of Physical Education, Physiotherapy and Dance, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
[2] Faculty of Medicine of the Federal University of Rio Grande do Sul, Department of Internal Medicine, Porto Alegre, RS, Brazil

Correspondence to: Caroline Pietta-Dias
Rua Felizardo, 750, Porto Alegre, Brazil, Postal code: 90690-200
https://orcid.org/0000-0002-3883-4938
email: carolpieta@yahoo.com.br
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HIGHLIGHTS

- Only nine studies regarding the effect of tDCS on BE symptoms were found
- Single and multiple tDCS sessions showed a positive effect on binge eating symptoms
- tDCS sessions showed a positive effect on food craving and intake.

ABBREVIATIONS

BE	Binge eating
BED	Binge eating disorder
DLPFC	Dorsolateral prefrontal cortex
DSM-5	Diagnostic and Statistical Manual of Mental Disorders
NCT	Nutritional counseling therapy
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
tDCS	Transcranial Direct Current Stimulation

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BACKGROUND: Binge eating disorder (BED) is the most prevalent eating disorder in the world and recent findings on neuromodulation suggest potential benefits of Transcranial Direct Current Stimulation (tDCS) on the symptoms of binge eating (BE).
AIM: To summarize the effects of tDCS on the symptoms of BE by a systematic review.
METHODS: This systematic review follows the Preferred Reporting Items for Systematic reviews and Meta-Analyses. Searches were carried out in May 2025 in PubMed, ScienceDirect, SciELO and LILACS. The included studies should have reported the effects of tDCS on the symptoms of BED, and the quality of the included studies was assessed through PeDro Scale.
RESULTS: This PRISMA-guided systematic review included 9 studies (n=337) investigating tDCS over the dorsolateral prefrontal cortex in adults with BED, binge-eating symptoms or overweight adults. Protocols using 2mA in single or multiple sessions reduced food craving and binge frequency, particularly in those with diagnosed BED. Effects were dependent on stimulation parameters and participant characteristics.
CONCLUSION: For the tested protocols, tDCS over dorsolateral prefrontal cortex improved binge eating symptoms, as well as food craving, and can be an option within the treatment strategy. In addition, more studies with specific populations should be conducted.

KEYWORDS: Eating disorder | Hyperphagia | Neuromodulation | Obesity | tDCS

INTRODUCTION

Binge Eating Disorder (BED) is the most prevalent eating disorder worldwide and is characterized by recurrent episodes of excessive food intake within a limited time frame, accompanied by a perceived inability to control eating behavior. Individuals often report being unable to stop eating or regulate the quantity and type of food consumed, even in the absence of hunger or despite feeling physically uncomfortable [1]. When referring to the etiologies of BED, multifactorial determinants such as genetic predisposition, neurobiological alterations, psychological factors, and environmental influences, must be considered. These interconnected factors contribute not only to the onset and maintenance of the disorder but also to its severity and comorbidities [2,3]. Although BED is primarily characterized by psychological and emotional dysregulation, evidence suggests that motor aspects of behavior may also be impacted. Individuals with BED frequently exhibit compulsive tendencies and compensatory behaviors, including maladaptive or excessive physical activity, which may reflect underlying alterations in motor control and behavioral inhibition [4].

Neurobiological models of BED suggest that stress plays a critical role in both the initiation and perpetuation of the disorder, while also contributing to the emergence of addiction-like behaviors, including craving, impulsivity, and compulsivity, as well as alterations in attention and reward-related decision-making [5]. Furthermore, BED has been associated with motor disinhibition and deficits in executive functioning, particularly in the areas of planning and cognitive control [6]. The dorsolateral prefrontal cortex (DLPFC), which is

involved in many of these functions, has consequently been a key focus in research on eating disorders. Moreover, the DLPFC is a therapeutic target in attention-deficit/hyperactivity disorder, addiction, and inhibitory control, reinforcing its potential role in BED [7].

One of the strategies related to the role of the DLPFC in treating BED is transcranial direct current stimulation (tDCS), a non-invasive brain stimulation technique that utilizes electrical currents to modulate neuronal activity. tDCS involves the application of a constant, low-intensity electrical current via surface electrodes positioned on the scalp. This technique does not induce seizures and is designed to modulate cortical excitability by enhancing neuronal activity through anodal stimulation or suppressing it via cathodal stimulation, depending on the polarity and targeted brain region [8,9]. In typical tDCS protocols, the anodal electrode is positioned over the target cortical region to enhance excitability, while the cathodal electrode is placed over a distant site to complete the circuit. The resulting current flow appears to alter the membrane potential of neurons within the stimulated area, thereby modulating neuronal firing rates and influencing synaptic plasticity [10].

