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Transcranial Direct Current Stimulation (tDCS)

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1,841

STUDIES IN
TOTAL

1,440

IN HUMANS

973

OF WHICH
CONTROLLED

48

IN ANIMALS

0

IN THE LAB

Figures from the IHR study database · Last updated 2026-10-04

How to Read This Dossier

ESTABLISHED

measured in humans, with a comparison group

PLAUSIBLE

supported by mechanism, animal studies or observation

HYPOTHESIS

a likely connection that still needs to be tested

Transcranial Direct Current Stimulation (tDCS) at a Glance

ORIGIN:

tDCS is a non-invasive brain stimulation procedure that works with weak direct current via scalp electrodes. Notable is the distribution of research: controlled studies in humans clearly predominate, and the most cited contribution in the field is not a single study but a guideline on chronic pain conditions.

EVIDENCE BASE:

1.841 evaluated works · 973 controlled studies in humans · 467 observational studies · 114 reviews · 48 animal studies · 0 cell culture studies

STRONGEST EVIDENCE:

- Pain: meta-analyses support tDCS effects in fibromyalgia (SMD -1.04) and in knee osteoarthritis (pain thresholds).
- Depression: in older adults large effect size favouring active tDCS (SMD -0.96), with high heterogeneity ($I^2 = 89\%$).
- Motor rehabilitation after stroke: combination of active tDCS and rehabilitation improves FMA-UE versus sham (MD 7.11).
- Schizophrenia: working memory and verbal learning were the most frequently improved domains (verbal learning g 0.26).
- Migraine: visual cortex tDCS over Oz-Cz achieved the highest rank for reduction of monthly migraine days (MD -1.75).

LIMITATIONS:

- The large randomised trials in subacute stroke (NETS) and in ADHD showed no significant effects.
- Augmentation of psychotherapy by tDCS was not significant in the moderator analysis.
- Montage, current intensity, session number and treatment duration vary considerably between studies.

CLASSIFICATION:

tDCS is a non-invasive brain stimulation procedure whose effect depends strongly on population, montage and endpoint.

1. What tDCS Is and How It Is Performed

tDCS is a non-invasive form of brain stimulation. A weak, constant direct current flows between an active electrode and a reference electrode via two electrodes applied to the scalp. Placement follows defined montage schemes; which brain region is reached depends on the position of the electrodes. A session lasts a limited period, and studies usually perform several sessions over days or weeks. The procedure is investigated in controlled studies against sham stimulation, in which the current does not flow or flows only briefly. In addition to supervised clinical use, home applications have recently come into focus and are being tested in randomised studies with remote supervision.

One point is decisive for the assessment of all studies: the procedure is not a single procedure but a family of protocols. Current intensity, duration, electrode position, number of sessions and target region vary considerably between the works. Two studies with the same label tDCS can stimulate different brain regions with different parameters. Added to this is the sham control: a good sham stimulation should not be distinguishable for the participant from the real stimulation, otherwise blinding breaks. Both together explain why the number of studies does not automatically lead to a uniform answer. Anyone reading results must therefore first ask which protocol was tested and what the control looked like.

2. What the Studies Show in Detail

The human studies, ordered by application and the controlled ones first — with participants, duration, preparation, measure and result as reported by the original works. Numbers appear only where the work states them.

Distribution of **controlled studies in humans** by application area — the numbers are not additive, as one work can be assigned to several areas:

APPLICATION AREA	CONTROLLED STUDIES
Cognition and psyche	465
Safety and tolerability	317
Musculoskeletal system	249
Fatigue and stress	125
Bones and joints	30
Skin	19
Inflammatory processes	15
Oncology	15

Transcranial Direct Current Stimulation (tDCS): Human Studies

The NET study tested anodal tDCS (1 mA, 20 min) over the primary motor cortex of the affected hemisphere in a subacute ischaemic stroke population, in addition to standardised rehabilitation training over ten days. 250 participants were planned; after a blinded interim analysis 123 were enrolled, 119 entered the intention-to-treat analysis. The primary endpoint, the Upper-Extremity Fugl-Meyer Assessment (UEFMA) one to seven days after the end of the intervention, was neutral: the control group (N = 61) improved by 8.9 (SD 7.7) points, the tDCS group (N = 58) by 9.0 (8.8) points ($p = 0.820$). The work shows that a single anodal M1 stimulation over ten days does not improve motor recovery in this population beyond rehabilitation²³. It remains open whether other montages, higher current intensities or longer treatment periods are effective.

The PsychotherapyPlus study investigated at six German university hospitals whether cognitive behavioural therapy (CBT) in major depression is enhanced by simultaneous tDCS. 148 adults aged 20 to 65 years with a single or recurrent depressive episode were randomised: 53 received CBT alone, 48 CBT plus tDCS, 47 CBT plus sham-tDCS. The intervention comprised six weeks with twelve CBT sessions. The work thus tested augmentation of psychotherapy, not tDCS as monotherapy²⁴. For classification it remains to be clarified how the combination behaves in pharmacologically stabilised versus untreated patients and whether simultaneous versus sequential application shows advantages.

