

MIRROR THERAPY COMBINED WITH REHABILITATION INTERVENTIONS FOR POST-STROKE UPPER LIMB MOTOR DYSFUNCTION: CURRENT EVIDENCE, MECHANISMS, AND FUTURE DIRECTIONS

GaoQiang Chen^{1,2}, JianMing Fu^{2*}, Ya Sun²

¹Huzhou Normal University, Huzhou 313000, Zhejiang, China.

²Department of Rehabilitation Medicine, The Second Hospital of Jiaxing, Jiaxing 314000, Zhejiang, China.

*Corresponding Author: JianMing Fu

Abstract: Post-stroke upper limb motor dysfunction is a common cause of long-term disability. Mirror therapy (MT) is a generally safe, accessible, and low-cost rehabilitation intervention, and its combination with other rehabilitation modalities has attracted growing clinical interest. This narrative review synthesized targeted literature available up to September 2026 on MT combined with electrical stimulation, non-invasive brain stimulation, task-oriented training, acupuncture, robot-assisted therapy, and electromyographic biofeedback. Higher-level clinical evidence and relevant mechanistic studies were prioritized, while no PRISMA-style systematic screening, de novo risk-of-bias assessment, or meta-analysis was undertaken. Across the six combined approaches, evidence suggests potential additional benefits for upper limb motor function and activities of daily living (ADL), but certainty varies substantially. Moderate-quality evidence supports major motor and ADL outcomes for robot-assisted MT, whereas evidence for several electrical stimulation outcomes remains low-certainty. Recent meta-analyses also support potential benefits of MT combined with tDCS and acupuncture, although protocol heterogeneity remains substantial. Patient selection, intervention dose and sequencing, and adverse-event reporting remain inconsistent across studies. MT combined with other rehabilitation interventions is a promising adjunctive strategy for post-stroke upper limb recovery, but current evidence does not support uniform superiority across all modalities or patient groups. Future studies should prioritize standardized reporting, stronger comparative trials, patient stratification, safety monitoring, and clinically meaningful outcome measures.

Keywords: Stroke; Upper limb motor dysfunction; Mirror therapy; Combined rehabilitation interventions; Neurorehabilitation

1 INTRODUCTION

Stroke is a major contributor to global disability [1], and upper-limb motor dysfunction is a common sequela that may persist into the chronic stage, compromising fine motor control, coordination, strength, and activities of daily living. Mirror therapy (MT), also referred to as mirror visual feedback, was initially developed from mirror-based approaches for phantom limb phenomena and was subsequently applied to post-stroke hemiparesis in 1999, providing early evidence that mirror visual feedback could facilitate upper-limb motor recovery [2-3]. Since then, MT has been investigated as an adjunct to conventional rehabilitation. Systematic-review evidence suggests beneficial effects on upper-limb motor function and activities of daily living, but study quality, treatment dose, patient characteristics, and control interventions remain heterogeneous [4]. Combined interventions have therefore become an important research direction. This review summarizes and critically appraises the research progress of MT combined with rehabilitation interventions for post-stroke upper limb motor dysfunction.

1.1 Review Methodology and Literature Selection

This article is a narrative review informed by targeted literature identification rather than a systematic review. Literature available up to 30 September 2026 was considered using combinations of terms related to “stroke,” “mirror therapy” or “mirror visual feedback,” “upper limb” or “upper extremity,” and each combined modality (electrical stimulation, non-invasive brain stimulation, task-oriented training, acupuncture, robot-assisted therapy, and electromyographic biofeedback). Priority was given to systematic reviews and meta-analyses, randomized or controlled clinical studies, and mechanistic neuroimaging or neurophysiological studies, with more recent and higher-level evidence emphasized where available. Because no prospectively registered protocol, PRISMA-style systematic screening, formal dual-reviewer study-selection process, de novo risk-of-bias assessment, or de novo meta-analysis was undertaken, the conclusions are presented as a narrative synthesis with explicit attention to heterogeneity and certainty of evidence.

2 MECHANISMS OF MIRROR THERAPY

MT uses the imaging principle of a plane mirror to reflect the movement of the unaffected upper limb while the affected side is occluded. Through visual feedback, MT induces the visual illusion that the affected limb is moving in a manner

congruent with the reflected movement of the unaffected limb, thereby engaging action observation, motor imagery, attention, and sensorimotor processing. The neurophysiological mechanisms of MT have not been fully established and are unlikely to be explained by a single pathway. Proposed mechanisms include modulation of the mirror neuron system, visual-proprioceptive integration, changes in corticospinal excitability and interhemispheric interactions, attentional effects, and reduction of learned non-use. Mirror neurons were described by Rizzolatti and colleagues during single-neuron recording experiments in macaques [5]. Their observation-execution matching properties provide one plausible framework for understanding MT, but the mirror neuron account should be regarded as one component of a broader sensorimotor network mechanism.

