



DOSSIER · THERAPY

Transcranial Magnetic Stimulation (TMS)

Transcranial magnetic stimulation is a non-invasive procedure for brain stimulation. This page classifies the research on it: how the procedure works, which application areas have been tested in controlled studies and where questions still remain open. It is striking that the most-cited controlled study concerns obsessive-compulsive disorder and not depression, with which the procedure is usually associated in everyday practice.

2,239

STUDIES IN
TOTAL

1,733

IN HUMANS

833

OF WHICH
CONTROLLED

31

IN ANIMALS

7

IN THE LAB

Figures from the IHR study database · Last updated 2026-10-15

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 Magnetic Stimulation (TMS) at a Glance

ORIGIN:

Transcranial magnetic stimulation (TMS) is a non-invasive brain stimulation procedure: A coil on the scalp generates short, strong magnetic field pulses that penetrate the skull and meninges and induce electrical currents in the underlying tissue, which briefly excite or inhibit nerve cells. No substance is administered; single- and double-pulse procedures are distinguished from repeated stimulation (rTMS).

EVIDENCE BASE:

2,239 evaluated papers · 833 controlled human studies · 900 observational studies · 135 review articles · 31 animal studies · 7 cell culture studies

STRONGEST EVIDENCE:

- Depression in children, adolescents and young adults: Meta-analysis of 34 RCTs with 2,705 participants; high-frequency rTMS showed the largest effect (SMD=-1.90, 95 % CI [-2.42, -1.37]).
- Cognitive impairment after stroke: Network meta-analysis of 74 RCTs with 5,478 patients; intermittent theta-burst stimulation achieved the best rankings for MoCA, MMSE and MBI scores.
- Depression, choice of target region: Network meta-analysis of 63 RCTs with 3,080 participants; active TMS with neuronavigational method was effective (standardised mean difference=1.19, 95 % CI 0.55–1.84).
- Insomnia: Meta-analysis of randomised controlled trials; rTMS improved sleep quality versus sham (PSQI total score, ISI; $p < 0.001$), and rTMS combined with medication was more effective than medication alone ($p = 0.003$).
- Obsessive-compulsive disorder: The most-cited controlled study addresses this indication. A systematic review describes growing evidence; deep TMS reaches deeper subcortical structures than conventional rTMS.

LIMITATIONS:

- In cerebral palsy, 18 studies with 1,675 patients showed no significant difference in language function after treatment (MD=2.80, 95 % CI -1.51 to 7.11, $P = 0.20$).
- In depression in young people, iTBS effects remained non-significant; outside stroke rehabilitation and neuropathic pain, neurological applications are at an early stage of investigation.
- The most-cited controlled studies concern treatment-resistant courses and compare stimulation forms with one another; they do not examine whether the result is transferable to other courses.

CLASSIFICATION:

TMS is a family of non-invasive stimulation protocols whose controlled evaluation is most advanced in treatment-resistant psychiatric courses.

1. What Transcranial Magnetic Stimulation Is

A coil on the scalp generates short, strong magnetic field pulses. The field penetrates the skull and meninges and induces electrical currents in the underlying tissue that briefly excite or inhibit nerve cells. No substance is therefore administered; the effect occurs via the field geometry of the coil and the position of the target region. In application, single- and double-pulse procedures, which test cortical excitability, are distinguished from repeated stimulation (rTMS) with series of pulses per session, repeated over several weeks. Special forms are deep TMS with dedicated coils and theta-burst stimulation with shorter, denser pulse trains. One paper traces the approval milestones of the US Food and Drug Administration for TMS devices.

For understanding all studies it is crucial that TMS is not a single procedure but a family of protocols. Frequency, intensity, coil shape, target region, number of sessions and pause length can be varied independently; two studies with the same name may therefore examine different things. The target region is determined either anatomically or via the strength of brain connections, i.e. connectivity-guided. A second point concerns measurement: Cortical excitability can be captured via the muscle response after a magnetic pulse. This value is a marker for the excitability of the system, not for disease progression. A study that changes the marker does not thereby demonstrate improvement in symptoms. A third point is control: A sham treatment must not be distinguishable from the real treatment for participants. If this succeeds only partially, expectation and perception can explain part of the result.

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 the original papers report them. Numbers appear only where the work states them.