Neuromod-COV tested cognitive training procedures in Post-COVID cognition at Greifswald University Medicine in a phase-IIb, prospective, randomised, open, endpoint-blinded design. Adults aged 18 to 60 years with confirmed SARS-CoV-2 infection at least six weeks previously and cognitive complaints were randomised 1:1:1: cognitive training with active tDCS, cognitive training with sham tDCS or progressive muscle relaxation with sham tDCS. The intervention consisted of nine 20-minute sessions over three weeks, with 2 mA tDCS over the left dorsolateral prefrontal cortex. The primary endpoint was untrained working memory performance (N-back task accuracy) in the comparison of cognitive training and progressive muscle relaxation after the intervention²⁵. The tDCS component was tested double-blind and sham-controlled. It remains open whether the effects remain stable beyond the intervention phase and whether they transfer to other cognitive domains.

A double-blind, sham-controlled crossover study examined the effect of 2 mA anodal tDCS over the left dorsolateral prefrontal cortex (right orbitofrontal cathode) for 20 minutes in 20 patients with severe brain injury and disorders of consciousness (12 in the minimally conscious state, 7 in the vegetative state/unresponsive wakefulness syndrome, one patient with emergence from the minimally conscious state). Coma Recovery Scale-Revised (CRS-R), event-related potentials in the local-global paradigm and resting EEG were recorded before and after each stimulation, with follow-up assessments after six weeks and six months. At group level, a significant treatment effect on CRS-R scores was observed ($p = 0.02$). Nine patients (45 %; 6 minimally conscious, 3 vegetative) responded to tDCS, five (25 %; 3 minimally conscious, 2 vegetative) showed new behavioural items that were absent in the sham measurements²⁶. The small sample size and heterogeneous population limit generalisability; it remains to be clarified which patient characteristics predict response.

The MODEST study tested at Greifswald University Medicine in a double-blind, sham-controlled randomised design whether transcranial electrical stimulation influences postoperative delirium in older surgical patients. Patients aged 65 years and over before elective surgery were included; persons with a neurological or psychiatric history or taking centrally active medication were excluded. α -transcranial alternating current stimulation of the salience network, tDCS of the frontoparietal network (20 minutes, 2 mA) and sham, applied in the recovery room after major elective surgery, were compared. The primary endpoint was delirium incidence on the ward on one of up to five postoperative days for the comparison of tACS versus sham; secondarily, among other things, tDCS versus sham was examined²⁷. The primary endpoint therefore concerned the tACS condition; the tDCS findings are secondary and their evidential value remains correspondingly limited.

The network meta-analysis compared non-invasive neuromodulation procedures in depressive episodes in the context of major depression and bipolar disorder. 129 randomised controlled trials with 7667 patients and 272 treatment arms were included, among them nine rTMS protocols, three theta-burst protocols as well as tDCS and tFUS. Primary endpoints were response rates and overall dropout rates. All protocols except low-frequency rTMS over the left dorsolateral prefrontal cortex showed higher response rates than sham; tFUS achieved the highest response rate (OR 7.24; 95 % CI 1.35–38.47), followed by bilateral rTMS (OR 5.75; 95 % CI not fully reported)²². The work places tDCS within a broad spectrum of procedures; the relative ranks of individual protocols remain to be examined owing to heterogeneity of the studies.

A systematic review with meta-analysis evaluated transcranial electrical stimulation in major depression and comorbid depressive states. Randomised clinical trials in adults with major depression, depression with psychiatric comorbidities or depression with medical comorbidities, treated with tDCS, tACS or tRNS versus sham or other treatments, were included. Primary endpoints were depression severity, response and remission rates as well as adverse events; continuous outcomes were pooled as standardised mean differences, categorical outcomes as odds ratios². The review summarises the evidence for the entire group of transcranial electrical procedures; the specific effect estimates for tDCS alone cannot be read from the reported excerpt and remain reserved for detailed evaluation.

A systematic review with dose-response meta-analysis examined which stimulation parameters in non-invasive brain stimulation achieve the greatest symptom improvement across various mental disorders. Randomised clinical trials on TMS or tDCS in adults aged 18 years and over with any mental disorder were included. The main target variable was the near-maximally effective doses of the total pulses delivered for TMS and the total current dose in coulombs for tDCS. A total of 110 studies were evaluated¹. The work thus provides a parameter-related perspective on tDCS; the transferability of the dose recommendations to individual disorders remains to be clarified.

A systematic review with meta-analysis compared device-based neuromodulation procedures for improving motor symptoms in Parkinson's disease. Randomised controlled trials examining deep brain stimulation, TMS or tDCS in Parkinson's patients were included, with the Unified Parkinson's Disease Rating Scale Part III (UPDRS3) as the primary endpoint. The meta-analysis of 39 effect sizes revealed considerable variation in the reported effect sizes between the studies²⁸. The work shows that the heterogeneity of the effect estimators represents a central challenge for the comparability of the procedures.

A systematic review with meta-analysis evaluated non-pharmacological treatments of auditory verbal hallucinations in schizophrenia spectrum disorders. The pooled mean effect size was -0.298 (95 % CI -0.470 to -0.126) and was statistically significant; subgroup analyses showed moderate, statistically significant effects for individual procedures²¹. The work places tDCS within a broad spectrum of non-pharmacological approaches; the procedure-specific effects cannot be read individually from the reported excerpt.

