

Repetitive transcranial magnetic stimulation in functional motor disorders: A systematic review of effects and targets

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ABSTRACT

Objective: To evaluate the effectiveness, safety, and potential mechanistic implications of repetitive transcranial magnetic stimulation (rTMS) in adults with functional motor disorders (FMD), focusing on possible phenotype-specific responses and stimulation protocols.

Methods: Seven databases were searched from inception to July 2026. Randomised and non-randomised interventional studies were included. Risk of bias and evidence certainty were assessed using PEDro, RoB 2, JBI tools, and GRADE. Because of substantial clinical and methodological heterogeneity, findings were synthesised qualitatively.

Results: Fourteen studies were included. The primary motor cortex was targeted in 11 studies. Functional tremor showed the most consistent evidence with inhibitory stimulation: one small sham-controlled trial found a significant group-by-time effect on tremor severity ($p = 0.007$), while an uncontrolled prospective series reported 40 % reduction in postural tremor amplitude ($p = 0.05$). Evidence for functional weakness was conflicting: excitatory M1 stimulation increased objective strength by 25 % versus 10 % with sham ($p = 0.004$), whereas the largest inhibitory sham-controlled trial found no benefit ($p = 0.80$). No severe adverse events were reported, but safety reporting was incomplete. GRADE certainty was moderate for tremor and very low for all other outcomes.

Conclusions: Current evidence is insufficient to establish the efficacy of rTMS in FMD or to recommend phenotype-specific protocols. Preliminary findings support further investigation of inhibitory stimulation for functional tremor, whereas evidence for excitatory stimulation in functional weakness remains uncertain.

Significance: The possible interaction between phenotype and stimulation direction is hypothesis-generating. rTMS should currently be considered an experimental, context-sensitive adjunct within multidisciplinary care, pending adequately powered phenotype-stratified sham-controlled trials.

Prospero Registration Number: CRD420251250969.

1. Introduction

Functional Neurological Disorders are characterised by impaired

control of voluntary motor or sensory function in the absence of structural neurological disease (Edwards et al., 2024). Functional movement disorders comprise a spectrum of hyperkinetic and hypokinetic motor

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manifestations, including functional tremor, dystonia, myoclonus, parkinsonism, gait disorders, and functional tics. In this review, we use the term Functional Motor Disorders (FMD) as a broader umbrella term encompassing both functional movement disorders and functional weakness/paralysis. FMD are characterised by abnormal movements or weakness experienced as involuntary and defined by positive clinical signs, including distractibility, variability, entrainment, Hoover's sign, and incongruence with known neurological disease patterns (Hallett et al., 2022). These disorders frequently present as mixed phenotypes and are often accompanied by non-motor symptoms such as pain, fatigue, and psychiatric comorbidity (Kola and LaFaver, 2022).

FMDs are common, affecting approximately 0.1 % of the population (Finkelstein et al., 2025), and are associated with chronic disability, reduced quality of life, and increased healthcare utilization and costs compared to healthy matched controls (O'Mahony et al., 2023). Despite increasing recognition and a shift towards positive diagnosis and multidisciplinary management, treatment outcomes remain variable, with limited high-quality evidence, hampering the development of effective protocols.

Advances in neuroimaging and neurophysiology have reframed FMD as disorders of distributed brain networks, involving motor, limbic, salience, and self-agency networks (Maurer et al., 2016; Sasikumar and Strafella, 2021). These models suggest potentially reversible dysfunction at the circuit level, providing a mechanistic rationale for neuro-modulatory interventions alone or in combination with multidisciplinary approaches rather than addressing symptoms through purely behavioural or pharmacological means.

Repetitive transcranial magnetic stimulation (rTMS) is a non-invasive technique capable of modulating cortical excitability: low-frequency protocols decrease excitability, whereas high-frequency stimulation increases it, thereby potentially inducing lasting changes in network connectivity (Sharbafshaaer et al., 2024). Its established efficacy in other motor disorders, including stroke hemiparesis, dystonia, and gait disorders, together with its ability to target networks implicated in FMD pathophysiology, make it a promising therapeutic candidate (Chino et al., 2023).

This review is motivated by the substantial burden of FMD, the limitations of currently available treatments, and the growing interest in neuromodulation techniques, including rTMS, as promising therapeutic approaches (Desai and Desai, 2025). Specifically, this review systematically evaluates rTMS as a therapeutic intervention for adults with FMD, integrating evidence from both randomized and non-randomized studies. The primary aims are to assess therapeutic effectiveness, safety, and durability of effect, and to identify optimal stimulation parameters and cortical targets. Together, these findings are intended to inform patient selection, guide future trial design, and support the integration of rTMS into personalised multidisciplinary care pathways.

2. Methods

This review was conducted according to the PRISMA 2020 guidelines and was prospectively registered in PROSPERO ID (CRD420251250969).

2.1. Eligibility criteria and selection

Eligibility criteria were defined according to the PICOS framework (Population, Intervention, Comparator, Outcomes, Study design) as follows: (1) Population: adults (≥ 18 years) with functional motor disorder; (2) Intervention: rTMS protocols, including intermittent or continuous theta-burst stimulation protocols (iTBS or cTBS), applied to any cortical target; (3) Comparator: sham stimulation, usual care, alternative interventions, or no comparator, when applicable; (4) Outcomes: any reported motor or non-motor clinical outcomes; (5) Study design: randomized or non-randomized interventional designs published in peer-reviewed journals in English or Spanish. Studies were

excluded if they did not provide original empirical data (e.g., reviews, theoretical articles, opinion pieces), did not directly assess clinical outcomes of rTMS, reported only neurophysiological or imaging outcomes without clinical measures, included participants under 18 years of age, or did not evaluate rTMS as the primary intervention.

2.2. Sources of information

A comprehensive search was conducted from inception up to July 2026 across PubMed, Scopus, Web of Science, MEDLINE, Dialnet, PEDro, and the Cochrane Library, combining terms related to rTMS (including iTBS and cTBS) and FMDs; full search strategies are provided in Appendix A.

2.3. Study selection and data extraction

Study selection is summarised in the PRISMA flow diagram (Fig. 1). Duplicate removal was performed using the Focused Deduplicator Algorithm of TERA Tools, yielding 862 unique records. Two independent reviewers (A.G.G., L.R.A.) screened titles, abstracts, and full texts using The Screenatron; disagreements were resolved by discussion, with a third reviewer (F.S.C.) adjudicating unresolved conflicts. Data from included studies were extracted and presented in Table 1, covering study characteristics, interventions, and main findings.

2.4. Data analysis

Data analysis was primarily descriptive due to substantial clinical and methodological heterogeneity across studies, including variability in design, stimulation protocols, control conditions, and outcome measures, which precluded formal meta-analysis. Summary statistics for age, symptom duration, and sex distribution were extracted. When individual participant data were available, descriptive measures were calculated directly; otherwise, reported aggregate data were used. Sample-size-weighted means were computed for descriptive purposes. Studies lacking standard deviation data and single-case reports were excluded from pooled variability estimates to ensure methodological consistency. No formal pooling of effect sizes was undertaken.

For studies including both adult and pediatric participants, only participants aged ≥ 18 years were included in pooled descriptive analyses and summary statistics, in accordance with the eligibility criteria. When adult-only data were available (e.g., Chastan et al., 2022), these were used for all descriptive and efficacy analyses presented in this review. When only aggregate results for the full cohort were reported (e.g., Garcin et al., 2017), the original published results are presented and the exclusion of underage participants applies only to pooled descriptive analyses. These cases are explicitly identified in Table 1.