Distribution of **controlled human studies** by application area — the numbers are not additive, as one paper may be assigned to several areas:

APPLICATION AREA	CONTROLLED STUDIES
Cognition and psyche	448
Safety and tolerability	282
Musculoskeletal system	174
Fatigue and stress	102

APPLICATION AREA	CONTROLLED STUDIES
Inflammatory processes	17
Oncology	10
Metabolism	10
Gut and microbiome	9

Transcranial Magnetic Stimulation (TMS): Human Studies

Controlled research on TMS covers a broad spectrum of psychiatric and neurological applications. For obsessive-compulsive disorders, an ongoing multicentre randomised controlled trial (TETRO) is examining the efficacy and cost-effectiveness of low-frequency (1 Hz) rTMS over the pre-supplementary motor area (pre-SMA) as add-on treatment to exposure therapy with response management in adults with insufficient response to first-line therapy. 250 adults are planned, randomised to receive either active or sham rTMS in combination with exposure therapy ²⁵. For persistent post-concussion syndrome, a double-blind, sham-controlled study in 44 adults (18–65 years, symptoms for more than 3 months up to 5 years) is investigating whether rTMS reduces symptom burden on the Rivermead Postconcussion Symptom Questionnaire; secondary outcomes include neuropathophysiological changes measured by functional near-infrared spectroscopy ²⁶.

In depression in the context of Parkinson's disease, a three-arm, randomised, sham-controlled study at Xinhua Hospital, Shanghai Jiao Tong University School of Medicine, China (August 2024 to January 2025) compares ultra-short intermittent theta-burst stimulation (iTBS) with active high-frequency rTMS and sham-iTBS. Patients aged 50 to 80 years with Parkinson's disease and HAMD-24 scores of 8 to 20 were included. Ten daily sessions over 2 weeks: active iTBS (3 minutes and 20 seconds), active HF-rTMS (20 minutes) or sham-iTBS. Primary endpoint was the HAMD-24 score at week 2, with follow-up to week 6 ²⁷.

For auditory verbal hallucinations in schizophrenia, a 6-week, double-blind, sham-controlled randomised study at the Anhui Mental Health Center, Hefei, China (September 2016 to August 2021) investigated the effect of imaging-navigated rTMS over the left temporoparietal junction. Of 66 included patients with AVH and schizophrenia, 62 completed the 2-week treatment (33 women [53 %]; mean age 27.4 [9.2] years); 32 were assigned to the active group. The primary endpoint was the improvement in AVH from baseline to week 2 and week 6, measured with the Auditory Hallucination Rating Scale (AHRS); secondarily, the TMS-induced electric field strength was used to estimate the AVH improvement ²⁸.

In chronic low back pain in veterans, an ongoing multicentre randomised controlled trial compares three arms: active rTMS plus psychologically informed physiotherapy (PiP), sham rTMS plus PiP, and usual physiotherapy. The primary aim is physical functioning in veterans with chronic low back pain and comorbid psychological risk factors; secondary outcomes include pain intensity, quality of life, depressive symptoms, pain catastrophising, movement-related fear and self-efficacy ²⁹.

A meta-analysis of variance across psychiatric disorders examined whether patients respond differently to TMS or tDCS by comparing variability in the active group with the sham group. Included were 130 double-blind, sham-controlled RCTs and crossover studies with 5748 patients with unipolar or bipolar depression, bipolar disorder, schizophrenia-spectrum disorder or obsessive-compulsive disorder. The authors calculated variance-weighted variability ratios for each comparison ¹. An earlier version of the same analysis included 114 studies with 5005 patients ³⁰.

A systematic review and dose-response meta-analysis defined optimal stimulation parameters for non-invasive brain stimulation in mental disorders. From 110 studies, randomised clinical trials of TMS or tDCS in adults aged 18 years and older with any mental disorder were included; the analysis was performed in one step using a random-effects model. The main outcome measures were the near-maximally effective doses of total pulses for TMS and total charge dose in coulombs for tDCS ³¹.

For post-stroke cognitive impairment, a systematic review and network meta-analysis evaluated different rTMS modalities. Included were 74 RCTs with a total of 5478 patients; the highest probability rankings showed that intermittent theta-burst stimulation (iTBS) was most effective at improving MoCA, MMSE and MBI scores ³. Another systematic review and meta-analysis of high-frequency rTMS in post-stroke cognitive impairment included 61 RCTs with 4012 patients. MoCA score, MMSE score, P300 amplitude, Loewenstein Occupational Therapy Cognitive Assessment score and overall cognitive function efficacy rate were higher in the HF-rTMS group at the end of treatment than in the control group; Alzheimer Disease Assessment Scale-Cognitive Subscale and P300 latency were lower ⁷.