Through observation of reflected movement, MT can modulate activity in motor, premotor, parietal, and sensorimotor networks. Experimental studies have shown changes in primary motor cortex (M1) excitability and motor plasticity after mirror visual feedback [6]. Resting-state functional magnetic resonance imaging (fMRI) research has also reported that improvement after MT is associated with reorganization of functional connectivity between bilateral M1 regions and recruitment of ipsilateral motor pathways [7]. These findings suggest that reorganization or recruitment of residual motor pathways may contribute to MT-related recovery; however, they do not establish that restoration of a single ipsilateral pathway is the primary mechanism. The clinical effect of MT is therefore better understood as a network-level neuroplastic process involving visual, attentional, sensory, and motor systems.

3 RESEARCH ADVANCES IN MIRROR THERAPY COMBINED WITH REHABILITATION INTERVENTIONS

With growing research interest, MT has been combined with electrical stimulation, non-invasive brain stimulation, task-oriented training, acupuncture, robot-assisted therapy, and electromyographic biofeedback. These combinations are intended to integrate visual feedback with peripheral sensory-motor input, cortical neuromodulation, task-specific practice, or technology-assisted training. However, the quantity and quality of evidence differ substantially across modalities; therefore, efficacy, mechanisms, and treatment parameters should be interpreted according to the strength and limitations of the available evidence.

3.1 MT Combined with Electrical Stimulation (ES)

Functional electrical stimulation (FES) and neuromuscular electrical stimulation (NMES) can provide peripheral motor and sensory input and are used to facilitate wrist and finger function. Meta-analyses suggest that, compared with monotherapy, MT combined with ES may provide additional improvement in upper-limb motor control and hand function after stroke, with some studies also reporting reductions in spasticity [8-9]. However, the 2024 systematic review assessed the certainty of evidence for several key outcomes as low, and ES type, stimulation parameters, stroke stage, MT dose, and treatment sequencing vary substantially across studies [8]. Simultaneous and sequential protocols have both been used, but current evidence does not establish an optimal timing strategy; therefore, specific schedules such as brief MT priming followed by simultaneous ES should be regarded as study-specific protocols rather than standardized recommendations. The two modalities have plausible complementary effects. MT primarily provides visual and action-observation input and may modulate cortical motor networks, whereas ES provides proprioceptive and tactile afferent input together with peripheral motor activation. Their combination may therefore facilitate multisensory sensorimotor integration rather than simply maximizing motor output. An fMRI study in healthy volunteers showed that adding visual information to tactile stimulation increased activation in bilateral primary sensorimotor and secondary somatosensory regions compared with tactile stimulation alone [10]. Although this finding is not direct evidence for MT plus ES in stroke, it supports the biological plausibility of integrating visual and somatosensory inputs. Whether such multisensory effects translate into clinically meaningful synergistic benefits in different stroke subgroups requires further study.

3.2 MT Combined with Non-Invasive Brain Stimulation (NIBS)

Non-invasive brain stimulation mainly includes repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS), both of which can modulate cortical excitability and neuroplasticity [11]. Conventional protocols often use excitatory stimulation of the affected hemisphere or inhibitory stimulation of the unaffected hemisphere, although the optimal strategy depends on lesion characteristics, residual corticospinal function, and stroke stage. A systematic review and meta-analysis of randomized clinical trials suggests that combining MT with NIBS may improve upper-limb motor outcomes compared with single-modality interventions, but substantial heterogeneity remains in stimulation type, target, timing, and dose [12].

3.2.1 MT combined with rTMS

rTMS uses pulsed magnetic fields to modulate cortical excitability and plasticity. The primary motor cortex (M1) is the most common target in post-stroke motor rehabilitation, and both low-frequency stimulation of the contralesional hemisphere and high-frequency stimulation of the ipsilesional hemisphere have been studied [13]. A 2026 systematic review and meta-analysis of seven randomized controlled trials (RCTs) involving 402 participants reported improvements in the Fugl-Meyer Assessment of the Upper Extremity (FMA-UE) and Box and Block Test outcomes with combined rTMS and MT, while emphasizing that the optimal stimulation parameters remain uncertain [14]. Individual clinical studies likewise report potential improvements in upper-limb motor function and neurophysiological outcomes [15-18], and this direction is consistent with the broader NIBS-plus-MT evidence base [12]. However, current evidence does not

justify a universal rule that high-frequency ipsilesional rTMS should be preferred in the acute stage and low-frequency contralesional rTMS in the chronic stage. Similarly, short intervals between rTMS and MT have been used in some protocols, but the optimal temporal interval has not been established. Stimulation target, frequency, intensity, and sequencing should therefore be regarded as protocol variables requiring further comparative study rather than fixed clinical recommendations.