Although the exact neurophysiological mechanisms underlying tDCS remain incompletely understood, a prevailing hypothesis in the context of BED is that the enhancement of DLPFC activity through electrical stimulation may improve cognitive control and inhibit reward-related neural circuits involved in craving and excessive food intake [11,12]. This technique has shown promise for acutely reducing the desire for food [13,14] and for the treatment of obese individuals [15,16,17]. Recent findings on neuromodulation have also demonstrated promising effects on the self-regulation of cognition, emotion, and motor behavior. In this context, tDCS emerges as a potential tool to modulate neural circuits involved in both executive functioning and motor planning, supporting more adaptive behavioral responses across domains [18]. However, BED is the only eating disorder recognized in the DSM-5 that is not yet associated with established neuromodulation strategies [1,19].

A recent review [20] has been conducted in this regard; nonetheless, the authors focus on the general mechanism of tDCS on BED and the search was not performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). In this sense, there is still a gap regarding different tDCs approaches (single or multiple sessions) in the treatment of BED. Therefore, the aim of the present review was to summarize the evidence on different tDCS approaches (single or multiple sessions) in the treatment of BED and to perform the search in accordance with best practices in systematic reviews.

METHODS

Study Design

A search strategy was applied to identify the main studies that evaluated the use of transcranial direct current stimulation (tDCS) in individuals with symptoms or a diagnosis of binge eating disorder (BED). For purposes of assessing the disease, subjective assessment criteria were adopted through the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [1]. Thus, the uncontrollable desire to eat scores was adopted as the primary outcome.

Protocol and Registration

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement checklist [21] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO, CRD42020140950).

Selection Criteria

To be eligible for inclusion in the present review, studies should be in accordance with the following criteria: (1) acute or long-term studies that (2) assessed the impact of tDCS on (3) symptoms of binge eating in (4) a young adult population (18 – 49 years old). The studies could be published in any language, with no restriction regarding publication date. To reduce possible confounders, case studies were excluded.

Search Strategy

Literature research was performed in 2023 and repeated in May 2025 to capture additional articles published during this time. Four electronic databases were used to conduct the literature research: PubMed (Medline), ScienceDirect (Elsevier), SciELO and LILACS. In addition, manual searches from the references of the included studies were performed. The search comprised the following terms: “Binge Eating Disorder”, “Transcranial Direct Current Stimulation”, “Cathodal Stimulation Transcranial Direct Current Stimulation”, “Anodal Stimulation Transcranial Direct Current Stimulation”, “Transcranial Random Noise Stimulation”, “Transcranial Alternating Current Stimulation”, “Transcranial Electrical Stimulation”, “Repetitive Transcranial Electrical Stimulation”. To optimize the capture of relevant references, such terms were combined by Boolean operators (OR and AND). The search was limited to the following fields: title, descriptors, and abstract. The complete searches were available on the Supplementary Material.

Selection of Studies

For the selection of eligible studies, the Rayan software was used. The selection of studies was based on the eligibility criteria previously adopted, and each phase was carried out separately by two researchers as follows. First, two researchers (M.A and N.G) independently evaluated the titles and abstracts of all studies found in the search. Papers whose abstracts did not provide sufficient

information as per the inclusion and exclusion criteria were assessed separately in full. Subsequently, each study selected in the previous phase was fully evaluated and selected by the reviewers independently. Disagreements were resolved by consensus, and, in cases of persistence, a third investigator (C.P-D) resolved the disagreement between the researchers.

Data extraction and presentation

Data were extracted through a standardized form containing information on the methodological characteristics of the studies, participants, interventions, and outcomes. This process was performed independently by two researchers (M.A and N.G). Eventually, disagreements were resolved by consensus or by a third reviewer (C.P-D).

Methodological quality of included studies

Two reviewers independently (E.B-R and M.B-G) assessed study quality using the PEDro scale, following the Delphi criteria by Verhagen et al. [22]. This procedure evaluates the methodological quality of the studies according to the following criteria: (1) eligibility criteria were specified (not considered for punctuation); (2) participants were randomly allocated to groups; (3) allocation was concealed; (4) the groups were similar at baseline regarding the most important prognostic indicators; (5) there was blinding of all participants; (6) there was blinding of all therapists; (7) there was blinding of all assessors; (8) measures of at least one key outcome were obtained for more than 85% of the participants initially allocated to groups; (9) all participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one main outcome were analyzed by "intention-to-treat"; (10) the results of between-group statistical comparisons were reported for at least one main outcome; (11) the study provided both point measures and measures of variability for at least one main outcome. When these characteristics were described in the study, the criteria were considered met and the score was determined. Studies that did not describe these aspects did not score (Table 1). PEDro scores of 0–3 are considered "poor", 4–5 "fair", 6–8 "good", and 9–10 "excellent" [23].