A network meta-analysis compared different TMS modalities in post-stroke cognitive impairment on the basis of 29 studies with 2123 patients. The rankings for MoCA, MMSE and MBI scores were: HF-rTMS > LF-rTMS > iTBS > sham stimulation > conventional rehabilitation therapy; for P300 amplitude: HF-rTMS > LF-rTMS > iTBS > conventional rehabilitation > sham ¹¹. A Bayesian network meta-analysis with 37 RCTs and 2543 patients found that high-frequency left DLPFC stimulation (HFL-rTMS) most effectively improved the MoCA score (MD=3.38, SUCRA=87.6 %), high-frequency right-sided stimulation (HFR-rTMS) was best for MMSE (MD=2.93, SUCRA=79.7 %) and high-frequency bilateral stimulation (HFB-rTMS) performed best for MBI (MD=13.47, SUCRA=89.6 %) ³⁷.

An electrical modelling meta-analysis in schizophrenia combined standard meta-analysis with E-field modelling. In particular, TMS improved negative and cognitive symptoms with high-frequency stimulation of the left prefrontal cortex, while positive symptoms decreased with low-frequency TMS of the left temporoparietal cortex. The E-field modelling identified stimulation of the left dorsomedial prefrontal cortex (L-DMPFC), the left orbitofrontal cortex (L-OFC) and the left cerebellar Crus II and right lobule IX as significantly associated with improvement across all symptom domains ³².

A systematic review and network meta-analysis compared non-invasive brain stimulation procedures as adjunctive treatment in treatment-resistant schizophrenia. Included were randomised controlled trials of electroconvulsive therapy, magnetic seizure therapy (MST), rTMS and transcranial electrical stimulation (tES). The primary endpoint was overall symptoms; secondary endpoints were adverse events.

A systematic review and meta-analysis compared acupuncture combined with rTMS versus rTMS alone for hemiparesis recovery after ischaemic stroke. Sensitivity analyses confirmed robustness ³³.

A network meta-analysis compared different TMS targeting methods in depression. Included were randomised controlled trials that compared sham with active TMS using at least one of the three targeting methods (5 cm, F3 or neuronavigational) or compared different targeting methods in active TMS. The network meta-analysis of 63 RCTs with 3080 participants showed that active TMS with the neuronavigational method (standardised mean difference=1.19, 95 % CI 0.55–1.84) and with the 5-cm method was effective ³⁴.

A systematic review and dose-response meta-analysis examined associations of total pulse dose and inter-session interval with antidepressant outcomes in accelerated rTMS (more than one session per day) in major depressive episodes. In sham-controlled RCTs, a higher total pulse count showed a consistent positive association with efficacy, response and remission; the inter-session interval showed a non-linear (bell-shaped) association ³⁵.

A meta-analysis of randomised controlled trials examined the efficacy and safety of TMS in depression in children, adolescents and young adults. 34 RCTs with 2705 participants showed that TMS significantly reduced depression severity (SMD=-1.55, 95 % CI [-1.88, -1.23], $p<0.001$, $I^2=93\%$). In pairwise comparisons, high-frequency rTMS showed the largest effect (SMD=-1.90, 95 % CI [-2.42, -1.37], $p<0.001$); low-frequency rTMS and bilateral TMS showed smaller effects; iTBS effects were not significant ³⁶.

A randomised controlled trial examined the efficacy of 5 Hz rTMS over the left DLPFC for consciousness recovery in children with disorders of consciousness after traumatic brain injury. 98 paediatric patients aged 2 years and older were randomised to an experimental group ($n=49$) and a control group ($n=49$). Primary endpoints were serum neuron-specific enolase (NSE), Coma Recovery Scale-Revised (CRS-R), Glasgow Coma Scale (GCS) and level of consciousness. After 3 weeks, the experimental group showed statistically significant improvements compared with baseline and the control group ($p<0.05$) ³⁸.

A randomised controlled trial examined real-time EEG-triggered rTMS combined with group therapy versus rTMS alone over the left DLPFC in adolescents with depression and self-injurious behaviour. 160 inpatients aged 12–18 years with depression and recent self-injury (≤ 2 weeks) were randomised 1:1 (rTMS alone $n=80$; rTMS plus group therapy $n=80$). The primary endpoint was the 4-week change in the HAMD-24 score. The intention-to-treat analysis showed a greater HAMD-24 reduction in the observation group (-14.5 ± 3.2 vs. -9.8 ± 2.9 , $P<0.001$); HAMA-14 also improved significantly ³⁹.