2.5. Assessment of methodological quality and risk of bias

Methodological quality of RCTs was assessed using the Physiotherapy Evidence Database (PEDro) scale, and risk of bias were independently evaluated by two reviewers using the Cochrane Risk of Bias 2 (RoB 2) tool. Observational studies, including case series and case reports, were appraised using Joanna Briggs Institute (JBI) critical appraisal tools appropriate to each design. Disagreements were resolved by consultation with a third reviewer. Inter-rater reliability was assessed using the kappa coefficient (κ). JBI assessments informed narrative judgements of methodological rigour rather than cumulative scores. The certainty of evidence for each primary outcome was additionally assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.

3. Results

Data extracted from the included studies are summarized in Table 1.

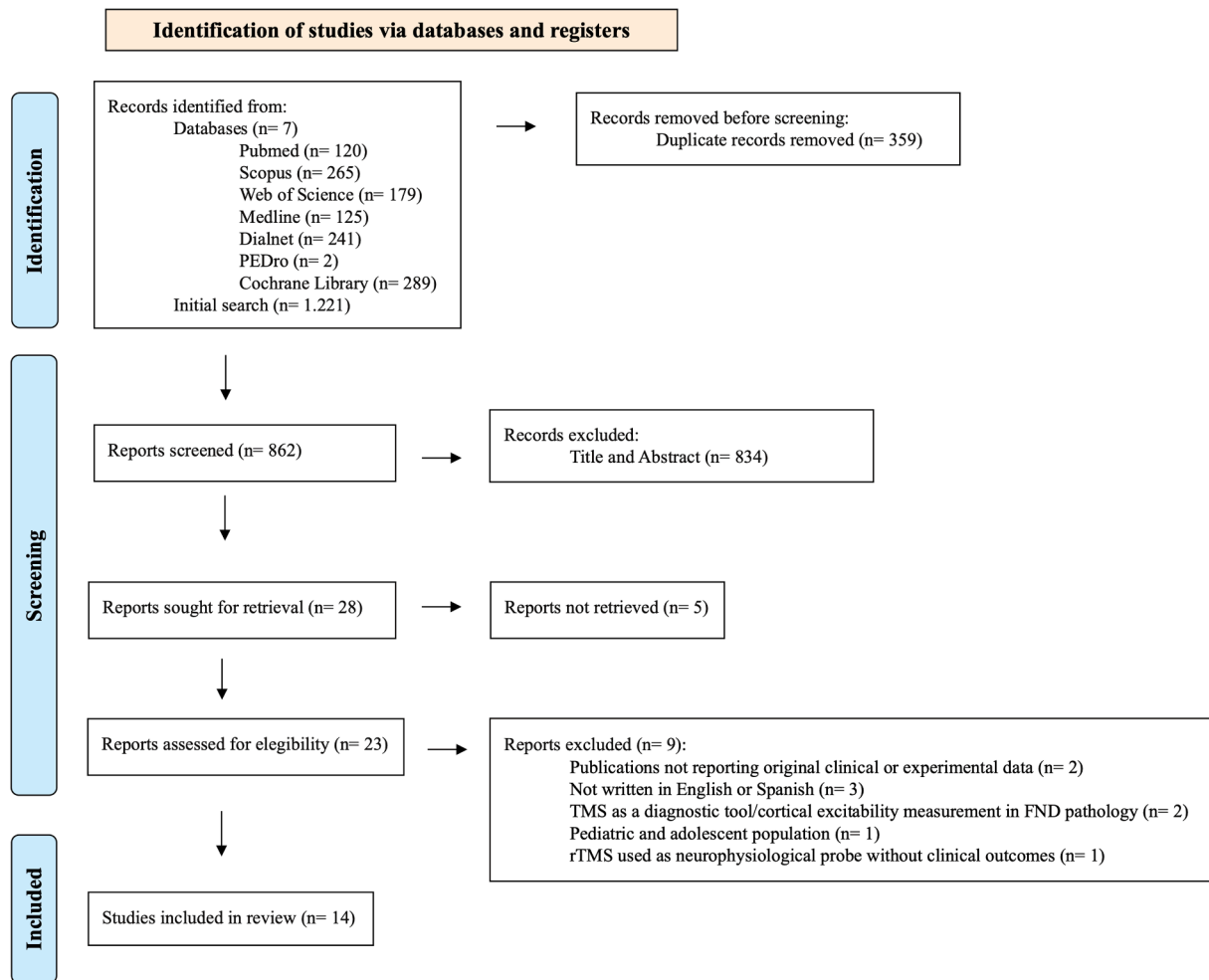


Fig. 1. PRISMA Flowchart. Note: PRISMA flowchart outlining the identification, screening, and selection of studies.

3.1. Study selection

Study selection is summarised in the PRISMA flow diagram (Fig. 1). Of the 23 full-text articles assessed for eligibility, nine were excluded because of ineligible populations or outcomes, or because they did not evaluate rTMS as a therapeutic intervention. Fourteen studies met the inclusion criteria, comprising four randomized controlled trials (RCTs) (Broersma et al., 2015; Chastan et al., 2022; Garcin et al., 2017; Taib et al., 2019), five open-label case series (Garcin et al., 2013; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2006; Shah et al., 2015; Spagnolo et al., 2021) and five single-patient case reports (Blades et al., 2020; İşik et al., 2024; Naro et al., 2020; Portaro et al., 2018; Schönfeldt-Lecuona et al., 2003).

3.2. Participant characteristics

Across the 14 included studies, 175 patients were included in the final pooled sample after exclusion of duplicated cases, participants younger than 18 years, and one participant reclassified as malingering by the original study authors. The final pooled sample demographic data are summarised in Table 2.

3.3. Functional motor disorder phenotype

Across the 13 studies included in the absolute phenotype analysis (n = 169), FMD presentations were markedly heterogeneous, with frequent co-occurrence of multiple phenotypes. Functional weakness/paresis

(29.8 %) and tremor (28.0 %) were the most prevalent manifestations, followed by dystonia (13.3 %), whereas other phenotypes such as myoclonus, bradykinesia, and gait disorders were less common. One additional study (Spagnolo et al., 2021), reporting phenotypes only as percentages, was excluded from absolute counts. When classified according to anatomical distribution, symptoms most commonly involved multiple body regions or the whole body, followed by the upper and lower limbs. Functional tremor predominantly affected the upper limbs, whereas functional weakness more often presented as a generalized or multi-region deficit. A substantial proportion of entries (16.1 %) lacked explicit regional specification, primarily due to incomplete reporting in one study (Taib et al., 2019). Phenotype-to-region mapping was performed using predefined coding rules, whereby limb-specific manifestations were classified as upper or lower limb, cranial and facial symptoms as head/neck, and generalized or multi-limb presentations as whole body/multi-region. The resulting distribution, including absolute counts and anatomical localization, is summarised in Fig. 2. Notably, total counts exceed the number of participants due to overlapping phenotypes within individuals. Across studies reporting symptom duration (13/14; n = 174), the sample-size-weighted mean duration was 5.5 ± 8.2 years (range 0.1–30.2), indicating substantial chronicity and variability across cohorts. Detailed participant characteristics by study are provided in Appendix B.

3.4. rTMS protocol

Across the 14 included studies, the primary motor cortex (M1) was

Table 1
Characteristics of Included Studies and Main Findings.

