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Systematic Review

Does acupuncture at motor-related acupoints affect corticospinal excitability? A systematic review and meta-analysis

Renming Liu^{a,*}, Aung Aung Kywe Moe^b, Weiting Liu^c, Maryam Zoghi^d, Shapour Jaberzadeh^a^a Monash Neuromodulation Research Unit, Department of Physiotherapy, School of Primary and Allied Health Care, Monash University, Melbourne 3199, Victoria, Australia^b Department of Medical Imaging and Radiation Sciences, Monash University, Melbourne 3199, Victoria, Australia^c School of Nursing and Midwifery, Edith Cowan University, Perth 6027, Victoria, Australia^d Discipline of Physiotherapy, Institute of Health and Wellbeing, Federation University, Melbourne 3353, Victoria, Australia

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ABSTRACT

Background: Acupuncture is widely used in modulating brain excitability and motor function, as a form of complementary and alternative medicine. However, there is no existing meta-analysis evaluating the effectiveness and safety of acupuncture on corticospinal excitability (CSE), and the credibility of the evidence has yet to be quantified.

Objective: This study was designed to assess the efficacy and safety of electroacupuncture (EA) and manual acupuncture (MA) in enhancing brain excitability, specifically focusing on CSE as measured by transcranial magnetic stimulation (TMS).

Search strategy: This study followed a systematic approach, searching 9 databases up to August 2024 and examining grey literature, in compliance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.

Inclusion criteria: Studies were included if they compared the clinical efficacy of EA or MA with sham acupuncture, no treatment or usual training.

Data extraction and analysis: Three investigators independently conducted literature screening, data extraction, and risk of bias assessment. The primary outcome focused on motor-evoked potentials as measured by TMS, with treatment effects quantified using mean differences or standardized mean differences between pre- and post-treatment. Subgroup analyses were conducted using mixed-effects models, while random-effects or fixed-effects models were used to estimate average treatment differences across studies.

Results: Based on 34 studies involving 1031 adults, acupuncture techniques significantly enhanced CSE. EA had a greater impact than MA, with effect sizes of 0.53 mV vs 0.43 mV (95% confidence interval [CI]: [0.30, 0.76], $P < 0.00001$ vs 95% CI: [0.28, 0.59], $P < 0.00001$). The 5 most frequently used acupoints were LI4 (Hegu, 32 times), ST36 (Zusanli, 10 times), LI11 (Quchi, 7 times), TE5 (Waiguan, 6 times), and GB34 (Yanglingquan, 5 times).

Conclusion: This systematic review indicates that both EA and MA could effectively and safely enhance CSE, bringing the corticospinal pathway closer to the threshold for firing, which may ultimately improve motor function. LI4, ST36, LI11, TE5 and GB34 are the most commonly used acupoints.

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* Corresponding author.

E-mail address: renming.liu@monash.edu (R. Liu).

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1. Introduction

Acupuncture therapy is an essential part of traditional Chinese medicine (TCM), with a history spanning thousands of years [1]. It involves the insertion of acupuncture needles into acupoints to treat diseases and symptoms [2]. A few studies have demonstrated that acupuncture can trigger neuroplastic changes within the brain, specifically modulating the connectivity and functionality of regions associated with motor function [3–5]. Acupuncture at different acupoints could activate different brain regions which are related to the acupoints' specific effects or acupoints' functions [6]. With progress in medical and scientific fields and other technological advancements, manual acupuncture (MA) has been integrated into modern medical systems. This integration has been accompanied by the evolution of new acupuncture techniques, such as electroacupuncture (EA) and laser acupuncture. These techniques maintain the core principles of tradition but offer different approaches to the advancement of physical rehabilitation, especially in the area of motor rehabilitation.

Motor function is intricately linked to brain excitability [7]. Modulations in relevant sensory, motor and cognitive cortices, especially the primary motor cortex (M1), are crucial for motor functions, significantly affecting how motor skills are performed. This not only involves direct control and precision of movements but also extends to the cognitive processes behind acquiring and adapting to the new motor skills [8,9]. The M1 excitability in general, or corticospinal excitability (CSE), exerts varying effects on movement in different contexts [10]. Changes in CSE can directly influence motor functions by altering the neural control of muscle activation and coordination. CSE may lead to enhanced muscle recruitment and stronger contractions [11], while decreased CSE can result in reduced muscle strength [12]. Also, in neurological injuries or diseases, CSE changes can affect motor recovery. Modulating CSE through interventions such as acupuncture can influence the rate and extent of motor recovery following injury [13–15]. Therefore, enhancing CSE contributes to improved motor performance and accelerated skill acquisition [16]. Maintaining an

appropriate level of excitability in the M1 is crucial for improving motor functions [17]. In this context, acupuncture therapies help to enhance the excitability of the brain's motor context by stimulating peripheral nerves and transmitting signals to the central nervous system.