A randomised clinical trial examined whether 1-Hz rTMS of the right DLPFC enhances the clinical benefits of Tai Chi Chuan in sleep disorders and mild cognitive impairment in older adults. The two-arm, sham-controlled, assessor-masked study was conducted at a university hospital in China between October 2022 and February 2024. Adults aged 60 to 75 years with sleep disorders and MCI were randomised 1:1 to Tai Chi Chuan plus 1-Hz rTMS or Tai Chi Chuan plus sham rTMS; each participant received 30 sessions of personalised rTMS over the right DLPFC ⁴⁰.

An open-label, non-randomised study reported clinical outcomes of an fMRI-personalised rTMS protocol at the Queensland Neurostimulation Centre. 61 participants aged 19 to 84 years with treatment-resistant MDD received 20 or 30 weekday sessions of DLPFC-rTMS; the stimulation site was personalised on the basis of individual fMRI connectivity data. The primary endpoint was change in the Montgomery-Åsberg Depression Rating Scale (MADRS). MADRS was lower after treatment ($d=1.78$, $p<0.001$), with 52 % response and 33 % remission rates; anxiety scores (Hamilton Anxiety Rating Scale) were also lower ($d=1.27$, $p<0.001$), with 46 % response and 28 % remission rates ⁴¹.

A randomised, open-label parallel-group study at Urgench Rehabilitation Hospital compared low-frequency rTMS with memantine in chronic motor aphasia after ischaemic stroke. Group 1 ($n=30$) received 10 sessions of a 1-Hz rTMS protocol; Group 2 ($n=30$) received memantine (starting dose 5 mg QD, titrated to 20 mg QD) over eight weeks. The Western Aphasia Battery (WAB) was assessed before and after the intervention. Both groups showed significant improvements ($p<0.001$); the rTMS group showed significantly greater improvements in word repetition and object naming compared with the memantine group ($p<0.001$) ⁴².

A four-arm, double-blind, randomised, sham-controlled study at a university hospital in Switzerland examined whether 15 sessions of inhibitory rTMS reduce psychomotor slowing in psychosis. Included were adults aged 18 to 60 years with schizophrenia-spectrum disorders and severe psychomotor slowing. Of 615 screened patients, 103 were randomised and 88 received at least one rTMS session: 22 were assigned to 1-Hz rTMS, 22 to iTBS, 22 to sham and 22 to a wait-list group. Follow-up took place after 6 weeks ⁴³.

A randomised controlled trial examined the synergistic effects of rTMS and Tui Na on upper-extremity motor function and cortical activity in ischaemic stroke. 90 patients are randomised 1:1 either to the rTMS + Tui Na + conventional rehabilitation group (experimental group) or to the rTMS + conventional rehabilitation group (control group). Activation and remodelling of sensorimotor neural circuits are examined by functional near-infrared spectroscopy ⁴⁴.

A double-blind, 4-week randomised clinical trial at two Canadian academic centres examined whether iTBS over the left DLPFC is safe and effective in acute bipolar depression. Included were adults with bipolar disorder type I or type II in an acute major depressive episode who had not benefited from first-line treatment and were receiving a mood stabiliser, an atypical antipsychotic or a combination thereof.

A double-blind randomised crossover study examined the preliminary effects of intermittent theta-burst stimulation combined with virtual-reality-based cycling training on upper-extremity function in children with spastic cerebral palsy. Twelve participants were enrolled and randomised; eight completed two consecutive intervention phases in balanced order: real stimulation combined with virtual cycling training ($n=10$ conditions) and sham stimulation combined with virtual cycling training ($n=10$ conditions). The training programme comprised twelve 60-minute sessions, two to three times per week; stimulation targeted the hand motor region of the affected hemisphere. Outcome measures were the Box and Block Test and the Bruininks-Oseretsky Test of Motor Proficiency ⁴⁵.

A randomised clinical trial examined whether navigated TMS is effective when added to intensive inpatient therapy in combat-related post-traumatic stress disorder. The 1:1 randomised study with 30-day treatment and follow-up at 1 and 3 months was conducted in an inpatient facility specialising in military mental health. Included were military personnel with PTSD. Both arms received intensive inpatient treatment as standard care (manualised prolonged exposure twice weekly combined with daily, full-day psychotherapeutic augmentations over 30 days). Navigated TMS (active or sham) was added to standard care, targeted individually anatomically and connectomically using MRI and robot-assisted stereotaxy, daily (7 days/week) for up to 20 sessions ⁴⁶.