Study	Design	n	FMD Phenotypes (n)	rTMS Intervention	Comparator	Complementary Therapies	Main Finding
Randomised and Controlled Studies							
Broersma et al. 2015	Placebo-controlled, single-blind, two-period crossover (proof-of-principle)	11	FW — flaccid paresis (n = 11)	Excitatory — cM1-hand (15 Hz)	Sham rTMS (inactive coil)	None reported	Dynamometry (blinded assessor) Muscle strength increase: active + 25 % vs. placebo + 10 % (p = 0.004); crossover analysis: active + 24 % vs. placebo + 6 % (p < 0.04). Subjective hand function: no difference between conditions (p = 0.40)
Garcin et al. 2017	Randomised, single-blind, controlled crossover	33†	FT (n = 13); dystonia (n = 10); jerky dystonia (n = 4); myoclonus (n = 2); stereotypies (n = 2); parkinsonism (n = 1)	Inhibitory — cM1-hand/leg (0.25 Hz)	Spinal root magnetic stimulation (RMS)	Pre-existing medication (stable)	Clinician-rated global motor severity scale (7–41; blinded video assessment; non-validated) (day 3): median improvement 70 % (IQR 27–100); 22/33 (66.7 %) achieved > 50 % improvement; 10/33 (30 %) complete resolution. No difference vs. spinal root stimulation (p = 0.26). CGI-I (1–7) (1 year): 56 % improved; 12/33 relapsed, all re-responded to a single subsequent rTMS session
Taib et al. 2019	Randomised, double-blind, parallel-group controlled + open-label phase	17	FT (UL n = 16, LL n = 4); bradykinesia (n = 13); functional gait (n = 5); dystonia (n = 5); chorea/athetosis (n = 2); speech disorder (n = 1)	Inhibitory — M1-hand/leg (1 Hz)	Sham rTMS (inactive coil)	Hypnosis + self-hypnosis training; pre-existing medication §	PMDRS (blinded video assessment): Active group 29.5 → 17.7 at month 1 (p = 0.0004), sustained through month 12; significant group × time interaction (p = 0.01). Sham group: no sustained improvement. PMDRS Tremor subscore: active group 15.0 → 10.5 at month 1 (p = 0.0001); group × time p = 0.007. Non-motor outcomes (QoL, HAD, CGI-S) between groups (p > 0.05).
Chastan et al. 2022	Randomised, double-blind, parallel-group, sham-controlled	51 ††	Hemiparesis (n = 22); paraparesis (n = 13); tetraparesis (n = 5); monoparesis (n = 5); triparesis (n = 2); aphonia (n = 3); other (n = 1)	Inhibitory — cM1-hand/leg (0.25 Hz)	Sham rTMS (inactive coil)	Pre-existing medication	Global Motor Score (range 0–5; blinded assessor; non-validated) No significant difference: 41 % active vs. 37 % sham achieved ≥ 1-point improvement (p = 0.80). Subgroup with symptom duration < 30 days showed better outcomes (p < 0.002).
Case Series Schönfeldt-Lecuona et al. 2006	Case series	3‡	FW — functional limb paralysis/paresis (n = 2 valid cases)	Excitatory — cM1-hand/leg (15 Hz)	—	OT, sports therapy, relaxation, educational sessions; pre-existing medication	Neurological motor score (range 0–5, MRC-based) Case 1: 1–2 → 4–5 (week 4–5). Case 3: 1 → 4–5 (week 10); complete recovery maintained at 6 months. Case 2 (malingering): no change (excluded from analysis). No statistics reported
Garcin et al. 2013	Prospective open-label case series	24	Dystonia (n = 11); myoclonus (n = 5); jerky dystonia (n = 3); FT (n = 3); parkinsonism (n = 1); stereotypies (n = 1)	Inhibitory — cM1-hand/leg (0.25 Hz)	—	Pre-existing medication	Clinician-rated global motor severity scale (range 7–41; blinded video assessment; non-validated) 18/24 (75 %) > 50 % improvement; 6/24 (25 %) complete resolution; response did not correlate with baseline clinical features. CGI-I (1–7) (median 19.8 months): 17/22 evaluable patients (71 %) improved; 10/24 (42 %) relapsed, all re-responded following additional rTMS sessions
Shah et al. 2015	Open-label pilot case series	6	FT (n = 3); myoclonus/body jerks (n = 3); functional gait (n = 3); jerky movements (n = 1); dystonia (n = 1); eye blinking (n = 1); RPM (n = 1)	Inhibitory — M1-hand phase 1, PMC phase 2 (0.33 Hz)	—	None reported	Rush psychogenic movements rating scale (blinded): no meaningful change after M1 or PMC rTMS. WHOQOL-BREF (range 0–100) physical domain improved after PMC rTMS (p = 0.04); psychological domain decreased after PMC rTMS (p = 0.05). GIC (–1 to + 2): 1/6

(continued on next page)

Table 1 (continued)

Study	Design	n	FMD Phenotypes (n)	rTMS Intervention	Comparator	Complementary Therapies	Main Finding
Spagnolo et al. 2021	Open-label proof-of-concept case series	6	FT + jerking movements (75 %)*; gait/balance disorder (65 %)*; speech disorder (50 %)*; dystonia/posturing (35 %)*	Excitatory — left DLPFC (iTBS)	—	None reported	substantially improved after PMC rTMS (patient-rated). S-FMDRS : Significant reduction pre → post ($p < 0.0001$); maintained at 24-hour follow-up ($p = 0.0004$). Significant decrease in fronto-amygdala connectivity (fMRI) ($p = 0.047$)
Prezelj et al. 2022	Prospective open-label case series	21	Functional tremor (n = 21); functional jerks (n = 1); functional gait (n = 1)	Inhibitory — cM1-hand (cTBS)	—	Pre-existing medication	Accelerometry (postural tremor amplitude) median – 40 % reduction (IQR – 90 to + 24; $p = 0.05$). Rest tremor: $p = 0.1$. S-FMDRS (blinded video assessment) : significant improvement (median change 0.5; $p = 0.01$). Cognitive-motor distractibility (clinical accelerometry-based assessment): predicted response (OR = 2.8, 95 % CI 1.1–7.2; $p = 0.03$). 8/11 initial responders maintained improvement at 1 year (median duration 7 months, range 0–12)
<i>Case Reports</i> Schönfeldt-Lecuona et al. 2003	Case report	1	Functional paresis — right UL	Excitatory — cM1-hand (15 Hz)	—	None reported	Arm circumference : 32.0 → 34.2 cm. Complete functional restoration at week 12; maintained at 6-month follow-up
Portaro et al. 2018	Case report	1	Functional paresis — LL (flaccid paraparesis); functional gait	Inhibitory — M1-hand/leg bilateral (1 Hz)	—	Psychological and sexological counselling §	Instrumented gait analysis Significant improvement: gait cycle $5.65 \pm 2.55 \rightarrow 1.71 \pm 1.2$ ms; cadence $19 \pm 13.8 \rightarrow 68.4 \pm 18.4$ steps/min. Walked independently. VAS pain (0–10) : 7 → 3/10
Blades et al. 2020	Case report	1	Multifocal dystonia; FT; myoclonus; global weakness (UL + LL); speech disorder	Inhibitory — ACC/SMA/PMC (1 Hz)	—	None reported	TWSTRS (dystonia severity) : reduced motor twitching (values in figure only, not extractable). GRC =+1. ACC-insula hyperconnectivity on fMRI (baseline)
Naro et al. 2020	Case report	1	Psychogenic myoclonus (right thigh, LL); functional weakness (bilateral UL + LL)	Inhibitory — left PMC (1 Hz)	—	Intensive rehabilitation (PT, robot-aided gait training, stair training) §	UMRS (myoclonus severity, 0–56) 34 → 14/56. MRC (0–60) : 26 → 34/60. FIM (maximum score 126) : 68/126 → 83/120. All outcomes maintained at 2-month follow-up. Secondary: normalization of EEG connectivity
İşık et al. 2024	Case report	1	Functional gait (sudden right knee bending); functional weakness (right LL)	Excitatory — left M1-leg (10 Hz)	—	Physiotherapy §	Clinical observation (no validated measures) : reduced involuntary knee flexion; improved gait stability; improvements not permanent

Notes: Studies ordered by design (controlled trials first, then case series, then case reports) and chronologically within each category. rTMS protocol classified as inhibitory (≤ 1 Hz or cTBS) or excitatory (≥ 10 Hz or iTBS) based on stimulation parameters reported. *†One participant (aged 16.6 years) excluded from pooled analysis of Garcin et al. (2017) as under 18 years; results reported as published (n = 33). ††Eleven participants under 18 years of age excluded from the pooled analysis (Chastan et al., 2022); results reported for the 51 participants meeting eligibility criteria (original trial n = 62). ‡ One participant excluded based on diagnosis of malingering (DSM-IV V65.2) as determined by study authors; results reported for all 3 published cases. § rTMS not administered as a standalone intervention; concurrent non-pharmacological therapy applied. * Phenotypes reported as percentages only (Spagnolo et al., 2021); individual counts not available.