Analysis of rater reliability

ICC, reported with 95% confidence interval (CI), were used to evaluate the level of agreement in the data across visits between the two observers during observations. The assessed variables included the results of the PARA audit, total number of users, assumed sex, perceived age group, PA level, and BMS recorded. PARA, SOPARC and BMS observational data were aggregated between observers for the count of users observed, assumed sex, perceived age, PA level, and BMS performed per visit if ICC was deemed to be at least moderate (≥0.5) [34].

RESULTS

Study Selection

A total of 432 studies were found in the databases and five were found through manual search. The PubMed database returned 181 studies, ScienceDirect 250, LILACS one study and SciELO no studies. After reading the titles and abstracts, four studies were selected for full text reading, met the inclusion criteria and were selected for qualitative analysis. In addition, the five studies resulting from the manual search were included (Figure 1), totaling 9 papers.

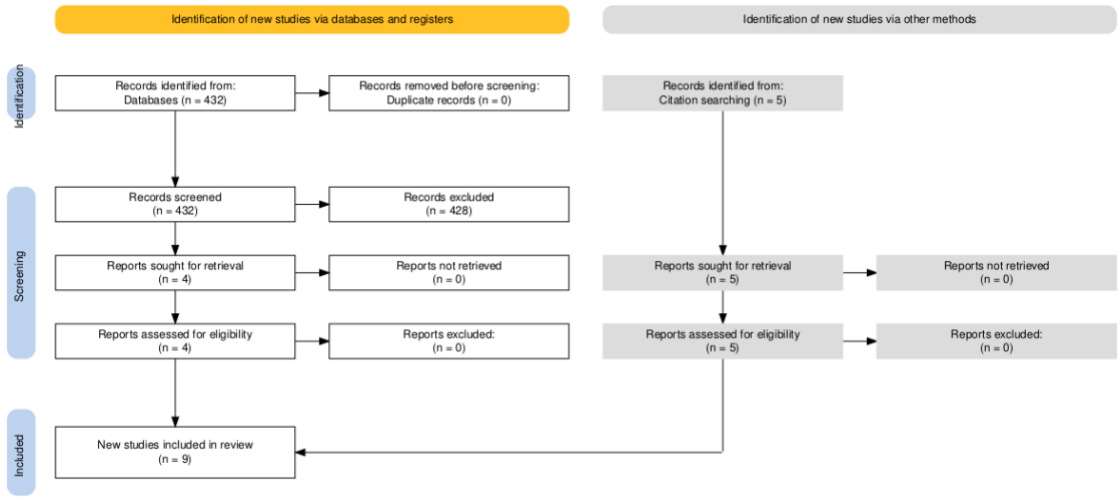

Figure 1. PRISMA flowchart, showing all stages of the selection process of included studies. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hofmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:71. https://doi.org/10.1136/bmj.n71

Quality of studies

Among the included studies, one was considered with "good" quality [24] and eight with "excellent" quality [25-32]. All studies (1) specified their eligibility criteria, reported that (2) participants were randomly allocated to groups and that (3) the allocation of participants was secret. In addition, all studies reported that (4) the groups were similar at baseline, (5) blinded the subjects, (8) obtained at least one key outcome in 85% of the participants, (9) performed treatment or control regarding allocation or intention to treat, (10) compared between-group statistics, and (11) presented point measures and measures of variability for at least one main outcome. Four studies [25-28] obtained the maximal punctuation on the scale (10 points). The details regarding the quality of each study are provided in Table 1.