A systematic review and meta-analysis of randomised controlled trials examined the effect of rTMS on insomnia. The rTMS group showed improved questionnaire scores compared with sham rTMS in people with insomnia (PSQI total scores; ISI; $p<0.001$) as well as improved sleep efficiency measured in the sleep laboratory (PSG (SE); $p=0.003$). Combined rTMS and medication were more effective than medication alone (PSQI total scores; $p=0.003$) ⁴⁷.

A systematic review and network meta-analysis evaluated the efficacy of rTMS in children with cerebral palsy and compared different treatment parameters. 18 studies with 1675 patients were included. rTMS did not differ significantly from other treatments after treatment in improving language function (MD=2.80, 95 % CI (-1.51, 7.11), Z=1.27, P=0.20). The network meta-analysis showed the highest probability rankings of three different rTMS frequencies on motor function scores ⁴⁸.

A case-control observational study examined short- and long-term rTMS effects on craving and psychopathological symptoms in individuals with gambling and cocaine use disorder. 42 individuals (age 40.7 ± 9.5 years; 40 men) were assigned after initial screening by visual analogue scales and Symptom Checklist-90-R to real or sham rTMS treatment over the left DLPFC for 2 weeks. Participants were re-examined after 1, 2, 4, 8, 12, 16, 20 and 24 weeks. Trend analysis showed a sustained decrease (up to 24 weeks) in the real rTMS group with a linear trend (p<0.001); the sham group returned to baseline levels after approximately 12 weeks (quadratic trend, p<0.001) ⁴⁹.

An observational study examined how voltage-gated sodium channel blockers modulate cortical excitability in vivo. Thirteen healthy adults received single doses of carbamazepine, lacosamide or placebo in a crossover design. TMS was used to capture changes in resting motor threshold and strength-duration properties (rheobase and strength-duration time constant) as indices of VGSC function. Both medications increased resting motor thresholds compared with placebo; carbamazepine increased thresholds proportionally across all pulse widths, while lacosamide influenced thresholds disproportionately. Lacosamide reduced the strength-duration time constant and increased rheobase, whereas carbamazepine had minimal effects on both measures ⁵⁰.

A review article on connectomic neuromodulation describes how brain connectivity information from advanced MRI data can be used to understand remote effects on brain regions connected to the stimulation site. The authors emphasise that instead of the local effect at the stimulation site, the remote effect on connected regions is considered, and show that the same principles apply to TMS and MRI-guided focused ultrasound in addition to deep brain stimulation ⁵¹.

An observational study examined the outcomes of patients who received interventional psychiatric procedures in a large integrated health system. Each IPP group showed significantly greater depression improvement after 6 weeks compared with the medication management group: TMS: 1.64 (p<0.001), KIT: 2.02 (p<0.001), ECT: 2.16 (p<0.001). Patient characteristics were associated with symptom worsening within the treatment groups, e.g. non-white race in ECT (2.33, p<0.01) and MM (0.29, p<0.001); anxiety disorder in TMS (1.73, p<0.001); personality disorder in all treatment groups, with significant coefficients for KIT (3.27, p<0.05) and MM (1.27, p<0.001) ⁵².

A scoping review mapped and synthesised the available evidence on clinical benefit and adverse effects of ECT and rTMS in adults with major depression and treatment-resistant depression. The search was conducted in PubMed-MEDLINE, Scopus and the Virtual Health Library from inception to October 2022; methodological quality was assessed with National Heart, Lung, and Blood Institute tools ⁵³.

A national cohort and Enroll-HD observational study compared clinical characteristics between juvenile and adult Huntington's disease. The Kruskal-Wallis test was applied to UHDRS-Total Motor Score (UHDRS-TMS) items from the Enroll-HD dataset to compare the severity of motor disease features 6–10 years after onset.

Review Articles and Mechanisms of Action

A review article on TMS in neurological disorders classifies repetitive TMS protocols for psychiatric applications such as depression or obsessive-compulsive disorder as an established and globally applied treatment option. In neurological disorders, rTMS is not yet as widespread, except in neurorehabilitation after (motor) stroke and in the treatment of neuropathic pain. New clinical studies on further neurological disorders are appearing at a rapid pace; most of these applications have not yet reached the same level of scientific scrutiny as motor stroke and neuropathic pain, yet the results are described as encouraging. The review covers movement disorders, Alzheimer's disease/mild cognitive impairment, epilepsy, multiple sclerosis and disorders of consciousness ⁵⁴.