A systematic review with network meta-analysis compared non-invasive brain stimulation procedures in fibromyalgia with regard to pain, fatigue and sleep quality. 43 randomised studies with 2120 participants were included. Pain was the primary endpoint, fatigue and sleep secondary endpoints. The network meta-analysis showed that low-frequency rTMS (SMD -1.20 ; 95 % CI -1.82 to -0.58), dual tDCS (SMD -0.91 ; 95 % CI -1.82 to -0.58) and high-frequency

rTMS (SMD -0.58; 95 % CI -1.00 to -0.17) probably reduce pain intensity at the end of the intervention compared with sham¹⁰. Dual tDCS thus appears to be one of the more effective options; the optimal stimulation location and intensity remain to be further examined.

The REDSTIM study tested the effect of tDCS on alcohol consumption in alcohol use disorder in a triple-blind, randomised, sham-controlled design at 14 centres in France and Monaco. Of 356 screened adult outpatients, 337 were included and randomised 1:1 to active or sham stimulation; 60.5 % were male, mean age was 51.3 ± 11.3 years. The intervention consisted of two daily stimulation sessions (anode F4, cathode F3, 2 mA) on five consecutive days, applied via a pair of surface sponge electrodes (25 cm²) soaked in 0.9 % NaCl; in the sham group an initial ramp-up time of 15 seconds (likewise up to 2 mA) was performed. Participants were followed up every four weeks over 24 weeks²⁹. The work compares active versus sham stimulation in a large sample; the long-term stability of the effects over the 24-week follow-up remains to be evaluated.

A network meta-analysis compared and ranked non-invasive brain stimulation procedures for migraine treatment in adults. Primary endpoints were changes in monthly migraine days and dropout rates. Visual cortex tDCS over Oz-Cz (anodal protocol over V1) achieved the highest rank for reduction of monthly migraine days (MD -1.75; 95 % CI -3.37 to -0.13; SUCRA 83.5 %). For acceptability, only transcutaneous occipital nerve stimulation significantly reduced dropout rates versus sham (RR 0.36; 95 % CI 0.16–0.82)³⁰. The work positions V1-tDCS as the most effective option for reducing migraine days; transferability to different migraine subtypes remains to be clarified.

A systematic review with meta-analysis evaluated the efficacy and safety of tDCS in attention-deficit/hyperactivity disorder. Core symptoms, hot and cold executive functions (inhibitory control, working memory, cognitive flexibility) as well as safety profiles were recorded. Versus sham, tDCS did not significantly improve core symptoms (SMD -0.29; 95 % CI -0.59 to 0.01; $p = 0.05$). No significant overall effects were shown for cold executive functions either: inhibitory control (Hedges' g -0.11; 95 % CI -0.26 to 0.05; $p = 0.19$), working memory (g 0.13; 95 % CI -0.06 to 0.32; $p = 0.26$) and cognitive flexibility (SMD -0.42; 95 % CI -1.13 to 0.29; $p = 0.24$). The effect on hot executive functions was likewise not significant (g 0.27; 95 % CI -0.14 to 0.70; $p = 0.19$). Exploratory analyses suggested that anode placement at Fp2 was associated with improvements³¹. The work shows that the overall evidence in ADHD does not support significant effects; the exploratory montage findings are to be regarded as indications and require confirmation.

A systematic review with meta-analysis examined the effect of tDCS on cognitive function in older adults with and without mild cognitive impairment. Global cognition as well as the domains learning and memory and executive function were recorded. The work aimed to analyse influencing factors of the tDCS effect⁸. The results of the pooled analysis cannot be fully read from the reported excerpt; the heterogeneity of the studies and the different cognitive endpoints remain central challenges for comparability.

A systematic review with meta-analysis evaluated the effect of tDCS in combination with rehabilitation on arm and hand function in stroke patients. The primary endpoint was motor impairment of the upper extremity, measured with the Fugl-Meyer Assessment for upper extremity (FMA-UE); secondary endpoints included functional activity, grip strength and safety. The combination of active tDCS and rehabilitation showed a statistically significant improvement in FMA-UE values versus sham (MD 7.11; 95 % CI 5.76 to 8.46; $p < 0.0001$)³². The work supports the combination as an effective adjunct; the clinical relevance of the improvement and the optimal stimulation modality remain to be examined.

A systematic review with meta-analysis examined the efficacy of non-invasive neuromodulation in chronic tinnitus. The primary endpoint was change in the Tinnitus Handicap Inventory (THI); secondary endpoints included Tinnitus Functional Index, Tinnitus Questionnaire, loudness measures as well as anxiety and depression scales. The pooled THI reduction was -6.96 points (95 % CI -10.67 to -3.26) in the short term; rTMS showed a significant benefit³³.