Abbreviations: ACC = anterior cingulate cortex; CGI-I = Clinical Global Impression-Improvement; CGI-S = Clinical Global Impression-Severity Scale; CI = confidence interval; cM1 = contralateral primary motor cortex; cTBS = continuous theta burst stimulation; DLPFC = dorsolateral prefrontal cortex; EEG = *electroencephalography; FIM = Functional Independence Measure (maximum score 126); FMD = functional motor disorder; fMRI = functional magnetic resonance imaging; FT = functional tremor; FW = functional weakness; GIC = Global Impression of Change; GRC = Global Rating of Change; HAD = Hospital Anxiety and Depression scale; IQR = interquartile range; iTBS = intermittent theta burst stimulation; LL = lower limb; M1 = primary motor cortex; MRC = Medical Research Council scale; OR = odds ratio; OT = occupational therapy; PMC = premotor cortex; PMDRS = Psychogenic Movement Disorder Rating Scale; PT = physiotherapy; QoL = quality of life; RMS = spinal root magnetic stimulation; RPM = rhythmic palatal movements; rTMS = repetitive transcranial magnetic stimulation; S-FMDRS = Simplified Functional Movement Disorders Rating Scale; SMA = supplementary motor area; TWSTRS = Toronto Western Spasmodic Torticollis Rating Scale; UL = upper limb; UMRs = Unified Myoclonus Rating Scale; VAS = Visual Analogue Scale; WHOQOL-BREF = World Health Organization Quality of Life Brief.

the most frequently targeted region, stimulated in 11 studies (78.6 %) (Broersma et al., 2015; Chastan et al., 2022; Garcin et al., 2017, 2013; İşık et al., 2024; Portaro et al., 2018; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2006, 2003; Shah et al., 2015; Taib et al., 2019), typically

over the hand or leg representation according to symptom distribution. Stimulation of M1 was heterogeneous in its physiological intent: most studies applied inhibitory protocols, predominantly low-frequency stimulation (≤ 1 Hz), as reported in (Chastan et al., 2022; Garcin et al.,

Table 2
Characteristics of Included Studies and Pooled Participant Demographics.

Characteristic	Value
Total participants (patients)	175
Female, n (%)	121 (69.1 %)
Age, years (weighted mean $\pm$ SD)	43.6 $\pm$ 13.1
Age range, years	18.0–75.9
Number of studies	14
Study sample sizes (per study)	1–51 participants

Note: Data are presented as n (%) or weighted mean $\pm$ standard deviation (SD), as appropriate. The weighted mean age was calculated based on study sample sizes.

2017, 2013; Portaro et al., 2018; Prezelj et al., 2022; Shah et al., 2015; Taib et al., 2019) or the use of continuous theta-burst stimulation (cTBS), which has inhibitory effects (Prezelj et al., 2022). In contrast, excitatory protocols using high-frequency stimulation (≥ 5 –10 Hz) were employed in several studies (Broersma et al., 2015; İşik et al., 2024; Schönfeldt-Lecuona et al., 2006, 2003). Five of the six studies targeting paresis or weakness employed excitatory protocols; the exception was one case report (Portaro et al., 2018), which used inhibitory stimulation. All hyperkinetic movement disorders used inhibitory protocols.

The premotor cortex (PMC) was targeted in three studies (21.4 %) (Blades et al., 2020; Naro et al., 2020; Shah et al., 2015), consistently using inhibitory stimulation protocols, including low-frequency stimulation (1 Hz or 0.33 Hz), either as a primary target (Naro et al., 2020), in combination with inhibition of the anterior cingulate cortex (ACC) and supplementary motor area (SMA) (Blades et al., 2020), or as a secondary target following M1 stimulation (Shah et al., 2015). The left dorsolateral prefrontal cortex (DLPFC) was stimulated in one study using excitatory intermittent theta-burst stimulation (iTBS) (Spagnolo et al., 2021).

The number of sessions and treatment duration varied substantially. The number of sessions ranged from a single session (Garcin et al., 2013) to 60 sessions over 12 weeks (Schönfeldt-Lecuona et al., 2003), delivered at frequencies of 1–3 sessions per day or 3–5 sessions per week, over durations ranging from 1 day to 3 months. Intensities were typically defined relative to motor threshold. A detailed overview of targets and stimulation parameters is provided in Table 3.

3.5. Outcome measures

Outcome assessment showed substantial heterogeneity across studies (Appendix C). Disorder-specific instruments were used in only three studies, including the PMDRS (Psychogenic Movement Disorder Rating Scale) (Taib et al., 2019), and the S-FMDRS (Simplified Functional Movement Disorders Rating Scale) (Prezelj et al., 2022; Spagnolo et al., 2021). Additional symptom-specific measures targeted tremor, dystonia, myoclonus, and motor strength (Blades et al., 2020; Broersma et al., 2015; Naro et al., 2020; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2006; Taib et al., 2019).

Quantitative instrumental assessments, such as dynamometry (Broersma et al., 2015), accelerometry (Prezelj et al., 2022), and instrumented gait analysis (Portaro et al., 2018) were used infrequently, whereas most studies relied on standardised clinical rating scales (Blades et al., 2020; Garcin et al., 2017; Naro et al., 2020; Prezelj et al., 2022; Shah et al., 2015; Spagnolo et al., 2021; Taib et al., 2019) and observer-based assessments.

Patient-centred outcomes were inconsistently evaluated, with quality of life assessed in only two studies (Shah et al., 2015; Taib et al., 2019), and subjective symptom reporting included in one case study (Portaro et al., 2018). Psychological and psychiatric outcomes were assessed in one RCT and two case reports (Blades et al., 2020; Portaro et al., 2018; Taib et al., 2019), mainly addressing depressive symptoms, anxiety, personality traits, and somatic or illness-related features. Global clinical impression measures based on clinician judgement were more commonly employed (Blades et al., 2020; Garcin et al., 2017, 2013; Shah et al., 2015; Taib et al., 2019).

3.6. Effectiveness of rTMS

Given the heterogeneity in outcome measures, meta-analysis was not feasible. Results are organised by primary motor symptom where possible, and by broader clinical phenotype otherwise, prioritising RCT evidence.