Table 1. Risk of Bias Assessment

Studies	Max et al., 2020	Ray et al., 2019	Elkfury et al., 2024	Ljubisavljevic et al., 2016	Burgess et al., 2016	Kekic et al., 2014	Beaumont et al., 2023	Giel et al., 2023	Goldman et al., 2011
Eligibility criteria have been specified	√	√	√	√	√	√	√	√	√
Subjects were randomly assigned	√	√	√	√	√	√	√	√	√
Allocation of subjects was secret	√	√	√	√	√	√	√	√	√
Similar groups at baseline	√	√	√	√	√	√	√	√	√
Blinding of subjects	√	√	√	√	√	√	√	√	√
Blinding of therapist	√	√	√	x	x	√	√	√	x
Blinding of evaluators	√	x	√	√	x	x	√	√	√
At least one key outcome was obtained in more than 85% of subjects	√	√	√	√	√	√	√	√	√
Treatment or control as per allocation or treatment intention	√	√	√	√	√	√	√	√	√
Intergroup statistical comparisons have been described for at least one key outcome	√	√	√	√	√	√	√	√	√
Displays both precision measures and variability measures	√	√	√	√	√	√	√	√	√
Total	**10**	**9**	**10**	**8**	**8**	**9**	**10**	**10**	**9**

x: criteria was not specified; √: criteria was met.

Characteristics of the included studies

Table 2 summarizes the main characteristics of the selected studies. Regarding the participants, the nine studies included in this systematic review assessed a total of 337 individuals. Participants' ages ranged from 19.9 [32] to 40.6 [25] and the sample size ranged from 17 [26,30] to 75 [32]. In addition, four studies included participants with BED [24,25,27,28] four included participants with frequent food craving [26,29-31] and only one study included participants without symptoms of BED [32] (Table 2).

Table 2. Characteristics of participants in the included studies General identification of studies, protocols used and main results.

Study	Participants	Study type	Group	BMI ± SD	Age ± SD
Max et al., 2020	Adults with BED	Randomized clinical trial	1mA (n = 15) 2mA (n = 12)	32.1 ± 10.9 33.8 ± 9.6	35.7 ± 13 40.6 ± 15.6
Ray et al., 2019	Adults with BMI ≥ 25	Randomized clinical trial	Told Fake/Got Fake (n = 18) Told Fake/Got Real (n = 19) Told Real/Got Fake (n = 17) Told Real/Got Real (n = 20)	31.8 ± 5.5	19.9 ± 3.4
Elkfury et al, 2024	Adults with BED	Randomized pilot, sham-controlled trial	Real tDCS (n = 13) NCT (n = 11) Real tDCS + NCT (n = 14) Sham tDCS + NCT (n = 11)	31.4 ± 6.4 32.1 ± 4 35.1 ± 4.7 32.5 ± 3.9	35.2 ± 6.2 31 ± 8.8 32 ± 7.8 33.7 ± 9.6
Ljubisavljevic et al., 2016	Healthy adults who reported frequent food cravings without a prior history of eating disorders	Randomized clinical trial	Real tDCS (n = 13) Sham tDCS (n = 14)	26.3 ± 5.1 24.9 ± 3.6	21 ± 2.1 21.6 ± 2
Burgess et al., 2016	Adults with BED or subBED	Crossover clinical trial with random order sessions	Real / Sham tDCS (n = 30)	36.1 ± 6.12	NA
Kekic et al. 2014	Healthy women who self-identified as having frequent food cravings	Crossover clinical trial with random order sessions	Real / Sham tDCS (n = 17)	23.81 ± 2.60	26.41 ± 8.31
Beaumont et al., 2023	Women with who presented with mild-to-moderate binge eating behavior	Crossover clinical trial with random order sessions	Real / Sham tDCS (n = 17)	25.4 ± 3.8	23 ± 7
Giel et al., 2023	Adult outpatients with full-syndrome BED	Monocentric clinical phase II double-blind randomized trial with two parallel arms	Real tDCS (n = 19) Sham tDCS (n = 20)	31.9 ± 9.4 36 ± 9.1	36.7 ± 17 35.5 ± 14.3
Goldman et al., 2011	Healthy individuals with frequent food cravings	Randomized within-subject crossover design	Real / Sham tDCS (n = 19)	27.25 ± 6.24	32.47 ± 10.85

BMI: Body mass index; BED: Binge-eating disorder; tDCS: Transcranial Direct Current Stimulation; NA: not available.

Regarding the tDCS protocol, the intensity of the electric current varied between 1 and 2mA. Max et al. [25] performed the protocol comparing both intensities, and the other studies adopted 2mA. Two studies [25,26] tested the effects of anodal stimulation, while seven [24,27-32] studies investigated the effects of combined anodal stimulation over the right side with cathodal stimulation over the left side. The control groups received tDCS in the initial 20 – 60 seconds with subsequent disconnection (sham condition). Six studies performed a single session of tDCS [24-26,30-32] and three performed multiple sessions [27-29] (Table 3).