The potential synergistic effect of MT combined with rTMS may be understood from several complementary mechanisms. (1) Central-sensory-motor co-modulation: rTMS can modulate excitability in targeted cortical regions, whereas MT provides repeated visual and sensorimotor information. Their combination may strengthen recruitment and reorganization of residual motor networks rather than induce direct regeneration of intact nerves near the lesion. (2) Modulation of interhemispheric interactions: inhibitory or excitatory rTMS protocols may alter abnormal interhemispheric excitability, while MT engages bilateral visual-motor networks and attention to the affected limb. (3) Enhancement of activity-dependent plasticity: repeated pairing of cortical neuromodulation with behaviorally relevant visual-motor training is consistent with Hebbian-type plasticity principles described in paired-stimulation paradigms [19], although direct demonstration of a specific Hebbian mechanism for MT combined with rTMS remains limited. These mechanisms should therefore be viewed as biologically plausible hypotheses rather than fully established causal pathways.

3.2.2 MT combined with tDCS

Recent systematic reviews and meta-analyses suggest that MT combined with tDCS may improve post-stroke upper-limb motor function and some activities of daily living (ADL) outcomes, but heterogeneity across protocols, comparators, and outcome measures limits certainty [20-21]. Individual clinical studies have also reported improvements in upper-limb motor function, hand function, and activities of daily living [22-26], and broader NIBS-plus-MT evidence is consistent with a potential benefit [12]. Treatment sequence may influence efficacy; timing-dependent effects have been reported in chronic stroke, and some studies have applied anodal tDCS to the affected hemisphere before MT [23, 26]. In a randomized pilot study involving 28 participants, sequential tDCS plus MT improved activities of daily living more than comparator schedules, but between-group differences in Fugl-Meyer Assessment and movement-kinematic outcomes were not significant [23]. However, evidence is insufficient to define a single optimal sequence. M1 remains a common stimulation target, while premotor cortex stimulation has also been investigated as an alternative approach, with work using electroencephalography (EEG) suggesting that target selection may influence motor recovery and longer-term response [24]. Mechanistically, anodal tDCS may transiently increase cortical excitability and thereby prime the motor network for subsequent mirror-based visual-motor training. This central neuromodulation, combined with the sensory and attentional inputs provided by MT, offers a plausible basis for complementary effects, but claims regarding specific mirror-neuron activation times or direct neural repair require further experimental confirmation.

3.3 MT Combined with Task-Oriented Training (TOT)

Task-oriented training (TOT) is a core approach to post-stroke upper-limb rehabilitation that emphasizes meaningful tasks, repeated practice, progression of difficulty, and performance feedback. Several studies have used MT as a priming intervention before or alongside TOT, but the duration and sequencing of MT vary and should not be interpreted as a standardized 10-min prescription. Clinical studies suggest that MT combined with TOT can improve motor function and activities of daily living in people with post-stroke hemiplegia [27-29]. One relatively large clinical study also reported reductions in the neurological injury-related biomarkers neuron-specific enolase (NSE) and S100 β after combined treatment [29]; however, these biomarker changes should be interpreted cautiously and do not by themselves establish neural repair. In this 304-participant study, the combined intervention included additional mirror training for both the upper and lower limbs; consequently, the effects of increased training dose and limb-specific MT cannot be fully disentangled. A plausible explanation for the combined approach is that mirror-based action observation and motor imagery may prime subsequent task-specific practice, while repeated TOT reinforces use-dependent motor learning and neuroplasticity. Current evidence supports this priming concept, but larger high-quality randomized trials are still needed to determine which patients benefit most and how the two components should be sequenced.

3.4 MT Combined with Acupuncture (AT)

Acupuncture is widely used in neurological rehabilitation in China and is sometimes combined with MT for post-stroke upper-limb dysfunction. Traditional Chinese medicine explains stroke-related dysfunction in terms of disturbances of qi, blood, and meridian function; these traditional constructs should be distinguished from modern neurophysiological hypotheses. Contemporary explanations for acupuncture-related effects include modulation of peripheral sensory input and brain-network activity. A meta-analysis of fMRI studies in stroke patients with motor dysfunction reported acupuncture-associated changes in the basal ganglia, insula, and motor-related cortical regions, providing evidence consistent with neuroplastic modulation while not establishing a single causal mechanism [30]. A 2024 systematic review and meta-analysis of 42 randomized controlled trials involving 3,340 participants examined post-stroke limb motor outcomes, including both upper and lower limbs. Only 23 trials contributed to the upper-limb Fugl-Meyer (FMA-UE) analysis, which showed substantial heterogeneity ($I^2 = 87\%$) and indications of publication bias [31]. Although the pooled findings favored acupuncture combined with MT for several motor and activities of daily living (ADL) outcomes, variability in acupuncture protocols, outcome assessment, and the geographic concentration of evidence limit certainty and generalizability. Individual clinical studies have also reported improvements in upper-limb FMA scores, activities of

daily living, and spasticity [32-34]. Some studies applied MT during the acupuncture retention period, but such timing should be considered protocol-specific rather than a standardized recommendation. The possible interaction between acupuncture-related somatosensory input and mirror-based visual feedback is biologically plausible; nevertheless, higher-quality multicenter trials with clearer blinding, adverse-event reporting, and standardized outcomes are required.