A review article on accelerated theta-burst stimulation describes TBS as a non-invasive brain stimulation technique for modulating neural networks in psychiatric and neurological disorders. The conventional intermittent TBS protocol is approved by the U.S. Food and Drug Administration for the treatment of otherwise treatment-resistant depression; the 6-week duration, however, limits applicability. Accelerated TBS protocols enable higher pulse doses in shorter time periods and thus faster and potentially clinically more effective treatment. The authors present data from accelerated TBS studies supporting safety and efficacy and identify the need for more durability data as well as stimulation parameters that appear important for efficacy ⁵⁵.

A systematic review on rTMS in obsessive-compulsive disorder describes that the evidence for rTMS in OCD is increasing and is advancing development in the neurostimulation field, most recently deep transcranial magnetic stimulation (dTMS). dTMS enables direct stimulation of deeper subcortical structures and a larger brain volume than conventional rTMS. The underlying neurobiological mechanisms are still being investigated but appear to offer a novel third pathway for addressing symptoms via localised electrical stimulation compared with pharmacotherapy and psychotherapy. The review focuses on the effects of rTMS and dTMS on various brain targets in OCD: dorsolateral prefrontal cortex, supplementary motor area, orbitofrontal cortex/medial prefrontal cortex and anterior cingulate cortex ⁵⁶.

A consensus review, supported by the National Network of Depression Centers, the Clinical TMS Society and the International Federation of Clinical Neurophysiology, updates the earlier consensus statement from 2018 on TMS in depression. The working group produced consensus statements with an updated narrative review on safety, efficacy and clinical characteristics of TMS in depression. TMS continues to show broad evidence for safety and efficacy in the treatment of depression. Newer forms of TMS are faster and potentially more effective than conventional repetitive TMS; further research into targeting methods, application in special populations and accelerated protocols is encouraged ⁵⁷.

A review article on regulatory approval and authorisation of therapeutic TMS protocols for psychiatric disorders describes that non-invasive brain stimulation techniques are widely used in clinical and research contexts in neuropsychiatry and are considered safe and well tolerated. TMS uses electromagnetic pulses for focal modulation of neuronal activity in cortical brain regions; repeated application (rTMS) is intended to induce long-lasting neuroplastic effects proposed as a therapeutic mechanism, with initially demonstrated efficacy and safety in treatment-resistant depression. Numerous clinical studies, including large multicentre studies and several meta-analyses, have confirmed clinical efficacy in various neuropsychiatric disorders and have led to evidence-based guidelines and recommendations. Currently, rTMS is approved by several regulatory authorities for treatment-resistant depression, depression with comorbid anxiety disorders, obsessive-compulsive disorder and substance use disorders such as smoking cessation ⁵⁸.

A review article asks whether TMS is a one-trick pony or the beginning of a neuroscientific revolution. Psychiatry has been at the forefront of clinical TMS since the mid-1990s, shortly after the invention of modern TMS in 1985 by Barker. Clinical TMS for psychiatric applications is developing rapidly, with new methods and innovations for the treatment of depression as well as a new clinical indication in obsessive-compulsive disorder. The review summarises the latest findings and looks to the near future of this fruitful and rapidly changing field. It is possible that many, perhaps even most, psychiatrists will integrate some form of brain stimulation into their practice within the next decade ⁵⁹.

Overall Picture

3. How Robust the Research Is

The research is clearly concentrated in a few areas. The largest block of controlled human studies consists of investigations into cognitive functions, followed by work on safety and tolerability. Then come studies on the musculoskeletal system and fatigue. The fields of inflammation, oncology, metabolism, gut, bone and immune system are markedly smaller. The most frequently cited controlled studies concern obsessive-compulsive disorder, smoking cessation, treatment-resistant depression, cognitive sequelae after stroke, post-traumatic stress disorder and cognition in Alzheimer’s dementia. Two influential review articles address the mechanisms of plasticity as well as the efficacy of neurostimulation across mental disorders; the second summarises 208 randomised controlled trials.

The methodological basis is broad: few neurostimulation procedures have so many randomised and sham-controlled studies, and several review articles bring them together. That is the strength of the field. The weakness lies in comparability. Because protocols, target regions and outcome measures vary between studies, individual results often cannot be directly pooled. Some of the larger studies also examine combinations, for example stimulation together with behavioural therapy or an additional active substance; from such studies the effect of stimulation alone cannot be derived. And many studies measure intermediate variables such as excitability or brain activity at rest, not disease course. Where several independent controlled studies agree, a finding carries weight; where a single study stands, it is an indication.