A systematic review with meta-analysis evaluated the efficacy and safety of tDCS in stroke patients with motor dysfunction of the upper extremity. 44 studies with 1555 participants comparing active and sham stimulation were included. Upper Extremity Fugl-Meyer Assessment, Action Research Arm Test, Barthel Index and safety were recorded. tDCS improved upper extremity motor function (SMD 0.22; 95 % CI 0.12–0.32; $p < 0.001$) and the Barthel Index (MD 4.65; 95 % CI 2.82–6.49; $p < 0.001$). Subgroup analyses showed the highest tDCS efficacy in subacute stroke; both anodal and cathodal stimulation were effective⁶. The work supports efficacy across both polarities; the optimal polarity and the optimal time point after stroke remain to be further clarified.

A systematic review with meta-analysis examined whether non-invasive brain stimulation enhances evidence-based psychotherapy in psychiatric disorders. 28 studies with 31 treatment arms and 1506 participants comparing active neuromodulation plus psychotherapy versus sham neuromodulation plus psychotherapy were included. Active neuromodulation plus psychotherapy achieved significantly greater symptom improvement than sham plus psychotherapy (SMD -0.38; 95 % CI -0.68 to -0.08), with considerable heterogeneity. Moderator analyses showed that rTMS conferred a significant benefit, whereas tDCS did not. Non-concurrent application showed significant effects, concurrent application did not. Cognitive behavioural therapy in combination with neuromodulation showed significant benefit, other psychotherapy formats did not. Psychotherapy delivered by humans significantly strengthened the results, computer-supported formats did not³⁴. The work thus provides important indications on implementation parameters; the tDCS-specific conditions remain to be further examined.

A systematic review with meta-analysis evaluated the effect of tDCS on cognitive impairments in schizophrenia. 33 randomised controlled trials with 1372 patients with schizophrenia or schizoaffective disorder were included. The studies varied in montage, intensity, duration and number of sessions. Quantitative meta-analyses were conducted across eight cognitive domains with multilevel random-effects models. Working memory and verbal learning were the most frequently improved domains. Other domains (e.g. working memory, processing speed, problem solving) showed small, non-significant trends towards improvement, while attention and social cognition showed no improvement¹⁹. The work shows a domain-specific finding; transferability to everyday life and the optimal number of sessions remain to be clarified.

A systematic review with meta-analysis examined the effect of various electrical stimulation procedures on postural control and gait after stroke. Randomised controlled trials on tDCS, functional electrical stimulation, transcutaneous electrical nerve stimulation and neuromuscular electrical stimulation were included. Meta-regression analyses within the FES subgroup showed that stimulation intensity, frequency and electrode location did not significantly influence treatment outcomes (all $p > 0.05$); however, outcome type was a significant moderator³⁵.

A systematic review with network meta-analysis examined the efficacy and acceptability of brain stimulation procedures in anxiety disorders, obsessive-compulsive disorder and post-traumatic stress disorder. 41 studies with 86 treatment arms and 1333 patients with various anxiety disorders, obsessive-compulsive disorder, post-traumatic stress disorder and agoraphobia were included. The network meta-analysis showed that some procedures exhibited higher efficacy versus controls, including deep brain stimulation, electroconvulsive therapy, cathodal tDCS, high-frequency rTMS and anodal tDCS³. The work positions cathodal tDCS as efficacy-relevant; the differential indication between the procedures remains to be clarified.

A systematic review with meta-analysis examined non-invasive brain stimulation for the treatment of cognitive and neuropsychiatric non-motor symptoms in Parkinson's disease and atypical parkinsonism. 27 studies on rTMS (N = 1309 patients, range 18–106) and 7 studies on tDCS (N = 221, range 10–77) were included. Cognition was recorded in 17 rTMS and 6 tDCS studies, depression in 24 rTMS and 4 tDCS studies, anxiety in 11 rTMS and 1 tDCS study, apathy in 4 rTMS and 1 tDCS study, psychosis in 1 tDCS study. Variability of target regions, parameters, outcome measures, treatment duration and follow-up led to some concerns (N = 26) or high risk of bias (N = 8). Despite high heterogeneity and low to moderate certainty of evidence, the meta-analysis suggested a benefit of excitatory rTMS of the left dorsolateral prefrontal cortex and the primary motor cortex. The tDCS evidence in Parkinson's disease is numerically substantially smaller than the rTMS evidence; the specific tDCS effects remain to be further examined.

A systematic review with meta-analysis evaluated the efficacy and safety of tDCS in depression in older adults. The results showed a large effect size in favour of active tDCS for depressive symptoms (SMD -0.96; 95 % CI -1.56 to -0.37), with high heterogeneity ($I^2 = 89\%$). Large effect sizes in favour of active tDCS were shown both in clinician-administered depression measures (Hamilton Depression Rating Scale, Montgomery-Åsberg Depression Rating Scale, Cornell Scale for Depression in Dementia) and in self-report measures (Beck Depression Inventory, Zung Self-Rating Depression Scale). Subgroup analyses showed a non-significant effect in studies that exclusively examined major depression and a large, albeit preliminary, effect in studies with a restricted population ³⁶. The work supports efficacy in geriatric depression; the high heterogeneity and the differing subgroup results remain to be clarified.

A systematic review with meta-analysis examined the effect of non-invasive brain stimulation on peripheral BDNF levels in major depression. The work provides a biomarker-related finding; the question whether BDNF can serve as a predictor of treatment success remains to be further examined.