Main findings

Single session of tDCS in BE symptoms

Six studies performed a single session to evaluate the effects of tDCS on BE symptoms. Max et al. [25] combined two intensities of anodal tDCS (1 and 2mA) with food inhibition training to decrease food-related responding through an intersection of impulsivity and increased cognitive control in patients with BED. In the 2mA condition, an improvement in the inhibition of the response to food stimuli and a significant reduction in self-reported BE frequency were observed, whereas no change was observed in the group receiving 1mA.

Table 3. General identification of protocols used and main results.

Study	Intervention	Outcomes	Results
Max et al., 2020	Participants were randomly allocated in anodal current of 1mA or 2mA groups and received 20 minutes of placebo and a verum session of tDCS. Each subject received an antisaccade-task in day 1 and a session of placebo/verum in day 2 and day 3 in accordance with the allocation.	Eye tracking; BIS; UPPS; TFEQ	The frequency of binge eating episodes did not change significantly at the 1mA condition. The frequency of binge eating episodes decreased significantly at the 2mA condition, with a strong effect.
Ray et al., 2019	Participants received a single session of real or sham (fake) 2 mA, anodal right and cathodal left tDCS. Real tDCS was 2 mA of current for 20 minutes; sham tDCS was 2 mA of current only during the first and the last minute of the 20 minutes session. The difference between groups was the expectation about the information received related to the session (sham or real).	Food craving task; Eating task; Hunger assessment; BIS; PEMS; DEBQ-R; BES; SSS	There was a positive significant main effect of expectation on craving. Although there was no main effect of tDCS on craving. There was a significant positive main effect of expectation for eating. Although there was no main effect of tDCS on eating.
Elkfury et al, 2024	Participants allocated in the groups with tDCS received an intensive phase of 20 sessions (five days/week) and a maintenance phase of three additional sessions (one day/week) of 2 mA, anodal right and cathodal left tDCS. The Real tDCS groups received the current for 20 minutes and the Sham tDCS groups received the same protocol, but the current stimulation automatically turned off 20 seconds after the stimulation had begun. Participants allocated in the groups with NCT received eight virtual sessions with a therapist, each lasting 40 minutes (20 minutes in recorded video and 20 minutes for activities and feedback about the previous session).	BES; Go/No-Go task; TFEQ; FCQ; Sleep quality; Mental health; Depressive and anxiety symptoms.	The combined therapy protocol did not synergically affect BED symptoms. The NCT effects might reduce BED symptoms even after treatment ends. In contrast, tDCS increased inhibitory function in the cortex and temporarily reduced BED symptoms.
Ljubisavljevic et al., 2016	The ACTIVE group received 5 consecutive days of 2 mA, anodal right and cathodal left tDCS while the SHAM group received on the first day active stimulation, followed by 4 days of sham stimulation. Stimulation: 20 minutes, anode right-cathode left montage, 2 mA with current density kept at 0.06 mA/cm2, 1 min ramp-up/ramp-down.	Depression Scale; FCQ; FCI	Craving was reduced shortly after a single session of active tDCS. Repeated tDCS for 5 days may induce more persistent (at least for 30 days) decrease in self-reported craving. tDCS reduced food craving for sweet, fast-food and fat but not for carbohydrates. Food cravings were reduced regardless of initial body weight or gender and were not associated with changes in body weight during and after the intervention.
Burgess et al., 2016	A “real” tDCS (2 mA anodal right and cathodal left current for 20 minutes) and “sham” condition (2 mA current during the first two and last 1 min of a 20 minute session) were administered in counter balanced fashion.	BES; DEBQR; PEMS; Mood; Food Photo Craving Test; Eating Test; At-Home Binge-Eating Survey	There were significantly reduced in lab food intake, in-lab food craving, and at-home desire to binge-eat, compared to sham.