3.7. Effects on functional paresis

Evidence on the effects of rTMS for functional weakness and paresis appears to vary according to stimulation frequency. All studies targeted the primary motor cortex (M1), but the largest double-blind RCT

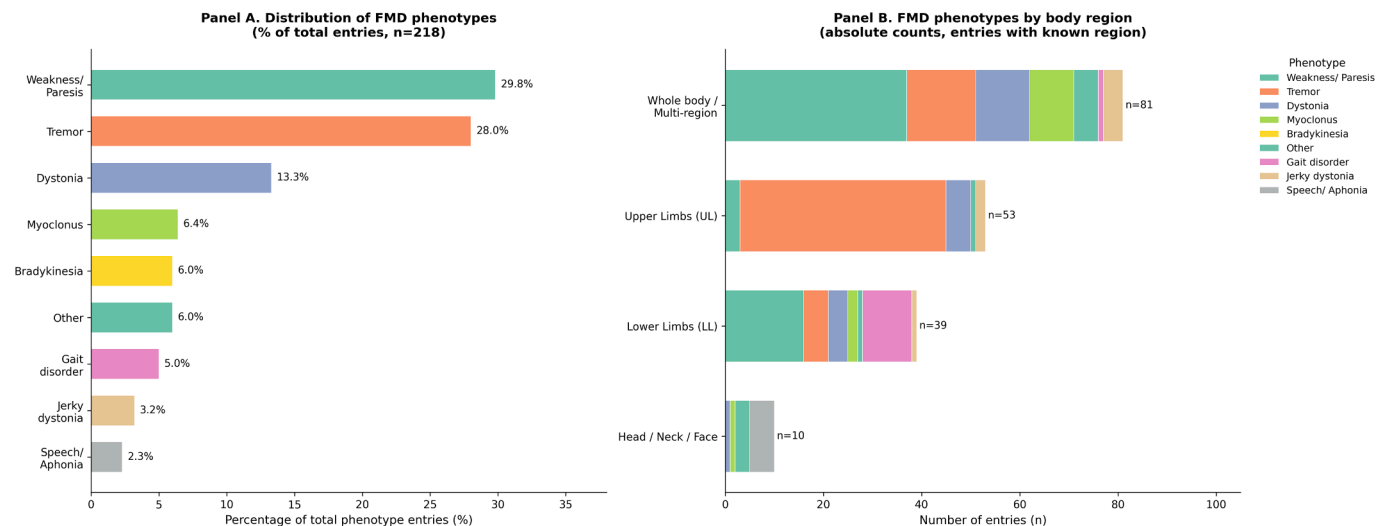


Fig. 2. Distribution of FMD Phenotypes and Body-region Involvement Across the Included Studies. Note: Panel A shows the percentage of entries for each FMD phenotype (derived from Table 4; n = 218). Panel B illustrates the distribution of phenotypes across body regions using absolute counts (derived from Table 5). Stacked bars allow for co-occurrence of phenotypes within individual participants. “Other” comprises stereotypies (n = 3), parkinsonism (n = 2), chorea/athetosis (n = 2), jerky movements (n = 3), other (n = 2; includes eye blinking and unspecified), and rhythmic palatal movements (n = 1).

Table 3

Rtms protocols and stimulation characteristics, grouped by target region and stimulation protocol.

Target Region	Study	Stimulation Protocol (Standardized)	Intensity	Sessions / Schedule
M1-leg				
Left M1-leg (parietal motor region)	Işık et al. 2024	10 Hz; pulses/session not reported	High intensity suprathreshold (exact value not specified)	10-week protocol; total sessions not reported
cM1-hand				
Phase 1: dominant M1	Shah et al. 2015	0.33 Hz; continuous; 50 pulses/session	90% RMT	10 total sessions; 5/week; (phase 1: 5 sessions)
	Schönfeldt-Lecuona et al. 2003	15 Hz; 2-s trains; 4-s intertrain interval; 4000 pulses/session	110% RMT (first 2 weeks), then 90% RMT	60 total sessions; 5/week, up to 12 weeks
	Broersma et al. 2015	15 Hz; 2-s trains; 4-s intertrain interval; 4000 pulses/session	80% RMT	10 total sessions; 5/week
	Prezelj et al. 2022	cTBS: 50 Hz triplets at 5 Hz; 200 bursts; 600 pulses/session	80% AMT	5 total sessions; 5/week
M1 — hand and/or leg				
cM1-hand/leg (bilateral if symptoms bilateral)	Garcin et al. 2013	0.25 Hz; continuous; ~20 pulses/session	120% RMT, ramped for comfort	1 total session (single session)
cM1-hand or leg	Garcin et al. 2017	0.25 Hz; continuous; ~50 pulses/session (range 30–80)	120–150% RMT	2 total sessions (crossover: TMS and RMS; consecutive days)
cM1-hand/leg (bilateral in paraparesis; right in aphonia)	Chastan et al. 2022	0.25 Hz; continuous; 60 pulses/session	Above RMT	2 total sessions (separated by 1 day)
M1-hand/leg (contralateral or bilateral)	Taib et al. 2019	1 Hz; continuous; 1600 pulses/session (800 × 2)	90% RMT	8 total sessions (Phase 1: 5 consecutive daily sessions; Phase 2: 3 weekly sessions)
M1-hand and leg (right and left)	Portaro et al. 2018	1 Hz; continuous; 100 pulses/session	100% MSO	36 total sessions; 3/week (3 months)
cM1-hand/leg (depending on symptom location)	Schönfeldt-Lecuona et al. 2006	15 Hz; 2-s trains; 4-s intertrain interval; 4000 pulses/session	110% RMT (first 2 weeks), then 90% RMT	20–60 sessions total; 5/week (4–12 weeks)
PMC				
Phase 2: dominant dorsal	Shah et al. 2015	0.33 Hz; continuous; 50 pulses/session	90% RMT	10 total sessions; 5/week (phase 2: 5 sessions)
ACC (primary target); SMA and PMC (secondary target)	Blades et al. 2020	1 Hz; continuous; pulses/session not reported	Not reported	36 total sessions; schedule not reported (2 months)
Left PMC	Naro et al. 2020	1 Hz; continuous; 1200 pulses/session	115% RMT	30 total sessions; 5/week (6 weeks)
Left DLPFC	Spagnolo et al. 2021	iTBS: 50 Hz triplets at 5 Hz; 2-s trains, 8-s intervals; 600 pulses/session	120% RMT	12 total sessions; 3 sessions/day, ≥20 min interval (4 visits)

Note: Data summarize rTMS protocol characteristics by study. Stimulation intensity is reported relative to resting motor threshold (RMT), active motor threshold (AMT), or maximum stimulator output (MSO), as defined in the original articles. Parameters not explicitly reported are indicated as NR. For multi-phase protocols, session structure reflects the active stimulation phase. Abbreviations: ACC, anterior cingulate cortex; AMT, active motor threshold; APB, abductor pollicis brevis; cM1, contralateral primary motor cortex; cTBS, continuous theta-burst stimulation; DLPFC, dorsolateral prefrontal cortex; FDI, first dorsal interosseous; fMRI, functional magnetic resonance imaging; iTBS, intermittent theta-burst stimulation; ITI, inter-train interval; MEP, motor evoked potential; MSO, maximum stimulator output; NR, not reported; PMC, premotor cortex; RMS, root magnetic stimulation; RMT, resting motor threshold; rRF, right rectus femoris; SMA, supplementary motor area; TBS, theta-burst stimulation.

(Chastan et al., 2022), which predominantly included patients with weakness (n: 56/62; 90.3 %), was the only controlled study to employ inhibitory low-frequency stimulation (0.25 Hz) and found no significant benefit over sham on blinded global motor outcomes.

In contrast, studies using excitatory high-frequency M1 stimulation generally reported positive findings. A smaller placebo-controlled study in functional neurological paresis (n: 11) (Broersma et al., 2015) demonstrated a significant median increase in objective muscle strength following active rTMS (25 %; $p = 0.004$), compared with a non-significant 10 % increase under placebo stimulation, although subjective hand function ratings did not differ between conditions ($p = 0.40$). Similarly, a small case series (Schönfeldt-Lecuona et al., 2006) reported clinically meaningful motor improvement in three of four patients treated with high-frequency M1 rTMS. One of these patients, previously described in a detailed case report (Schönfeldt-Lecuona et al., 2003), maintained full recovery at six-month follow-up.

The certainty of evidence for functional paresis was rated as very low, primarily due to directly contradictory findings between the two available RCTs and high risk of bias in one trial (Broersma et al., 2015).

3.8. Effects on functional gait disorders

Evidence on gait outcomes is limited to case reports. Improvements in objective gait parameters were described following combined low-frequency M1-hand/leg rTMS and multidisciplinary psychological interventions (Portaro et al., 2018), with enhancements in gait cycle and cadence. Another study (Işık et al., 2024) reported improved knee

stability and gait based on clinical observation following high-frequency (10 Hz) rTMS over M1-leg combined with physiotherapy. However, in all cases rTMS was delivered alongside concurrent therapies, precluding attribution of these effects to rTMS specifically.