3.5 MT Combined with Robot-Assisted Therapy (RT)

Robot-assisted therapy (RT) can provide high-intensity, repetitive, and quantifiable upper-limb training [35], while mirror-based feedback may enhance attention, embodiment, and visual-motor engagement. A 2026 meta-analysis of 16 randomized controlled trials involving 736 participants found that robot-mirror therapy (RMT) improved upper-limb motor function and activities of daily living, with moderate-quality evidence for major upper-limb motor and ADL outcomes; certainty was lower for several distal, hand, strength, and quality-of-life outcomes [36]. This represents one of the stronger evidence bases among the combined interventions reviewed here, although heterogeneity in robotic devices, delivery modes, dose, and patient populations remains substantial. Therefore, specific session durations or progression schedules should not yet be treated as standardized prescriptions. Clinical and neuroimaging studies have reported changes in motor function and bilateral sensorimotor cortical activity with sequential or integrated MT-robot approaches [37-40]. Importantly, a randomized study with 37 participants in the final analysis found no significant additional improvement in motor function or daily function from MT priming before robot-assisted therapy, although a benefit in self-efficacy was reported [37]. Conceptually, this combination may couple centrally mediated visual-motor engagement with intensive peripheral movement and sensory experience; however, the relative contribution of each component and the optimal level of robotic assistance remain to be clarified.

3.6 MT Combined with Electromyographic Biofeedback (EMG-BF)

Electromyographic biofeedback (EMG-BF) records muscle activity through surface electrodes and converts the signal into visual or auditory feedback that can help patients recognize and voluntarily regulate muscle activation. A 2020 systematic review and meta-analysis of combined MT interventions included an EMG-BF-plus-MT subgroup and reported favorable effects on upper-limb functional recovery, although the number of contributing trials was limited and overall heterogeneity was substantial [41]. More recent clinical studies also suggest that MT combined with EMG-BF may improve upper-limb motor function, activities of daily living, and muscle recruitment efficiency after stroke [42-44]. However, EMG thresholds, feedback rules, session duration, and the sequencing of MT and EMG-BF differ across studies; currently reported protocols should therefore be regarded as experimental or study-specific rather than standardized. The most direct mechanistic rationale is enhancement of voluntary motor control and sensorimotor learning: MT provides visual action-related feedback, whereas EMG-BF provides real-time information about actual muscle recruitment, allowing patients to adjust activation and reduce inefficient or abnormal co-contraction. Current evidence more directly supports this sensorimotor feedback mechanism than specific claims that EMG-BF directly stimulates Renshaw cells or Ib afferent pathways. Larger randomized trials are needed to establish efficacy, optimal dosing, effects on spasticity, and long-term retention.

3.7 Comparative Evidence, Patient Selection, and Safety

The strength of evidence varies substantially among combined approaches. Table 1 summarizes representative evidence and the principal limitations that should be considered when translating these findings into clinical practice. In general, the presence of a statistically significant treatment effect should not be interpreted as proof of a true synergistic mechanism, and protocol heterogeneity limits direct comparison across modalities.

Table 1 Comparative Appraisal of MT Combined with Rehabilitation Interventions

Combination	Representative evidence	Main findings	Key limitations
MT + ES	Systematic reviews/meta-analyses [8-9]	Potential additional benefit for upper-limb motor control and hand function; however, the 2024 review graded several key outcomes as low-certainty evidence.	Heterogeneity in ES type, stimulation parameters, timing, dose, stroke stage, and outcome measures; optimal sequencing remains uncertain.
MT + NIBS	Systematic reviews/meta-analyses [12, 14, 20-21]; representative clinical studies [15, 23].	Potential additional benefit for upper-limb motor recovery with both rTMS- and tDCS-based combinations, but effect estimates and certainty vary by protocol and outcome.	Variable targets, frequency or polarity, sequencing, comparators, and patient characteristics; optimal parameters remain uncertain. Evidence base is smaller.
MT + TOT	Clinical studies [27-29]	MT may function as priming before task-specific practice and may improve motor and functional outcomes.	Intervention dose, task content, sequencing, and outcome domains vary.