Kekic et al. 2014	This study employed a double-blind sham-controlled within-subjects crossover design in which all participants received real and sham tDCS. The real session consisted of 20 minutes of 2 mA, anodal right and cathodal left tDCS. The sham session consisted of 2mA current during the first 30 seconds of a 20 minute session.	VAS; Food Challenge Task; FCQ; Saliva sample; TD task	There were significantly reduced in cravings for sweet but not savory foods. Participants who exhibited more reflective choice behavior were more susceptible to the anti-craving effects of tDCS than those who displayed more impulsive choice behavior.
Beaumont et al., 2023	The present study adhered to a double-blind, within-participant, repeated-measures design. A constant anodal current of 2 mA was delivered. The current was delivered for 20 minutes in active condition and 36 seconds in sham condition.	BES; TFEQ; 24h-Control of Eating Questionnaire (CoEQ); FCQ; Leeds Food Preference Questionnaire (LFPQ); VAS	No difference between pre- and post-tDCS scores were found across fullness, prospective consumption, desire to eat or FCQ-S measures when comparing active and sham protocols. Only explicit liking and wanting for high-fat sweet foods were significantly different between conditions, with increased scores following active tDCS. When controlling baseline hunger, the significant differences were removed.
Giel et al., 2023	The intervention comprised a food-related inhibitory control training which was combined with either sham or verum 2 mA, anodal right and cathodal left tDCS stimulation to the right DLPFC. The training comprised six sessions within 14 days (three sessions/week).	BE frequency; Examination (EDE); Food-related eye tracking task; Structured Clinical Interview for DSM-5; Beck Depression Inventory; Well-being Index of the World Health Organization; BIS; UPPS; Side effects of tDCS with Likert scale	Food related inhibitory control training enhanced by tDCS can sustainably reduce BE frequency in patients with full syndrome BED. In the 4 weeks after the end of treatment, BE frequency was found to be reduced by about two-thirds in patients who received active and sham tDCS parallel to the training. While the primary outcome was negative, at 3-month follow-up, patients who were treated with real tDCS reported significantly fewer BE than patients in the sham group. Feasibility, acceptability and safety were reflected in only 2 patients dropping out from the treatment trial and reporting of only mild side effects.
Goldman et al., 2011	Participants viewed computerized images of food and used computerized visual analogue scales to rate food cravings and inability to resist foods before, during, and after receiving either real or sham anodal right and cathodal left tDCS.	Relationship between cravings and tDCS condition; Relationship among cravings for specific food groups and tDCS; Relationship among the inability to resist food and tDCS; Relationship of the inability to resist specific food groups and tDCS; Relationship between food ingested and tDCS condition	Food cravings ratings were reduced in both conditions, however, the percent change in cravings ratings from pre- to post-stimulation was significantly greater for real stimulation than for sham. The percentage change in inability to resist food from pre- to post-stimulation also showed a greater decrease in the real condition than for sham. Post hoc analyses suggest that active prefrontal tDCS acutely and significantly decreased food cravings ratings for sweet foods and carbohydrates more so than sham tDCS. No significant differences were seen in the amount of food ingested between real and sham tDCS.

BIS: Barratt impulsiveness scale; BES: Binge-Eating Scale; VAS: Visual analogue scale; TFEQ: Three Factor Eating Questionnaire; UPPS: impulsive behavior scale; PEMS: Palatable Eating Motives Scale; DEBQR: Dutch Eating Behavior Quest-Restraint; SSS: Short Suggestibility Scale; FCQ: Food Craving Questionnaire; FCI: Food Craving Inventory.

Burgess et al. [24] conducted a randomized protocol including both active and sham tDCS sessions to assess the effects of stimulation on food intake, food craving, and the desire and frequency of binge eating episodes in individuals diagnosed with BED. The findings indicated that a single 20-minute session of 2mA tDCS resulted in significant reductions in food intake, food cravings, and binge eating episodes compared to the sham condition. Similarly, Kekic et al. [30] investigated the effects of 2mA tDCS, in a placebo-controlled design, on food cravings, intertemporal decision-making, and actual food consumption. Their results demonstrated that tDCS selectively reduced cravings for sweet foods, but not salty foods. Furthermore, individuals who displayed more reflective (as opposed to impulsive) decision-making tendencies were more responsive to the anti-craving effects of tDCS.

A similar protocol was employed by Goldman et al. [31], who found that food craving decreased in both the active and sham tDCS conditions. However, the reduction in craving ratings from pre- to post-stimulation was significantly greater in active tDCS compared to the sham condition. Additionally, the self-reported inability to resist food decreased more substantially after active stimulation. Despite these findings, no significant differences were observed in the actual amount of food consumed between the two conditions.