The sham treatment decides, not the marker

The central weakness of the field is the control. A sham treatment must not be distinguishable from the real stimulation for the participants, otherwise some of the treated individuals know whether they are receiving the real treatment. This means that part of a measured effect can arise from the expectation of being treated. Studies that separately test their sham procedure or subsequently control the connection are therefore to be weighted more highly than those that leave this point open. Anyone reading the study situation should look at this first; it determines the strength of the statement more than the number of participants.

The second point concerns the outcome measure. Many controlled studies capture cortical excitability or the activity of a network at rest. Both are markers. A changed marker means that the stimulation has moved something in the system; whether this is apparent to the affected person is another question. This becomes even clearer with the combined protocols: when stimulation is tested together with behavioural therapy or an additional active substance, the study carries a statement about the combination, not about stimulation alone. For practice this means distinguishing between three things: the change in a marker, the improvement in the controlled comparison and the course under everyday conditions.

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

STATEMENT	EVIDENCE BASE
TMS Helps in Depression	The most frequently cited controlled trials concern treatment-resistant courses and compare different forms of stimulation with one another. Whether the result is due to the stimulation or to the comparison is another question.
TMS Acts Against Inflammation, in the Gut, in Bone and in the Immune System	For these areas, only very few controlled studies in humans are available. The question has been posed but not yet decided.
TMS Is a Diagnostic Procedure	Single- and paired-pulse protocols measure the excitability of the cerebral cortex. This is a marker of system function, not a diagnosis of a disease.
TMS Is a Harmless Procedure	Safety and tolerability form a large block of controlled studies in their own right. That speaks for systematic examination, but does not mean that the procedure is harmless.

5. The Most Robust Studies

Ordered by strength of evidence, not by prominence: review articles 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 Treatment effect variability in brain stimulation across psychiatric disorders: A meta-analysis of variance (2021) — Review article, 5,748 participants
- ² Examining the effectiveness of motor imagery combined with non-invasive brain stimulation for upper limb recovery in stroke patients: a systematic ... (2024) — Review article, 886 participants
- ³ Efficacy of repetitive transcranial magnetic stimulation on post-stroke cognitive impairment: A systematic and a network meta-analysis (2024) — Review article, 5,478 participants
- ⁴ Efficacy of Non-Invasive Brain Stimulation for Refractory Obsessive-Compulsive Disorder: A Meta-Analysis of Randomized Controlled Trials (2022) — Review article, 663 participants
- ⁵ Effects of Cerebellar Repetitive Transcranial Magnetic Stimulation in the Treatment of Post-Stroke Dysphagia: A Meta-Analysis and Systematic Review ... (2024) — Review article, 673 participants
- ⁶ Acupuncture combined with repetitive transcranial magnetic stimulation for the treatment of post-stroke depression: a systematic evaluation and ... (2024) — Review article, 800 participants
- ⁷ High-Frequency Repetitive Transcranial Magnetic Stimulation on Overall Cognition in Patients With Poststroke Cognitive Impairment: A Systematic ... (2024) — Review article, 4,012 participants
- ⁸ Effects of Non-Invasive Brain Stimulation for Degenerative Cerebellar Ataxia: A Systematic Review and Meta-Analysis (2024) — Review article, 661 participants
- ⁹ Comparison of efficacy of deep brain stimulation, repeat transcranial magnetic stimulation, and behavioral therapy in Tourette syndrome: A systematic ... (2022) — Review article, 661 participants
- ¹⁰ Effectiveness of personalized repetitive transcranial magnetic stimulation for major depressive disorder: A systematic review and meta-analysis of ... (2025) — Review article, 647 participants
- ¹¹ Effects of different modalities of transcranial magnetic stimulation on post-stroke cognitive impairment: a network meta-analysis (2024) — Review article, 2,123 participants
- ¹² Evidence for Intermittent Theta Burst Transcranial Magnetic Stimulation for Dysphagia after Stroke: A Systematic Review and Meta-analysis (2025) — Review article, 567 participants
- ¹³ Optimally combining transcranial magnetic stimulation with antidepressants in major depressive disorder: A systematic review and Meta-analysis (2024) — Review article, 654 participants
- ¹⁴ Symptom Provocation and Clinical Response to Transcranial Magnetic Stimulation: A Systematic Review and Meta-Analysis (2025) — Review article, 3,246 participants
- ¹⁵ Cerebellar transcranial magnetic stimulation for improving balance capacity and activity of daily living in stroke patients: a systematic review and ... (2024) — Review article, 542 participants
- ¹⁶ The stratified effects of repetitive transcranial magnetic stimulation in upper limb motor impairment recovery after stroke: a meta-analysis (2024) — Review article, 865 participants
- ¹⁷ Noninvasive Neuromodulation Combined With Rehabilitation Therapy Improves Balance and Gait Speed in Patients With Stroke: A Systematic Review and ... (2024) — Review article, 915 participants
- ¹⁸ The effect of repetitive transcranial magnetic stimulation on sleep quality in patients with more than mild depressive mood: a systematic review and ... (2025) — Review article, 548 participants
- ¹⁹ Comparative efficacy, tolerability, and acceptability of aducanumab, lecanemab, and donanemab with repetitive transcranial magnetic stimulation on ... (2025) — Review article, 6,918 participants
- ²⁰ Repetitive Transcranial Magnetic Stimulation Strategies for Poststroke Dysphagia: A Systematic Review and Network Meta-analysis (2025) — Review article, 760 participants
- ²¹ The impact of the number of sessions and stimulation parameters on repetitive transcranial magnetic stimulation efficacy for post-stroke upper ... (2025) — Review article, 897 participants
- ²² Repetitive transcranial magnetic stimulation for musculoskeletal pain: A systematic review and meta-analysis (2025) — Review article, 1,158 participants
- ²³ Efficacy, Effectiveness, and Safety of Transcranial Magnetic Stimulation for Bipolar Depression: A Systematic Review and Meta-Analysis (2026) — Systematic review, 1,709 participants
- ²⁴ Comparative efficacy of different repetitive transcranial magnetic stimulation protocols for lower extremity motor function in stroke patients: a ... (2024) — Systematic review, 2,022 participants