Combination	Representative evidence	Main findings	Key limitations
MT + acupuncture	Systematic review/meta-analysis [31]; clinical studies [32-34]	Pooled and clinical evidence reports improvements in motor outcomes and activities of daily living, with some studies also reporting reduced spasticity.	Only 23 of 42 trials reported FMA-UE ($I^2 = 87\%$; indications of publication bias); protocol heterogeneity, geographic concentration, and variable blinding limit generalizability.
MT + robot-assisted therapy	Meta-analysis [36]; clinical and imaging studies [37-40].	Moderate-quality evidence supports improvements in motor function and activities of daily living, but one randomized trial found no additional motor or ADL benefit from MT priming; certainty remains lower for some distal and hand outcomes.	Robot/device and delivery heterogeneity, small samples in many trials, and limited geographic generalizability.
MT + EMG-BF	Systematic review/meta-analysis [41]; clinical studies [42-44]	Potential improvements in motor function, activities of daily living, and voluntary muscle recruitment.	The meta-analytic EMG-BF subgroup is based on few trials; feedback thresholds, dose, long-term effects, and effects on spasticity remain uncertain.

Note: MT = mirror therapy; ES = electrical stimulation; NIBS = non-invasive brain stimulation; TOT = task-oriented training; EMG-BF = electromyographic biofeedback; rTMS = repetitive transcranial magnetic stimulation; tDCS = transcranial direct current stimulation; FMA-UE = Fugl-Meyer Assessment of the Upper Extremity; ADL = activities of daily living. Certainty descriptors reflect the cited reviews and meta-analyses; no de novo Grading of Recommendations Assessment, Development and Evaluation (GRADE) assessment was conducted for this narrative review.

Clinical selection should also account for stroke stage, lesion characteristics, baseline upper-limb severity, residual voluntary movement, cognition and attention, visuospatial neglect or visual deficits, sensory impairment, spasticity, and the patient's ability to engage with mirror-based feedback. MT itself appears to have a favorable safety profile: the 2018 Cochrane review reported no adverse effects, although adverse-event reporting across trials was limited [4]. Combined modalities have additional modality-specific considerations. ES can cause discomfort or skin irritation. rTMS commonly causes transient scalp discomfort or headache and, although rare, seizure is a recognized safety risk requiring guideline-based screening; tDCS is more commonly associated with mild tingling, itching, skin irritation, or headache [11]. Acupuncture carries bleeding and infection risks, and robot-assisted therapy requires monitoring of joint range, load, and human-machine interaction. Adverse-event reporting remains inconsistent and should become a routine component of future trials.

4 DISCUSSION AND FUTURE DIRECTIONS

In post-stroke upper-limb rehabilitation, MT combined with electrical stimulation, non-invasive brain stimulation, task-oriented training, acupuncture, robot-assisted therapy, and electromyographic biofeedback has generally shown potential for additional benefit, but the certainty of evidence is not uniform across modalities. Meta-analytic evidence is now available across several combined modalities, but its certainty and methodological robustness differ substantially. The 2024 ES meta-analysis graded several key outcomes as low-certainty evidence [8], whereas the 2026 robot-assisted meta-analysis reported moderate-quality evidence for major motor and activities of daily living (ADL) outcomes [36]. Recent meta-analyses have also strengthened the evidence base for MT combined with tDCS and acupuncture, although heterogeneity and protocol variation remain substantial [20-21, 31]. Future research should focus on the following directions: (1) Mechanistic exploration—from “superposition of effects” to testable synergistic pathways. Neuroimaging and neurophysiological methods such as fMRI, functional near-infrared spectroscopy (fNIRS), EEG, and transcranial magnetic stimulation (TMS) should be used to test whether combined protocols produce additive or interactive effects across motor, sensory, attentional, and network-level processes. (2) Protocol standardization and transparent reporting. Rather than prescribing a universal fixed dose, future studies should consistently report MT duration, movement content, treatment frequency, sequencing with the combined modality, patient selection criteria, and clinically meaningful outcomes such as FMA-UE, the Wolf Motor Function Test (WMFT), the Action Research Arm Test (ARAT), and ADL measures. (3) Cost and dissemination. Resource-intensive technologies such as rTMS and rehabilitation robots may limit widespread use, whereas tDCS is relatively lower cost and more portable but still requires standardized safety screening and stimulation procedures. Low-cost electrical stimulation, virtual or augmented mirror-feedback systems, and home task-training kits warrant further evaluation. (4) Technological innovation and monitoring. Continuous or repeated monitoring using surface electromyography (sEMG), EEG, fNIRS, inertial or wearable sensors may support real-time assessment and adaptive training, whereas fMRI is better suited to intermittent mechanistic assessment rather than continuous monitoring throughout treatment. (5) Patient stratification and safety. Stroke stage, lesion characteristics, baseline motor severity, residual voluntary movement, cognition and attention, visuospatial neglect or visual impairment, somatosensory deficits, and spasticity may influence response to MT. Adverse events and tolerability should also be reported systematically, particularly for NIBS, electrical stimulation, acupuncture, and robot-assisted interventions. Recent evidence also indicates that the mode of MT delivery itself may be an important effect modifier. A 2026 systematic review of 19 trials involving 618 participants found that unilateral MT may improve motor recovery, whereas bilateral

MT provided little or no additional benefit over matched practice without mirror feedback [45]. This finding reinforces the need to treat the MT protocol itself as an active design variable rather than as a uniform intervention.