A systematic review with meta-analysis examined the effect of tDCS on pain threshold in knee osteoarthritis. Primary endpoints were pain thresholds (pressure pain threshold, conditioned pain modulation, heat pain threshold, heat pain tolerance); secondary endpoints included pain intensity (VAS/NRS), physical function (WOMAC/KOOS) and walking ability (6MWT/10MWT) ³⁷. The work examines a mechanism-oriented endpoint; the clinical relevance of the threshold changes and transferability to pain intensity remain to be clarified.

A network meta-analysis examined the efficacy and acceptability of non-invasive brain stimulation procedures in obsessive-compulsive disorder. 34 randomised controlled trials with 1089 participants and 24 different procedures were included. Primary endpoints were changes in overall severity of obsessive-compulsive disorder and acceptability (dropout rates). Three procedures significantly improved overall severity versus sham: high-frequency rTMS over the dorsolateral prefrontal cortex (MD -10.81; 95 % CI -20.80 to -0.82), high-frequency deep TMS over the dorsomedial prefrontal cortex/anterior cingulate cortex (MD -9.74) and one further procedure ¹⁵. The work places tDCS within a broad spectrum of procedures; the specific tDCS effects in obsessive-compulsive disorder cannot be read individually from the reported excerpt.

A systematic review with meta-analysis examined the effect of cathodal tDCS over the contralesional primary motor cortex on upper extremity rehabilitation in stroke patients. Twenty-six randomised controlled trials with 1038 patients were included. Compared with controls, cathodal tDCS significantly improved upper extremity motor function, manual dexterity and activities of daily living and reduced elbow spasticity as well as overall neurological impairment (all $p < 0.05$). Resting motor threshold remained unchanged. Subgroup analyses showed stable efficacy at 1–2 mA, 20 min/session, 5 sessions/week and ≥ 2 weeks of treatment. Short-term benefits were maintained; long-term stability still requires verification. Adverse events were mild and transient, predominantly local tingling and itching ³⁸. The work supports cathodal tDCS as an adjunct; long-term effects remain to be clarified.

A systematic review examined the efficacy of anodal tDCS on upper extremity function after ischaemic stroke. Nineteen studies with 1032 participants were included. Pooled results showed a positive influence of anodal tDCS on the Fugl-Meyer Assessment Upper Extremity, the Wolf Motor Function Test, resting motor threshold and the Barthel Index ⁷. The work focuses on anodal stimulation in ischaemic stroke; optimal treatment duration and combination with other therapies remain to be examined.

A retrospective observational study at the National Hospital for Paraplegics in Toledo, Spain, examined the safety and effect of tDCS in 155 patients with pharmacologically resistant chronic pain. Anodal tDCS over M1 was applied for 20 minutes at 1.5 mA over ten treatment sessions from Monday to Friday (induction phase), followed by two to three sessions per month (maintenance phase). Pain intensity was recorded with a visual analogue scale. Anodal tDCS over M1 confirmed reduction in pain intensity; 58 % of outpatients completed one year of treatment. Only baseline VAS values influenced treatment response ³⁹. The work provides evidence from routine care; the lack of randomisation limits causal interpretation.

An observational study compared the effect of one versus two daily sessions of anodal tDCS over the left dorsolateral prefrontal cortex for ten days in 30 women with chronic migraine (mean age 28.0 ± 6.92 years; disease duration 37.8 ± 48.41 months). Participants were randomly assigned to three groups: one daily session, two daily sessions or one daily sham session. Migraine Disability Assessment, Montreal Cognitive Assessment, d2 test, Trail Making Test (Part B), Digit-Symbol Coding from the Wechsler Adult Intelligence Scale III and Nine Hole Peg Test were recorded before, after and one month after treatment. No group differences appeared in cognitive measures or manual dexterity. After treatment a significant decrease in migraine-related disability was found in the group receiving one daily session. No cumulative effects of two daily sessions versus one daily session were observed for any variable ⁴⁰. The work provides preliminary evidence for future studies on different intervals between tDCS sessions.

A cross-sectional study analysed, using data from the ELETRON study, the affected cortical and subcortical brain structures and quantified ischaemic lesion volume in 23 patients with hemispatial neglect after stroke who received anodal tDCS, cathodal tDCS or sham tDCS. Lesion mapping was based on high-resolution volumetric CT images with an automated anatomical labelling atlas. The Behavioral Inattention Test (BIT-C) was significantly higher in the cathodal tDCS group than in the sham group ($p = 0.03$). Grey-matter lesion extent was $325,580 \text{ mm}^3$ in the anodal group, $231,700 \text{ mm}^3$ in the cathodal group and $241,574 \text{ mm}^3$ in the sham group; white-matter lesion extent was $37,076 \text{ mm}^3$ in the anodal group, $22,258 \text{ mm}^3$ in the cathodal group and $40,556 \text{ mm}^3$ in the sham group, all centred on the superior longitudinal fasciculus. The anodal group showed a larger lesion area in grey matter than the cathodal group ($p = 0.046$) ⁴¹. The small sample and cross-sectional design limit the strength of the findings.