6. Summary

Evidence is established primarily for psychiatric and neurorehabilitative applications. Meta-analyses with several thousand participants demonstrate efficacy in depression, most clearly under high-frequency rTMS, as well as in cognitive impairment after stroke, where intermittent theta-burst stimulation achieved the best rankings. The choice of target region has also been investigated in controlled studies: neuronavigational procedures were effective in a network

meta-analysis of 63 RCTs. For insomnia, rTMS improved sleep quality compared with sham. For obsessive-compulsive disorder, the most-cited controlled study provides an indication. Regulatory authorities have approved rTMS for treatment-resistant depression, depression with comorbid anxiety disorders, obsessive-compulsive disorder and substance use disorders.

Plausible is the proposed mechanism: electromagnetic pulses modulate neuronal activity focally, and repeated application is intended to induce long-lasting neuroplastic effects. Accelerated theta-burst protocols allow higher pulse doses in shorter time periods; in sham-controlled studies a higher total pulse count was consistently associated with efficacy, response and remission, while the inter-session interval showed a bell-shaped association. **Hypothesis:** If this dose relationship holds, accelerated protocols could shorten the conventional six-week duration and broaden applicability; connectomic neuromodulation also suggests that remote regions connected to the stimulation site are involved in the outcome.

What remains to be clarified is whether results from treatment-resistant courses can be transferred to other courses. For obsessive-compulsive disorder the ongoing multicentre TETRO study is examining low-frequency rTMS over the pre-supplementary motor area as an adjunct to exposure therapy in 250 adults. Also open is whether the TMS-induced electric field strength can estimate improvement in acoustic verbal hallucinations and whether a change in cortical excitability markers indicates improvement in symptoms. For accelerated theta-burst protocols, reviews identify the need for durability data and for stimulation parameters that appear important for efficacy.

7. What Remains Open

- **Sham treatment:** Which sham procedure replicates the real stimulation so that participants cannot guess the allocation, and how strongly does this change the result?
- **Marker or course:** Which of the observed marker changes is accompanied by an improvement that those affected themselves notice?
- **Transfer:** Can results from treatment-resistant courses be transferred to other courses and to the smaller application areas?

Frequently Asked Questions

How many sessions does a treatment comprise?

The number of sessions differs considerably between the protocols; the studies work with series of varying lengths over several weeks. A general value cannot be derived from this, and it depends on the target region and the form of stimulation.

Does repeated stimulation differ from theta-burst stimulation?

Several of the most-cited studies compare both forms directly, including a large investigation in older people with depression and a connectivity-guided study in treatment-resistant depression. Whether one form is equivalent or superior is examined in these comparisons and is the subject of ongoing work.

Why is the connection such a topic in these studies?

Because a sham treatment must not be distinguishable from the real stimulation, so that the participants do not know which one they receive. If this succeeds only partially, expectation can explain part of the result. Therefore studies with a verified sham procedure carry more weight than those that leave this point open.

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