5 CONCLUSION

Overall, MT combined with other rehabilitation interventions is a promising adjunctive strategy for post-stroke upper-limb recovery, but it should not yet be regarded as uniformly superior across all techniques or patient groups. Future work should prioritize clearer mechanisms, stronger comparative trials, transparent reporting of evidence certainty and adverse events, standardized yet adaptable protocols, and clinically meaningful patient stratification. Integrating these priorities with accessible technologies may support more precise, safe, and scalable rehabilitation pathways.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

This work was supported by the Zhejiang Provincial Medical and Health Science and Technology Project (No. 2024KY1691 and No.2024KY447).

DATA AVAILABILITY

No new primary data were collected or generated for this narrative review. All evidence synthesized is derived from the cited published literature.

ARTIFICIAL INTELLIGENCE DISCLOSURE

OpenAI ChatGPT (including GPT-6) was used to assist with English-language editing, structural refinement, identification of potentially relevant literature, preliminary citation and evidence-consistency checks, and manuscript formatting. The authors are responsible for independently verifying all scientific claims, bibliographic records, and the final submitted manuscript.

REFERENCES

- [1] GBD 2021 Stroke Risk Factor Collaborators. Global, regional, and national burden of stroke and its risk factors, 1990-2021: A systematic analysis for the Global Burden of Disease Study 2021. *The Lancet Neurology*, 2024, 23(10): 973-1003. DOI: 10.1016/S1474-4422(24)00369-7.
- [2] Ramachandran V S, Rogers-Ramachandran D, Cobb S. Touching the phantom limb. *Nature*, 1995, 377(6549): 489-490. DOI: 10.1038/377489a0.
- [3] Altschuler E L, Wisdom S B, Stone L, et al. Rehabilitation of hemiparesis after stroke with a mirror. *The Lancet*, 1999, 353(9169): 2035-2036. DOI: 10.1016/S0140-6736(99)00920-4.
- [4] Thieme H, Morkisch N, Mehrholz J, et al. Mirror therapy for improving motor function after stroke. *Cochrane Database of Systematic Reviews*, 2018(7): CD008449. DOI: 10.1002/14651858.CD008449.pub3.
- [5] Rizzolatti G, Fadiga L, Gallese V, et al. Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, 1996, 3(2): 131-141. DOI: 10.1016/0926-6410(95)00038-0.
- [6] Nojima I, Mima T, Koganemaru S, et al. Human motor plasticity induced by mirror visual feedback. *The Journal of Neuroscience*, 2012, 32(4): 1293-1300. DOI: 10.1523/JNEUROSCI.5364-11.2012.
- [7] Zhang K, Ding L, Wang X, et al. Evidence of mirror therapy for recruitment of ipsilateral motor pathways in stroke recovery: A resting fMRI study. *Neurotherapeutics*, 2024, 21(2): e00320. DOI: 10.1016/j.neurot.2024.e00320.
- [8] Pan H, Liu T W, Ng S S M, et al. Effects of mirror therapy with electrical stimulation for upper limb recovery in people with stroke: A systematic review and meta-analysis. *Disability and Rehabilitation*, 2024, 46(24): 5660-5675. DOI: 10.1080/09638288.2024.2310757.
- [9] Saavedra-García A, Moral-Muñoz J A, Lucena-Antón D. Mirror therapy simultaneously combined with electrical stimulation for upper limb motor function recovery after stroke: A systematic review and meta-analysis of randomized controlled trials. *Clinical Rehabilitation*, 2021, 35(1): 39-50. DOI: 10.1177/0269215520951935.
- [10] Kwon H G, Jang S H, Lee M Y. Effects of visual information regarding tactile stimulation on the somatosensory cortical activation: A functional MRI study. *Neural Regeneration Research*, 2017, 12(7): 1119-1123. DOI: 10.4103/1673-5374.211191.
- [11] Kesikburun S. Non-invasive brain stimulation in rehabilitation. *Turkish Journal of Physical Medicine and Rehabilitation*, 2022, 68(1): 1-8. DOI: 10.5606/tftrd.2022.10608.
- [12] Zhao Q, Li H, Liu Y, et al. Non-invasive brain stimulation associated mirror therapy for upper-limb rehabilitation after stroke: Systematic review and meta-analysis of randomized clinical trials. *Frontiers in Neurology*, 2022, 13: 918956. DOI: 10.3389/fneur.2022.918956.