In contrast, Ray et al. [32] investigated the effects of tDCS on food cravings and intake under strict control of treatment expectancy. Participants were randomly assigned to one of four groups based on a balanced placebo design: real or sham tDCS combined with information indicating whether they were receiving real or sham stimulation (Told Sham/Received Sham; Told Sham/Received Real; Told Real/Received Sham; Told Real/Received Real). Notably, treatment expectancy alone led to a 37.4% reduction in caloric intake, highlighting the significant role of psychological factors in modulating eating behavior. Contrary to the authors' initial hypotheses, tDCS demonstrated neither independent nor synergistic effects on craving, food intake, or treatment expectancy. It is important to note, however, that the study by Ray et al. [32] was conducted with individuals who did not meet diagnostic criteria for BED and did not report binge eating symptoms, which may represent a significant confounding variable.

In this context, Beaumont et al. [26] examined the effects of tDCS on sensations of fullness, prospective food consumption, desire to eat, and food craving in women without a diagnosis of BED but presenting mild to moderate binge eating behavior. The study found no significant differences between the active and sham stimulation conditions. Notably, it was the only study among those reviewed that compared exclusively anodal stimulation with sham.

These findings suggest that the effects of single-session tDCS on BE symptoms may be influenced by several factors, including current intensity (e.g., 1mA vs. 2mA), stimulation protocol (anodal-only vs. anodal combined with cathodal), and participants' baseline characteristics, such as the presence of a formal BED diagnosis or the frequency of binge eating behaviors. The methodological features and main outcomes of each study are summarized in Table 3.

Multiple sessions of tDCS in BE symptoms

All studies involving multiple tDCS sessions included in this review utilized a current intensity of 2 mA and applied a montage combining anodal stimulation over the right side and cathodal stimulation over the left side. Elkfury et al.28 investigated the effects of 23 sessions of tDCS and/or nutritional counseling therapy (NCT) in individuals with BED. Participants were randomized into four groups: active tDCS, NCT alone, active tDCS combined with NCT, and sham tDCS combined with NCT. The results indicated that both interventions independently contributed to the improvement of binge eating symptoms; however, the combined approach (active tDCS + NCT) did not produce synergistic effects. Additionally, Ljubisavljevic et al.29 found that a single session of active tDCS significantly reduced the intensity of current food cravings. Moreover, five consecutive sessions of active tDCS led to a significant reduction in habitual food cravings compared to baseline in adults who self-reported binge eating behavior. These reductions were maintained at a 30-day follow-up, while the sham condition showed no significant effects.

Furthermore, Giel et al. [5] evaluated the effect of six sessions of real or sham tDCS combined with enhanced inhibitory control training in BE episodes of 40 participants with BED. A significant reduction in BE episodes in both groups was found after four weeks of treatment. Nonetheless, at 3-month follow-up, patients who were treated with real tDCS reported significantly fewer BE than patients in the sham group.

These results demonstrate that multiple sessions of tDCS appear to be an efficient strategy to decrease BE symptoms in patients with BED or previously self-reported BE symptoms. However, other strategies such as nutritional counseling or specific inhibitory training also appear to produce beneficial effects for this population.

DISCUSSION

The purpose of this systematic review was to synthesize current evidence regarding the effects of various tDCS protocols on BE symptoms in patients diagnosed with BED, individuals with self-reported BE symptoms, and overweight subjects. A total of nine studies met the inclusion criteria; although limited in number, these studies were relatively recent and demonstrated high methodological rigor. This highlights that research in this domain is still emerging but is being conducted with robust study designs. The primary findings of this review suggest that both single and multiple sessions of 2mA, anodal right and cathodal left tDCS produce reductions in BE symptoms among individuals with BED or self-reported BE, whereas such effects were not observed in healthy overweight adults.

Single-session studies showed greater methodological variability and, consequently, more heterogeneous results. The effects of single tDCS sessions appear to depend primarily on the characteristics of the population studied. The study by Ray et al. [32] examined

the effects of treatment expectancy on total food intake in individuals with overweight and obesity, but without symptoms or a diagnosis of BED. No synergistic effects of tDCS were found for this variable. Similarly, the study by Beaumont et al. [26] analyzed the effects of transcranial electrical stimulation on satiety, food desire, and craving in women presenting some binge eating symptoms but without a formal BED diagnosis and also did not find significant effects.

Our findings suggest that the effects of tDCS on the DLPFC may depend on the pre-existing neural network [33]. Since BED is characterized by dysfunctions associated with the DLPFC [7], it is expected that individuals without the disorder do not present such neural alterations, which may reduce the efficacy of tDCS in non-BED populations. As highlighted in the study of Beaumont et al. [26], the participants had a Binge Eating Scale score of 21 ± 4 AU, which is considered subclinical. In contrast, the study by Burgess et al. [24] found significant effects of tDCS on binge eating symptoms in patients with a mean score of 27 ± 6 AU on the Binge Eating Scale, a value considered clinically relevant. Conversely, in studies involving clinically diagnosed BED populations, a single session of tDCS has been shown to reduce the frequency of binge eating episodes and food cravings. However, no significant reductions in actual food intake associated with the stimulation were observed. These findings suggest that modulating cognitive and biopsychological mechanisms in individuals with BED, particularly through stimulation of the DLPFC, may enhance response inhibition [25].