A methodological study introduced a prospective, empirically informed, multimodal fMRI framework for target selection and hypothesis-based analysis of future focal tDCS-fMRI studies. Data from 37 healthy individuals (19 women; mean age 25.8 ± 5.9 years) from two tDCS-fMRI studies on the same scanner with placebo tDCS were used. Participants completed two resting-state sessions and two task-fMRI sessions (object-location memory or associative picture-pseudoword learning). Seed-based resting-state analyses identified functional networks of target regions for focal tDCS (right occipito-temporal cortex, left ventral inferior frontal gyrus) and established their test-retest reliability using intraclass correlation coefficients. Dice coefficients quantified overlap between seed-based resting-state networks and task-evoked activity ⁴². The work provides a methodological framework; transferability to clinical populations remains to be examined.

A double-blind anodal tDCS study examined the role of the hippocampus and retrosplenial cortex in spatial memory. Eighteen participants performed a spatial localisation task in a virtual environment under three stimulation conditions: anodal tDCS over the left retrosplenial cortex, anodal tDCS over the left hippocampus and sham. Task conditions varied in reference frame (viewer-, object- and environment-centred) and perspective shift (0°, 45°, 135°). Accuracy was analysed with non-parametric statistics. Performance declined with increasing viewpoint rotation, especially in environment-centred trials. Retrosplenial cortex stimulation selectively reduced accuracy in environment-centred trials with large perspective shifts (135°), whereas hippocampal stimulation did not significantly modulate performance ⁴³. The work provides causal evidence for the involvement of the retrosplenial cortex in viewpoint-invariant spatial updating; the small sample limits generalisation.

A study examined how informational priming influences expectations of tDCS in the motor domain and whether prior knowledge of tDCS moderates this effect. A modified expectation scale measuring expected tDCS-related motor performance was administered before and after receipt of information about tDCS efficacy. The high-expectation-priming group received evidence for such efficacy; the low-expectation-priming group received information emphasising the lack of evidence for tDCS efficacy. Expectations of tDCS efficacy rose significantly across all motor domains in the high-expectation-priming group and fell significantly in the low-expectation-priming group ⁴⁴. The work shows that expectations of tDCS are modifiable by information; the implications for interpreting study results remain to be clarified.

Reviews and Mechanisms of Action

A systematic review examined the optimal electrode montage for tDCS in obsessive-compulsive disorder on the basis of meta-analyses of rTMS and deep brain stimulation. Only three references met the inclusion criteria; four different electrode montages were simulated and current direction and intensity analysed. The authors found that a montage with the cathode over the pre-supplementary motor area and an extracephalic anode best reached the structures of interest ⁴⁵. The theoretical model requires empirical validation.

A narrative review describes the physiological mechanisms of tDCS for improving motor performance. The technique applies a stable, low-intensity (1–2 mA) direct current to modulate neuronal activity in the cerebral cortex. Numerous studies show that tDCS can improve muscle strength, explosive strength and aerobic metabolism, reduce fatigue and enhance cognition. Mechanisms described include modulation of the neuronal resting membrane potential to alter cortical excitability, enhancement of synaptic plasticity to regulate long-term potentiation, modulation of neurovascular coupling to improve regional cerebral blood flow and improvement of functional connectivity of cerebral networks ⁴⁶.

A review examined the combination of TMS and tDCS with medication and psychotherapy in depression. Fifty-eight studies were included (7 TMS plus psychotherapy, 32 TMS plus medication, 7 tDCS plus psychotherapy, 12 tDCS plus medication) ⁴⁷. The work places combination treatments in context; specific effects of the tDCS combinations cannot be read individually from the reported excerpt.

Twenty studies were included. Active tDCS had a positive effect on pain (SMD –1.04; 95 % CI –1.38 to –0.69) and depression (SMD –0.46; 95 % CI not fully reported). Subgroup analyses examined different stimulation regions (M1, DLPFC, operculo-insular cortex, occipital nerve) ⁴⁸. The work supports the analgesic effect; the optimal stimulation region remains to be clarified.

A comprehensive review examined the role of tDCS in stroke with a focus on neuroprotection in the acute phase and modulation of cerebral blood flow in acute and chronic phases. Cathodal tDCS shows potential for neuroprotection in acute ischaemic stroke in small clinical studies, improves cerebral blood flow and promotes vascular recanalisation, whereas anodal tDCS shows stronger effects on cerebral blood flow, especially in chronic stroke and hypoperfusion. Bihemispheric stimulation may offer additional benefits, with evidence of a dose-dependent relationship between stimulation parameters and therapeutic outcomes ⁴⁹. The work provides an overview; optimisation of protocols and assessment of safety and feasibility remain open.

An evidence-mapping study presented, organised and assessed the methodological quality of research on tDCS and motor function after stroke. One hundred seventy-two articles from 5759 records were included, comprising 46 systematic reviews and 126 randomised controlled trials from 29 countries. More than half of the systematic reviews (65.22 %) were rated low or critically low quality, while 78.58 % of the randomised controlled trials showed excellent or good quality. Twenty-six systematic reviews and 93 randomised controlled trials reported results on the upper extremity; 15 systematic reviews and 44 randomised controlled trials reported results on the lower extremity. Studies with safety concerns reported no or mild adverse events ⁵⁰. The work identifies gaps and clinical implications; methodological heterogeneity of the reviews remains a challenge.