- [13] Safdar A, Smith M C, Byblow W D, et al. Applications of repetitive transcranial magnetic stimulation to improve upper limb motor performance after stroke: A systematic review. *Neurorehabilitation and Neural Repair*, 2023, 37(11-12): 837-849. DOI: 10.1177/15459683231209722.
- [14] Alashram A R. Combined repetitive transcranial magnetic stimulation and mirror therapy for upper limb rehabilitation in stroke survivors: A systematic review and meta-analysis. *Neurological Sciences*, 2026, 47(10): 823. DOI: 10.1007/s10072-026-09437-y.
- [15] Chen B, Jiang L, Qiu M, et al. Effect of repetitive transcranial magnetic stimulation combined with mirror therapy on upper limb motor function and neuroelectrophysiology in stroke patients with hemiplegia. *Chinese Journal of Rehabilitation Theory and Practice*, 2023, 29(10): 1201-1207. DOI: 10.3969/j.issn.1006-9771.2023.10.012.
- [16] Si Y. Effect of repetitive transcranial magnetic stimulation at different frequencies combined with mirror therapy on neuroelectrophysiology in patients with cerebral infarction. *Clinical Medicine (China)*, 2021, 41(5): 46-47.
- [17] Xu R, Liu Y, Zou S, et al. Effect of repetitive transcranial magnetic stimulation combined with mirror therapy on upper limb motor function in stroke patients with hemiplegia. *China Modern Medicine*, 2025, 32(30): 66-70.
- [18] Yang J, Meng D H, Shao Z Y, et al. Effect of high-frequency transcranial magnetic stimulation combined with mirror therapy on upper limb function recovery in male stroke patients. *Chinese Journal of Physical Medicine and Rehabilitation*, 2018, 40(2): 91-95.
- [19] Xu R, Zhu G Y, Zhu J, et al. Using Hebbian-type stimulation to rescue arm function after stroke: Study protocol for a randomized clinical trial. *Frontiers in Neural Circuits*, 2022, 15: 789095. DOI: 10.3389/fncir.2021.789095.
- [20] Alashram A R. Combined transcranial direct current stimulation and mirror therapy for upper limb rehabilitation in patients with stroke: A systematic review and meta-analysis. *Neurological Sciences*, 2026, 47(8): 619. DOI: 10.1007/s10072-026-09240-9.
- [21] Zong B, Zhang C, Zhang Q. Effect of mirror therapy combined with transcranial direct current stimulation on upper limb motor function in stroke patients: A meta-analysis. *Medicine*, 2026, 105(31): e50057. DOI: 10.1097/MD.00000000000050057.
- [22] Chen H, Cai Q, Xu L, et al. Effect of transcranial direct current stimulation combined with mirror therapy on upper limb motor function in stroke patients. *Chinese Journal of Rehabilitation Theory and Practice*, 2020, 26(3): 301-305. DOI: 10.3969/j.issn.1006-9771.2020.03.007.
- [23] Liao W W, Chiang W C, Lin K C, et al. Timing-dependent effects of transcranial direct current stimulation with mirror therapy on daily function and motor control in chronic stroke: A randomized controlled pilot study. *Journal of NeuroEngineering and Rehabilitation*, 2020, 17: 101. DOI: 10.1186/s12984-020-00722-1.
- [24] Liu C L, Su K H, Horng Y S, et al. Theory-driven EEG indexes for tracking motor recovery and predicting the effects of hybridizing tDCS with mirror therapy in stroke patients. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2024, 32: 4042-4051. DOI: 10.1109/TNSRE.2024.3493926.
- [25] Vlotinou P, Tsiptsios D, Karatzetou S, et al. Transcranial direct current stimulation in conjunction with mirror therapy for upper extremity rehabilitation in chronic stroke patients. *Maedica*, 2022, 17(1): 169-176. DOI: 10.26574/maedica.2022.17.1.169.
- [26] Zhu L, Qu S W, Liu L, et al. Effect of anodal transcranial direct current stimulation combined with mirror therapy on upper limb function in stroke patients. *Chinese Journal of Rehabilitation Theory and Practice*, 2022, 28(11): 1247-1251. DOI: 10.3969/j.issn.1006-9771.2022.11.002.
- [27] Bondoc S, Booth J, Budde G, et al. Mirror therapy and task-oriented training for people with a paretic upper extremity. *American Journal of Occupational Therapy*, 2018, 72(2): 7202205080p1-7202205080p8. DOI: 10.5014/ajot.2018.025064.
- [28] Wang X, Zhang X, Zhang Y. Effects of mirror therapy combined with task-oriented training on functional recovery and electromyography in elderly patients with hemiplegia after stroke. *Practical Journal of Clinical Medicine*, 2023, 20(5): 41-44.
- [29] Zhang Y, Lü W, Liu J. Effects of mirror therapy combined with task-oriented training on limb function recovery in stroke patients with hemiplegia. *Journal of Sichuan University (Medical Sciences)*, 2023, 54(5): 1046-1051. DOI: 10.12182/20230960602.
- [30] Lv Q, Xu G, Pan Y, et al. Effect of acupuncture on neuroplasticity of stroke patients with motor dysfunction: A meta-analysis of fMRI studies. *Neural Plasticity*, 2021, 2021: 8841720. DOI: 10.1155/2021/8841720.
- [31] Ke W, Cheng H, Ren X, et al. Efficacy of acupuncture combined with mirror therapy in the treatment of post-stroke limb movement disorders: A systematic review and meta-analysis of randomised controlled trials. *Frontiers in Rehabilitation Sciences*, 2024, 5: 1464502. DOI: 10.3389/fresc.2024.1464502.
- [32] Duan C, Li Z, Xia W, et al. Effect of acupuncture combined with mirror therapy on upper limb motor function after stroke. *Neural Injury and Functional Reconstruction*, 2020, 15(3): 155-158.
- [33] Si L. Effect of mirror therapy combined with acupuncture on upper limb motor dysfunction after stroke. *Yunnan University of Chinese Medicine*, 2022(3). DOI: 10.27460/d.cnki.gyzyc.2021.000216.
- [34] Zhang Y, Zheng P, Yan X, et al. Clinical study on acupuncture at Baxie acupoints combined with mirror therapy for upper limb and hand function in patients with hemiplegia after stroke. *Chinese Journal of Rehabilitation*, 2021, 36(6): 353-355.
- [35] Liu S, Zhang X, Zhou L, et al. Robot-assisted therapy for upper limb rehabilitation after stroke: Umbrella review. *Journal of Medical Internet Research*, 2026, 28: e79363. DOI: 10.2196/79363.