The certainty of evidence was very low, given the single-case designs, combined interventions in all studies, and the inability to isolate the effect of rTMS.

3.9. Effects on functional tremor

Evidence of effects on functional tremor is primarily derived from a single double-blind sham-controlled RCT including 17 patients (Taib et al., 2019), which demonstrated a significant and sustained reduction in tremor severity following low-frequency (1 Hz) rTMS over M1-hand/leg. PMDRS tremor subscores decreased markedly in the active group over 12 months ($p < 0.001$), with no significant change in the sham group, resulting in a significant group × time interaction ($p = 0.007$). Non-motor outcomes, including quality of life, psychological measures, and global clinical impression, did not differ between groups. Quality-of-life improvements observed over time in both groups suggest non-specific temporal effects, while greater motor improvement at 12 months correlated with better perceived general health (PMDRS total: $r = -0.67$; tremor subscore: $r = -0.53$). Long-term outcomes were further confounded by concomitant hypnosis during the open-label phase, precluding isolation of the standalone rTMS effect.

Findings from uncontrolled studies provide additional support for a potential effect. A case series including 21 patients (Prezelj et al., 2022),

applying inhibitory continuous theta-burst stimulation (cTBS) over contralateral M1-hand reported significant reductions in postural tremor amplitude measured by accelerometry (median decrease ~ 40 %) and in clinical severity scores (S-FMDRS), with a strong correlation between objective and clinical measures ($r_s = -0.83$, $p < 0.001$). Notably, rest tremor did not show significant improvement. Cognitive-motor distractibility emerged as a significant predictor of treatment response (OR = 2.8, $p = 0.03$; 95 % CI 1.1–7.2), with responders showing higher baseline distractibility scores than non-responders ($p = 0.001$).

The overall certainty of evidence for functional tremor was rated as moderate, reflecting convergent findings from a low-risk RCT and a prospective case series using objective kinematic measures, downgraded for imprecision given the small RCT sample ($n = 17$).

3.10. Effects on functional myoclonus

Evidence for functional myoclonus as a specifically analysed outcome is limited to a single case report (Naro et al., 2020). Low-frequency rTMS over the left PMC, delivered alongside intensive multidisciplinary rehabilitation, was associated with a marked reduction in UMRS score, with improvement maintained at two-month follow-up. Concurrent gains in functional independence were also observed, although these cannot be attributed to rTMS in isolation due to the combined intervention with other physical therapies.

The certainty of evidence was very low, given the single-case design and the inability to attribute observed improvements to rTMS in isolation.

3.11. Effects on mixed phenotypes

No phenotype-specific outcome data were available for several functional motor presentations, including functional dystonia—one of the most prevalent phenotypes—as well as bradykinesia, speech disorders, stereotypies, parkinsonism, chorea/athetosis, and jerky movements. These phenotypes were represented exclusively within mixed-phenotype cohorts, precluding any assessment of rTMS efficacy specific to these clinical entities.

Accordingly, evidence from studies including mixed or heterogeneous FMD populations is considered. A single-blind crossover RCT including 33 patients with mixed hyperkinetic phenotypes (Garcin et al., 2017) reported substantial short-term improvement following low-frequency (0.25 Hz) M1-hand/leg stimulation, with 66.7 % of patients achieving greater than 50 % improvement and 30 % attaining complete symptom resolution. However, no difference was observed compared to spinal root magnetic stimulation, and no predictors of response were identified.

Consistent with these findings, the largest uncontrolled cohort ($n = 24$) (Garcin et al., 2013), comprising patients with mixed hyperkinetic presentations, reported high rates of clinical improvement following a single low-frequency (0.25 Hz) rTMS session over M1, with 75 % achieving > 50 % symptom reduction and 25 % complete resolution. At a median follow-up of 19.8 months, 71 % of evaluable patients remained improved, although 42 % relapsed, all responding to re-treatment. Improvement did not correlate with any baseline clinical parameter.

Additional smaller studies reported variable results. A study including six patients (tremor and jerking movements, gait and balance disorder, speech disorder, and posturing/dystonia) (Spagnolo et al., 2021) showed significant short-term reductions (24 h) in symptom severity following accelerated iTBS over the left DLPFC, whereas another study in six patients with chronic mixed FMD (Shah et al., 2015) receiving low-frequency (0.33 Hz) rTMS over M1 found minimal clinical improvement and inconsistent changes across global impression and quality-of-life measures. Evidence from a single case report (Blades et al., 2020) of a patient with functional dystonia, tremor, body jerks, muscle spasms, speech disorder, and global weakness described

improvement on the GRC Global Rating of Change (GRC = 1) and on depression and anxiety scales following fMRI-guided low-frequency (1 Hz) rTMS targeting medial frontal regions (ACC/SMA/PMC), although the absence of quantitative data and control conditions precludes attribution of effects to rTMS.

The certainty of evidence for mixed hyperkinetic phenotypes was very low, reflecting high risk of bias in the only available RCT, non-specific stimulation effects (TMS = RMS, $p = 0.26$), and substantial indirectness due to phenotypic heterogeneity.

3.12. Psychological characteristics and predictors of treatment response

Psychological characteristics as potential predictors of rTMS response were examined in two studies (Prezelj et al., 2022; Taib et al., 2019), both in patients with functional tremor. In the RCT (Taib et al., 2019), alexithymia (TAS-20 ≥ 61) was present in 35 % of patients and was associated with higher baseline depressive symptoms and greater motor severity, as well as with anxiety scores. However, baseline TAS-20 scores did not predict rTMS outcomes at any timepoint. In contrast, the case series (Prezelj et al., 2022) found that higher baseline cognitive and motor distractibility significantly predicted response to cTBS (OR = 2.8, 95 % CI 1.1–7.2, $p = 0.03$), with responders showing greater distractibility than non-responders.

3.13. Concurrent and complementary therapies

Most studies (9/14; 64.3 %) administered rTMS as a standalone intervention (Blades et al., 2020; Broersma et al., 2015; Chastan et al., 2022; Garcin et al., 2017, 2013; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2003; Shah et al., 2015; Spagnolo et al., 2021), while a minority (5/14; 35.7 %) combined rTMS with additional non-pharmacological therapies (Işık et al., 2024; Naro et al., 2020; Portaro et al., 2018; Schönfeldt-Lecuona et al., 2006; Taib et al., 2019). These adjunctive interventions included psychological approaches (e.g., hypnosis, counselling), physiotherapy-based rehabilitation, or multidisciplinary programmes. Notably, combined interventions were predominantly applied in patients with functional weakness or gait disturbances (Işık et al., 2024; Naro et al., 2020; Portaro et al., 2018; Schönfeldt-Lecuona et al., 2006), whereas only one study incorporated hypnosis in patients with tremor or mixed phenotypes (Taib et al., 2019).

3.14. Treatment duration and durability of rTMS effects

Follow-up ranged from two weeks (Shah et al., 2015) to 20 months (Garcin et al., 2013); five studies reported no post-treatment follow-up (Blades et al., 2020; Broersma et al., 2015; Işık et al., 2024; Portaro et al., 2018; Spagnolo et al., 2021).