One hypothesis is that DLPFC stimulation alters reward-related neural signaling, thereby inhibiting circuits involved in impulsive eating behaviors [34]. The improved ability to suppress impulsive actions and exert greater cognitive control is considered a key mechanism by which tDCS over the DLPFC reduces food cravings [14,34]. It is also important to consider individual factors that may influence the effectiveness of tDCS interventions. For instance, individual differences in intertemporal decision-making abilities may moderate the prefrontal cortex's response to craving-related stimuli [30,35]. In the study of Kekic et al. [30], the participants who exhibited more impulsive choice behaviors showed less reduction in cravings after active stimulation than those who exhibited more reflective choice behaviors.

Regarding multiple session tDCS protocols in individuals with BED, although studies are still limited, the findings appear to be more consistent, likely due to the adoption of more homogeneous methodologies [27-29]. The mechanisms underlying the effects of multiple tDCS on binge eating symptoms seem to be related to the stimulation of glutamatergic neurons in the prefrontal cortex, which may reduce the responsiveness of the dopaminergic reward system, thereby decreasing the motivational value and desire for specific types of food [12,36].

These effects are supported by neuroimaging studies, which have provided significant insights into the neurobiological basis of obesity, craving and disordered eating behavior [37]. Although distinct conditions, BED and obesity share overlapping neurobiological characteristics, particularly in the domains of reward processing and cognitive control. Studies involving individuals with obesity have identified dysfunctions in various brain regions, including heightened reactivity in motivational and reward circuits, impaired striatal responses to food-related cues [37], and reduced activation in prefrontal areas such as the DLPFC, which is crucial for cognitive control and inhibitory regulation [28,29].

While BED is largely defined by psychological and emotional dysregulation, alterations in motor behavior, including compulsive tendencies and maladaptive physical activity, also contribute significantly to its clinical presentation. Thus, findings of this review support the hypothesis that tDCS targeting the DLPFC can modulate not only cognitive and affective processes, but also behavioral control mechanisms closely tied to motor function. The DLPFC is involved in motor planning, action selection, and inhibitory control, functions that are often compromised in individuals with BED [38,39]. Thus, by enhancing executive function and response inhibition, tDCS may help regulate the impulsive motor responses commonly observed in binge eating episodes. From a motor behavior perspective, these results underscore the potential of neuromodulatory interventions to support the restoration of more adaptive and goal-directed action patterns in clinical populations with dysregulated motor and behavioral control [40,41].

Despite encouraging results, several important methodological limitations remain in the current research. One major issue is the wide variety of assessment tools and outcome measures used across studies, including different self-report questionnaires and objective tests. This diversity makes it difficult to compare results directly or combine data in meta-analyses, limiting the strength of conclusions about tDCS effectiveness. Additionally, few studies have investigated the effects of repeated or long-term tDCS sessions, so there is still limited knowledge about how well these treatments work over time and whether they are safe for extended use, and no study has compared tDCS to other neuromodulatory therapies, such as repetitive transcranial magnetic stimulation or neurofeedback. To move the field forward, future research should use more standardized measures and focus on longer-term studies to better understand the lasting impacts of tDCS.

CONCLUSION

In conclusion, this systematic review offers preliminary evidence supporting the efficacy of tDCS, specifically protocols employing anodal stimulation over the right DLPFC coupled with cathodal stimulation over the left hemisphere at 2mA, in mitigating BE symptoms in individuals diagnosed with BED or exhibiting self-reported BE behaviors. In addition, tDCS is an accessible, portable, and low-cost intervention, which enhances its relevance in clinical settings. Although the current body of literature is limited in size, the methodological rigor of the included studies underscores the potential of tDCS as a viable neuromodulatory approach for BED. Notably, the lack of consistent therapeutic effects observed in overweight individuals without BED emphasizes the necessity for further research to elucidate the neurobiological specificity and underlying mechanisms of tDCS across distinct populations. Future investigations with

larger cohorts and extended follow-up periods are imperative to validate these findings and refine stimulation parameters to optimize clinical outcomes.

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