- [36] Gao C, Zhang H, He K, et al. Effectiveness of mirror and robot-assisted therapy for upper extremity rehabilitation in post-stroke patients: A meta-analysis. *Journal of NeuroEngineering and Rehabilitation*, 2026, 23: 61. DOI: 10.1186/s12984-026-01877-z.
- [37] Chen Y W, Li K Y, Lin C H, et al. The effect of sequential combination of mirror therapy and robot-assisted therapy on motor function, daily function, and self-efficacy after stroke. *Scientific Reports*, 2023, 13: 16841. DOI: 10.1038/s41598-023-43981-3.
- [38] Kim D H, Lee K D, Bulea T C, et al. Increasing motor cortex activation during grasping via novel robotic mirror hand therapy: A pilot fNIRS study. *Journal of NeuroEngineering and Rehabilitation*, 2022, 19: 8. DOI: 10.1186/s12984-022-00988-7.
- [39] Qiu Y, Zheng Y, Liu Y, et al. Synergistic immediate cortical activation on mirror visual feedback combined with a soft robotic bilateral hand rehabilitation system: A functional near infrared spectroscopy study. *Frontiers in Neuroscience*, 2022, 16: 807045. DOI: 10.3389/fnins.2022.807045.
- [40] Wei Y, Wu L, Huang F, et al. Effects of robot assisted mirror therapy on motor function and cortical activation in patients with right hemisphere damage. *Scientific Reports*, 2025, 15: 33490. DOI: 10.1038/s41598-025-16686-y.
- [41] Luo Z, Zhou Y, He H, et al. Synergistic effect of combined mirror therapy on upper extremity in patients with stroke: A systematic review and meta-analysis. *Frontiers in Neurology*, 2020, 11: 155. DOI: 10.3389/fneur.2020.00155.
- [42] Jin L, Ye P. Application of electromyographic biofeedback combined with mirror therapy in patients with hemiplegia after subacute stroke. *Modern Medicine and Health Research Electronic Journal*, 2026, 10(4): 138-141.
- [43] Ke M, Jin X, Meng Z, et al. Effect of mirror therapy combined with electromyographic biofeedback on upper limb function in patients recovering from stroke. *Chinese Journal of Rehabilitation*, 2020, 35(4): 183-186. DOI: 10.3870/zgkf.2020.04.004.
- [44] Luo M, Wang T. Effects of mirror therapy combined with electromyographic biofeedback training on upper limb function recovery in patients with upper limb dysfunction after stroke. *China Medical Innovation*, 2026, 23(16): 81-86.
- [45] Boening A, Ada L, Alvarenga M T M, et al. Unilateral mirror therapy may improve upper limb motor recovery after stroke but bilateral mirror therapy provides little or no additional benefit: A systematic review. *Journal of Physiotherapy*, 2026, 72(1): 33-41. DOI: 10.1016/j.jphys.2025.12.008.