Long-term follow-up data from two RCTs (Garcin et al., 2017; Taib et al., 2019) suggest that the effects of rTMS may persist for up to 12 months. Relapses occurred in 12 of 33 patients (36.4 %), with a median time to first relapse of 6 months and a total of 19 relapse episodes reported (Garcin et al., 2017). Notably, all relapsing patients responded to a single additional rTMS session. Beyond controlled trials, one study (Garcin et al., 2013) found that 71 % of evaluable patients maintained clinical improvement at a median follow-up of 19.8 months, despite a relapse rate of 42 %. Importantly, all patients who relapsed achieved a level of improvement comparable to their initial response after receiving one or more additional rTMS sessions. Similarly, a case series (Prezelj et al., 2022) described sustained subjective improvement at one year in 8 of 11 initial responders, with a median duration of benefit of 7 months (range 0–12 months). However, interpretation of long-term efficacy remains limited by potential confounding factors, particularly the concomitant use of hypnosis in one trial (Taib et al., 2019), which precludes definitive attribution of sustained benefits to rTMS alone.

3.15. Adverse events

Reporting of adverse events (AEs) was inconsistent, with over half of studies (8/14) not reporting safety outcomes (Blades et al., 2020; Broersma et al., 2015; Garcin et al., 2017; Işik et al., 2024; Portaro et al., 2018; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2006; Taib et al., 2019). Two studies explicitly stated that no AEs occurred (Garcin et al., 2013; Naro et al., 2020). Among the four studies reporting safety data, no severe AEs were identified. The most frequently reported event was transient headache, observed across several studies in both active and sham conditions (Chastan et al., 2022; Shah et al., 2015; Spagnolo et al., 2021).

3.16. Methodological quality and risk of bias

The four included RCTs demonstrated overall good methodological quality, with a mean PEDro score of 8.0 (range 7–9) and high inter-rater reliability ($\kappa = 0.86$). Higher scores were observed in studies incorporating key methodological safeguards, including allocation concealment and blinded outcome assessment (Chastan et al., 2022; Taib et al., 2019).

RoB 2 assessments identified two trials at low risk of bias (Chastan et al., 2022; Taib et al., 2019), while two were judged at high risk (Broersma et al., 2015; Garcin et al., 2017), primarily due to limitations in allocation concealment, incomplete outcome data, and limitations inherent to crossover designs, including potential carryover and inadequate control of period effects. Although all studies reported randomisation and blinded outcome assessment, only two were prospectively registered with a pre-specified analysis plan (Chastan et al., 2022; Taib et al., 2019), and one excluded a substantial proportion of participants from analysis (Broersma et al., 2015). Traffic light plots and summary risk of bias assessments are presented in Appendix D.

Methodological quality of uncontrolled studies, assessed using JBI checklists, showed high inter-rater reliability ($\kappa = 0.81$) but heterogeneous rigour. Among case series, quality ranged from moderate to high, with strengths in condition identification and clinical reporting, but limitations in demographic detail, inclusion criteria, and recruitment procedures (Garcin et al., 2013; Prezelj et al., 2022; Schönfeldt-Lecuona et al., 2006; Shah et al., 2015; Spagnolo et al., 2021). Among case reports, two demonstrated high quality (Naro et al., 2020; Schönfeldt-Lecuona et al., 2003), whereas the remainder showed important limitations (Blades et al., 2020; Işik et al., 2024; Portaro et al., 2018), particularly regarding adverse events, patient timelines, and intervention details.

Using the GRADE framework, certainty of evidence was rated as moderate for functional tremor and very low for all other outcomes, mainly because of risk of bias, inconsistency, indirectness, imprecision, and probable publication bias. Results are summarised in Appendix E.

4. Discussion

This systematic review synthesised evidence from 14 studies including 175 participants, suggesting that the apparent effectiveness of rTMS in FMD may depend on the interaction between stimulation parameters and clinical phenotype rather than reflecting a uniform therapeutic effect. Although uncontrolled studies frequently reported high clinical improvement rates exceeding 70 % (Garcin et al., 2013), findings from RCTs were more heterogeneous and appeared to vary according to stimulation protocol and symptom profile. In the studies reviewed, excitatory high-frequency protocols were predominantly applied in functional weakness/paresis and were associated with positive findings in the smaller and mostly uncontrolled reports, although the largest sham-controlled RCT was negative; inhibitory protocols were predominantly applied in hyperkinetic and mixed phenotypes, with functional tremor showing the most convergent evidence. The preferential responsiveness of functional tremor may reflect its dependence on

attentional resources (as indexed by distractibility and entrainability) which inhibitory M1 stimulation may disrupt, thereby interrupting the attentionally maintained motor oscillation underlying this phenotype (Huys et al., 2021; Schwingenschuh and Deuschl, 2016). The predictive value of baseline distractibility for cTBS response further supports this. In contrast, it has been hypothesised that functional paresis might instead require facilitation rather than suppression of motor circuits; this proposal has not been tested directly, and the predominant use of excitatory protocols in this phenotype reflects prevailing pathophysiological assumptions rather than comparative evidence.

Methodological quality was variable. RCTs were generally of good quality, with adequate blinding and allocation in some cases (Chastan et al., 2022; Taib et al., 2019), whereas others were limited by incomplete outcome data and crossover-related biases (Broersma et al., 2015; Garcin et al., 2017). Evidence from case series and reports had frequent limitations in patient selection and intervention reporting, reducing confidence in the high response rates.

FMD presentations were highly heterogeneous, with functional weakness/paresis and tremor predominating. Multi-regional and whole-body involvement was most frequent, with upper-limb presentations particularly common. This diffuse and overlapping distribution, together with the generally chronic symptom duration (mean 5.5 ± 8.2 years), is consistent with the recognised tendency of FMD symptoms to spread beyond the initially affected region over time (Ercoli et al., 2022; Forejtová et al., 2023), suggesting that maladaptive motor and cognitive-perceptual mechanisms become progressively consolidated (Demartini et al., 2021; Gelauff et al., 2014), potentially reducing responsiveness to neuromodulation and supporting the need for approaches targeting multiple biopsychosocial factors and distributed networks (Hallett et al., 2022; Perez et al., 2021; Westlin et al., 2025).

Overall, the pattern of findings across studies is compatible with the hypothesis that the therapeutic effects of rTMS are phenotype-specific and linked to the inhibitory or excitatory nature of the protocol. This should be read as a hypothesis generated by the present synthesis rather than as an established effect: no included study compared inhibitory and excitatory protocols within the same phenotype. Nevertheless, studies targeting hyperkinetic and mixed phenotypes almost exclusively employed inhibitory stimulation protocols, including low-frequency rTMS and cTBS over M1, with generally positive results (Blades et al., 2020; Garcin et al., 2017, 2013; Naro et al., 2020; Prezelj et al., 2022; Shah et al., 2015; Taib et al., 2019). Functional tremor showed the most consistent evidence, with an inhibitory contralateral M1 protocol, demonstrating sustained improvements in clinical severity and objective kinematic measures (Prezelj et al., 2022; Taib et al., 2019). For dystonia, myoclonus, bradykinesia, and gait disorders, evidence remains insufficient due to mixed cohorts, absent phenotype-specific analyses, and predominance of small uncontrolled studies.

In contrast, excitatory high-frequency M1 stimulation in functional weakness/paresis generally yielded positive findings (Broersma et al., 2015; Işik et al., 2024; Schönfeldt-Lecuona et al., 2006, 2003), although three of these four reports were uncontrolled case series or single cases and the only RCT was small and at high risk of bias. Importantly, the only inhibitory low-frequency protocol evaluated (the largest sham-controlled RCT (Chastan et al., 2022)) failed to demonstrate superiority over placebo, raising the possibility that excitatory stimulation may be more suitable for hypokinetic presentations, excitatory and inhibitory protocols have not been directly compared within the same study, precluding definitive conclusions. Nevertheless, objective motor improvements were not consistently paralleled by subjective functional gains (Broersma et al., 2015), suggesting a dissociation between motor performance and perceived recovery related to altered mechanisms of self-agency (Maurer et al., 2016). The failure of recent studies targeting the right temporoparietal junction to produce clear clinical benefit (Buhler et al., 2024), underscores the difficulty of translating network-level modulation into meaningful functional recovery (Buhler et al., 2024; Burke et al., 2018; Cheng et al., 2023).