Overall Picture

Across applications a differentiated picture emerges. Meta-analyses support tDCS effects on pain (fibromyalgia: SMD –1.04; knee osteoarthritis: pain thresholds), depression (older adults: SMD –0.96; BDNF: SMD 1.05), motor rehabilitation after stroke (FMA-UE: MD 7.11; SMD 0.22) and verbal learning in schizophrenia (g 0.26). Network meta-analyses place tDCS in comparison with rTMS and other procedures: in fibromyalgia dual tDCS achieves an SMD of –0.91; in migraine V1-tDCS leads the ranking (MD –1.75). In contrast, the large randomised trials in subacute stroke (NETS) and in ADHD show no significant effects, and augmentation of psychotherapy by tDCS was not significant in the moderator analysis. The findings are therefore strongly dependent on population, montage and endpoint.

The question of optimal stimulation parameters remains open. The dose-response meta-analysis across 110 studies and the evidence-mapping study across 172 articles show that montage, current intensity, session number and treatment duration vary considerably between studies. The NET study was terminated early after a blinded interim analysis, limiting the strength of the findings for the planned population. Observational studies provide evidence from routine care, for example one-year application in chronic pain (58 % completion rate) and the absence of cumulative effects of two daily sessions in chronic migraine. The question of which patient characteristics predict response and whether effects remain stable long-term must be further examined in controlled designs.

3. How Robust the Research Is

Research is distributed very unevenly. The largest block consists of controlled studies on cognition, followed by work on safety and applications to the musculoskeletal system. Fatigue is also a distinct field. Areas such as bone, skin, inflammation, oncology, cardiovascular and metabolism are markedly smaller; each contains only isolated controlled studies. Alongside controlled studies stand observational studies, basic-research work and reviews and

mechanism studies. The most-cited individual studies concern aphasia after stroke, chronic pain, bipolar depression, negative symptoms in schizophrenia and anxiety — that is, clinical applications, not cognitive enhancement in healthy individuals.

Methodologically the field is above average: controlled, sham-blinded studies form the majority, and systematic reviews with dose-response analyses exist, for example on mental disorders. A guideline on chronic pain conditions is among the most-cited works overall. The weakness lies less in quantity than in dispersion: different protocols can be combined only to a limited extent, and individual application areas rest on few studies. The most recently added home-use applications are early randomised trials designated as phase-2 studies. A finding is therefore considered confirmed only when it can be replicated protocol-faithfully.

Sham control is the real benchmark

The widespread assumption about tDCS is that the method is particularly easy to test because of its weak currents and simple handling. The opposite is true. Because the stimulation is supposed to be barely perceptible, almost everything depends on the quality of the sham stimulation: anyone who can distinguish real from sham stimulation unblinds the study, and expectation effects enter the result. Safety research is therefore not a side issue but one of the largest controlled categories in the field.

Protocol diversity adds to this. When current intensity, electrode placement and session number vary between studies, a pooled analysis measures not one effect but an average across different interventions. Reviews with dose-response analyses attempt precisely to capture this by treating the parameters as their own variable. For practice it follows that a study always supports only the protocol it tested. The open question is not whether tDCS works, but which protocol works for which target condition.

4. What Is Frequently Claimed — and What the Data Provide

CLAIM	EVIDENCE BASE
tDCS relieves chronic pain	This field includes a guideline and several review articles that rank among the most cited of the procedure. However, the individual studies vary, and the guideline
tDCS enhances cognitive performance	Cognition is the largest controlled field of application. Tests are usually carried out on laboratory tasks; whether this translates to everyday function is a separat
tDCS is free of side effects	Safety is one of the largest controlled categories. That a great deal of research is conducted on this is an indication of good tolerability, but no evidence of an a
tDCS can readily be applied at home	For home applications, randomised, sham-controlled trials exist that are designed as phase-2 studies with remote supervision. They are the beginning, not the c

5. The Most Robust Studies

Ordered by strength of evidence, not by prominence: reviews and studies with many participants first. The complete evaluation includes significantly more studies; the most robust ones are listed here.

Controlled Studies in Humans

- ¹ Transcranial Magnetic Stimulation and Transcranial Direct Current Stimulation Across Mental Disorders: A Systematic Review and Dose-Response ... (2024) — Systematic review, 4.820 participants
- ² Transcranial Electrical Stimulation in Treatment of Depression: A Systematic Review and Meta-Analysis (2025) — Systematic review, 5.522 participants
- ³ Efficacy and acceptability of brain stimulation for anxiety disorders, OCD, and PTSD: A systematic review and network meta-analysis of randomized ... (2025) — Systematic review, 1.333 participants
- ⁴ Evidence-Based Umbrella Review of Non-Invasive Neuromodulation in Chronic Neuropathic Pain (2025) — Systematic review, 8.151 participants
- ⁵ Effects of transcranial direct current stimulation on pain and physical function in patients with knee osteoarthritis: a systematic review and ... (2024) — Systematic review, 503 participants
- ⁶ Transcranial direct current stimulation for upper extremity motor dysfunction in poststroke patients: A systematic review and meta-analysis (2024) — Systematic review, 1.555 participants
- ⁷ Efficacy of anodal transcranial direct current stimulation for upper extremity function after ischemic stroke: A systematic review of parallel ... (2025) — Systematic review, 1.032 participants
- ⁸ Effects of Transcranial Direct Current Stimulation on Cognitive Function in Older Adults with and without Mild Cognitive Impairment: A Systematic ... (2024) — Systematic review, 1.761 participants