Beyond M1, inhibitory stimulation of PMC, SMA, and ACC was explored in hyperkinetic presentations (Blades et al., 2020; Naro et al., 2020; Shah et al., 2015), but yielded inconsistent findings without clear additional benefit over conventional M1 stimulation.

Conversely, excitatory DLPFC stimulation showed promising results in a single study of mixed hyperkinetic phenotypes (Spagnolo et al., 2021), potentially reflecting the relevance of limbic and salience-network dysfunction in FMD and the observed modulation of fronto-amygdalar connectivity (Riedel et al., 2019).

At a clinical level, rTMS may produce sustained symptomatic improvement in selected FMD phenotypes but does not appear curative or disease-modifying. Improvements have been reported for up to 12 months in controlled studies and longer periods in uncontrolled cohorts (Garcin et al., 2017, 2013; Prezelj et al., 2022; Taib et al., 2019). Relapse occurs in 36–42 % of patients (Garcin et al., 2017, 2013), but most respond to re-treatment, supporting a conceptualisation of rTMS as a repeatable adjunctive or “booster” intervention within a rehabilitation framework rather than a one-time therapy.

The transient nature of the immediate cortical excitability changes induced by rTMS makes a purely neuromodulatory explanation for the sustained clinical improvements observed in FMD unlikely (Jung et al., 2008). This is particularly notable because rTMS was delivered as a standalone intervention in 9 of the 14 included studies, several of which reported benefits lasting months after treatment. Instead, therapeutic effects are more plausibly explained by the interruption of disorder-specific dysfunctional sensorimotor and cognitive feedback loops rather than by persistent modulation of cortical excitability alone (Perez et al., 2021). In functional paresis, suprathreshold stimulation produces visible muscle contractions that may provide patients with direct evidence of preserved motor output, thereby challenging maladaptive motor predictions and facilitating restoration of the sense of agency (Müller et al., 2025). In functional tremor, inhibitory stimulation of the primary motor cortex may transiently disrupt the attentional–motor coupling (Kuhn et al., 2017) that sustains pathological oscillatory activity, consistent with the observation in this review that greater baseline distractibility predicted a better therapeutic response.

A notable proportion of studies combined rTMS with other interventions such as physiotherapy or psychological interventions, particularly in patients with weakness and gait disorders, introducing complexity that may complicate attribution of effects to stimulation parameters alone. Unlike post-stroke rehabilitation, where rTMS is typically paired with physiotherapy to capitalize on a transient window of altered cortical excitability, most studies in FMD have applied rTMS as a standalone intervention or have not explicitly integrated motor retraining immediately after stimulation. It therefore remains unclear whether immediate motor retraining could consolidate or prolong any therapeutic effect.

An important factor is the contribution of contextual and expectancy-related mechanisms alongside direct neuromodulatory effects. In a crossover RCT (Garcin et al., 2017), transcranial M1 stimulation and RMS produced comparable clinical improvements (66.7 % short-term benefit) despite targeting distinct neural structures, suggesting that gains may partly reflect expectation, suggestion, demonstration of preserved motor output and motor relearning (Nielsen et al., 2015), mechanisms particularly relevant in FMD given its close links to attentional, emotional, sensorimotor, predictive and agency-related processes (Kola and LaFaver, 2022; Szejko et al., 2025).

In open-label designs, rTMS may induce symptomatic improvement through contextual and expectancy-related mechanisms (Desai and Desai, 2025) that are not necessarily “non-biological”, as expectancy modulates circuits involved in salience, attention, and agency (Weber et al., 2024). Distractibility, but not alexithymia, predicted rTMS response in two studies (Prezelj et al., 2022; Taib et al., 2019), suggesting partially distinct neural substrates: distractibility may reflect aberrant frontoparietal engagement, whereas alexithymia relates to salience and interoceptive dysfunction (Drane et al., 2021), less

responsive to M1-based stimulation. The preferential responsiveness of functional tremor may therefore derive from its characteristic dependence on attentional control, as reflected by distractibility and entrainability. Inhibitory M1 stimulation could disrupt the sustained attentional–motor coupling that maintains pathological tremor oscillations (Huys et al., 2021; Schwingschuh and Deuschl, 2016). Together, these findings suggest that attentionally driven symptoms may respond preferentially to rTMS, supporting the use of mechanistically informed clinical markers to guide stratified treatment (Prezelj et al., 2022; Schwingschuh and Deuschl, 2016).

Outcome measures were highly heterogeneous, with validated FMD-specific instruments used in only three studies (PMDRS (Taib et al., 2019); S-FMDRS (Prezelj et al., 2022; Spagnolo et al., 2021)). Most studies relied on clinician-rated scales and global impression measures (Garcin et al., 2017, 2013; Taib et al., 2019), with patient-centred outcomes infrequently assessed despite the central role of symptom perception in FMD. Notably, two studies identified a dissociation between objective motor improvement and broader clinical benefit: in Broersma et al. (2015), significant gains in muscle strength were not reflected in subjective hand function ratings ($p = 0.40$), while in Taib et al. (2019) sustained motor improvement was not accompanied by between-group differences in quality of life, psychological outcomes, or global clinical impression, suggesting that observable motor changes may not fully translate into perceived recovery. Such discrepancies may reflect altered self-agency and symptom appraisal (Maurer et al., 2016) and highlight the need for consensus on FMD-specific efficacy endpoints encompassing clinician-rated, objective and patient-reported dimensions (Pick et al., 2020).

The safety profile of rTMS appears favorable in studies reporting safety outcomes, consistent with published safety guidelines (Kim and Paik, 2021).

Several limitations should be considered. First, the evidence base is dominated by uncontrolled studies, with consistently high response rates, whereas RCTs are smaller and more heterogeneous. Second, substantial heterogeneity in protocols, targets, outcomes, and follow-up, together with clinical variability, reduces comparability and precludes quantitative synthesis. Third, outcome assessment was inconsistent, with limited use of objective and patient-reported measures, and the frequent use of adjunctive therapies introduces confounding. A further limitation is the absence of neurophysiological manipulation checks. No study verified whether rTMS induced the expected changes in corticospinal excitability, leaving uncertainty regarding target engagement despite the known inter-individual variability in rTMS responses. Future studies should incorporate such measures as standard. Finally, the lack of phenotype-specific analyses and probable publication bias further limit the strength and generalizability, as reflected in the GRADE certainty ratings.

Taken together, the available evidence suggests that rTMS efficacy in FMD may depend on underlying clinical and pathophysiological mechanisms. Although rTMS appears safe, the phenotype-specific pattern outlined here, inhibitory stimulation in functional tremor and excitatory stimulation in functional paresis, must be regarded as preliminary and hypothesis-generating. Only functional tremor reached moderate certainty under GRADE, whereas certainty was very low for all remaining outcomes, including functional paresis, and the results are further constrained by small samples, heterogeneous outcomes, variable sham conditions and a substantial risk of contextual or expectancy-related effects. At present, rTMS should be regarded as a context-sensitive adjunctive neuromodulatory intervention within a multidisciplinary treatment program. Responsiveness to re-treatment following relapses further supports its role within a symptom-management framework.

Future research should prioritise adequately powered, multicentre RCTs with rigorous sham conditions, standardised outcomes, and phenotypic stratification, alongside objective assessments and mechanistic biomarkers, to distinguish specific neuromodulatory effects from contextual and expectancy-related influences. Rather than viewing

contextual effects merely as confounders, future studies should clarify how neuromodulation, expectancy, attentional redirection and motor relearning interact, and how these mechanisms can be optimally integrated within multidisciplinary care pathways.

Registration and protocol

The review protocol can be accessed in PROSPERO with the following ID number: CRD420251250969.

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Declaration of competing interest

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Appendix A. Supplementary data

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