- ⁹ Non-invasive brain stimulation for stroke-related motor impairment and disability: an umbrella review of systematic review and meta-analysis (2025) — Systematic review, 1.654 participants
- ¹⁰ Comparative Effectiveness of Noninvasive Brain Stimulation for the Treatment of Pain, Fatigue, and Sleep Quality in Fibromyalgia. A Systematic Review ... (2025) — Systematic review, 2.120 participants
- ¹¹ Effects of non-invasive brain stimulation on impulsivity in patients with mental disorders: a systematic review and meta-analysis of randomised ... (2024) — Systematic review, 655 participants
- ¹² Effect of transcranial direct current stimulation combined with cognitive rehabilitation on cognitive function and activities of daily living in ... (2025) — Systematic review, 663 participants
- ¹³ Assessing tDCS efficacy in reducing negative symptoms in schizophrenia spectrum disorders: A systematic review and meta-analysis (2025) — Systematic review, 709 participants
- ¹⁴ The effects of combined transcranial direct Current stimulation with physiotherapy for physical function in subjects with knee osteoarthritis: a ... (2025) — Systematic review, 628 participants
- ¹⁵ The Efficacy and Acceptability of Non-Invasive Brain Stimulation Interventions for Obsessive-Compulsive Disorder Management: A Network Meta-Analysis ... (2025) — Systematic review, 1.089 participants
- ¹⁶ The effects of rTMS and tDCS on repetitive/stereotypical behaviors, cognitive/executive functions in intellectually capable children and young adults ... (2025) — Systematic review, 813 participants
- ¹⁷ Maintenance of Noninvasive Brain Stimulation for Preventing Relapse in Depression: A Systematic Review and Meta-Analysis (2025) — Systematic review, 837 participants
- ¹⁸ Effects of Transcranial Direct Current Stimulation on Cognitive Deficits in Depression: A Systematic Review (2023) — Review article, 972 participants
- ¹⁹ Transcranial direct current stimulation (tDCS) for cognitive impairment in schizophrenia: A systematic review and meta-analysis of randomized ... (2025) — Review article, 1.372 participants
- ²⁰ Efficacy of non-invasive brain stimulation on theory of mind and emotion processing in neuropsychiatric disorders: A systematic review and ... (2025) — Review article, 1.486 participants
- ²¹ The effectiveness of non-pharmacological treatments for auditory verbal hallucinations in schizophrenia spectrum disorders: A systematic review and ... (2025) — Review article, 2.314 participants
- Non-invasive brain stimulation for treating cognitive and neuropsychiatric non-motor symptoms in Parkinson's disease and atypical parkinsonism: a ... (2026) — Review article, 1.309 participants
- ²² Comparison of multiple non-invasive neuromodulation strategies for depressive episodes in major depressive disorder and bipolar disorder: A ... (2026) — Review article, 7.667 participants
- Efficacy and safety of non-invasive brain stimulation for chronic low back pain: a systematic review and meta-analysis of randomised controlled trials (2026) — Review article, 744 participants

6. Summary

PLAUSIBLE The narrative review describes as mechanisms the modulation of the neuronal resting membrane potential to alter cortical excitability, the enhancement of synaptic plasticity to regulate long-term potentiation, the modulation of neurovascular coupling to improve regional cerebral blood flow and the improvement of functional connectivity of cerebral networks. **Hypothesis:** If these mechanisms can be confirmed, this could lead to a parameter-based selection of montage and current strength for individual applications.

7. What Remains Open

- **Sham control:** How can a sham stimulation be designed so that participants and examiners cannot guess the assignment?
- **Protocol:** Which combination of electrode placement, current strength and number of sessions is superior for a given target presentation?
- **Home use:** Can the effect demonstrated under supervision be reproduced and safely monitored with remote supervision at home?

Frequently Asked Questions

How many sessions are necessary?

This cannot be stated in general terms. The studies work with different numbers of sessions and treatment periods, and the number of sessions is one of the parameters that vary between the protocols. A general statement would therefore not be covered by the state of research; what matters is which protocol was tested in which study.

Is tDCS a tested procedure for depression?

Several randomised, sham-controlled studies exist on depression, including a trial as add-on treatment in bipolar depression, a combination with cognitive behavioural therapy and two home-use studies in a depressive episode. A systematic review with dose-response analysis summarises work on mental disorders. The results are protocol-dependent.

How do I recognise whether a tDCS study is reliable?

By the control and the protocol. A reliable study describes how the sham stimulation was performed, how blinding was checked and which parameters were used. If these details are missing, the result can hardly be classified, even if the study is randomised.

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