Transcranial magnetic stimulation (TMS), a non-invasive assessment tool, is essential for quantifying M1 excitability and functions by eliciting motor-evoked potentials (MEPs) and enabling evaluation of CSE and corticocortical excitability [18]. Larger MEP amplitudes indicate greater excitability in the corticospinal tract, suggesting enhanced brain-to-muscle communication and motor function [19]. Factors influencing CSE include non-invasive brain stimulation, motor or cognitive tasks, mental state, and acupuncture therapies.

Acupuncture therapies have been widely adopted in clinical settings for motor rehabilitation, with their efficacy underscored by numerous clinical trials [20–22]. However, systematic studies comparing the effect of different acupuncture techniques on motor recovery are limited, especially regarding the most effective approaches for specific muscle groups. Specifically, it remains unclear which kind of acupuncture technique is most effective for enhancing the recovery of motor functions in specific muscle groups. Moreover, research focusing on motor-related acupoints and studies using TMS to assess the effects of acupuncture are relatively scarce. Based on this context, systematically summarizing and analyzing all relevant evidence to evaluate and compare the effect sizes of acupuncture therapies across studies is crucial for understanding and evaluating their application in motor rehabilitation. This study uses the existing literature on the efficacy and safety of EA and MA techniques on CSE to (1) evaluate their impact on CSE, (2) explore their safety, (3) identify commonly used meridians acupoints, and (4) address gaps in the current literature to improve motor rehabilitation strategies.

This systematic review and meta-analysis focus on EA and MA due to their widespread clinical use and strong research support. Their prevalence and extensive literature make them ideal candidates for rigorous analysis. Additionally, their invasive nature

and elicitation of pain suggest a shared mechanism underlying their therapeutic effects. This allows for a comprehensive evaluation of their efficacy, safety, and impact on brain excitability and motor function. By examining the effects of EA and MA on CSE, this study provides insights into their role in motor rehabilitation, highlighting their advantages and limitations within medical practice.

2. Methods

2.1. Study protocol and registration

The recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline were followed [23]. This study has been preregistered in the International Prospective Register for Systematic Reviews (registration number: CRD42023495803).

2.2. Search strategies

A comprehensive literature search was conducted across 9 databases and grey literature (produced outside of traditional publishing and academic channels like theses) to identify studies relevant to the investigation of acupuncture’s effects on motor function and also used TMS. The databases included 5 English-language sources: the Allied and Complementary Medicine Database, the Cochrane Library, Web of Science, PubMed, and Embase, and 4 Chinese-language sources, including the China National Knowledge Infrastructure, China Biology Medicine, VIP for Chinese Journal Service Platform, and Wanfang Database. The search covered the period from the inception of each database until August 2024. The search strategy consisted of three principal components: clinical condition (brain excitability and corticospinal excitability), intervention (MA and EA), and study design (randomized and non-randomized control trials), as detailed in Table S1. To ensure a thorough and unbiased search, two investigators RL and WL independently conducted the search, employing a diverse set of terms related to “acupuncture therapies,” “brain excitability,” and “transcranial magnetic stimulation.” Notably, special acupuncture methods based on the holographic theory or microsystem acupuncture theory, such as Yamamoto scalp acupuncture, ocular acupuncture, auricular acupuncture, were not included in this study.

Additionally, the research team extended their search to include references from pertinent reviews and systematic reviews to uncover potentially eligible studies that might have been missed in the initial database search.

Criteria developed for including and excluding studies returned by the database searches used the Population, Intervention, Comparison, Outcome, and Study Design framework (Table 1) [24]. Criteria for excluding studies were: (1) duplicated studies; (2) data that could not be converted into mean and standard deviation; (3) papers that lacked detailed results or whose full text was not

Table 1
Eligibility criteria of studies are based on the PICOS framework.

Parameter	Inclusion criteria
Population	Healthy or diseased subjects aged more than 18 years old
Intervention	Manual acupuncture or electroacupuncture
Comparison	Placebo or no treatment or the combination of other therapies with acupuncture therapies
Outcome	Peak-to-peak amplitude of transcranial magnetic stimulation-evoked motor-evoked potential
Study design	Randomized and non-randomized controlled trials

PICOS: Population, Intervention, Comparison, Outcome, and Study design.

available; (4) review papers, case reports, special communications, letters to the editor, invited commentaries and conference papers.

2.3. Data extraction

The data extraction process for this meta-analysis was divided into two principal stages. In the initial stage, two researchers (RL and WL) independently conducted a preliminary literature screening using the Rayyan software (<https://rayyan.qcri.org>) [25], based on predefined inclusion criteria and keywords. Literature that both researchers unanimously agreed to retain progressed to the subsequent phase. For the studies with discrepancies, a third researcher (AAKM) was involved in discussions to help decide if the study should be included in the final analysis.

In the second stage, the screening was subjected to detailed data extraction by two independent researchers (RL and WL), to ensure the completeness and accuracy of information. The extracted data included the first author’s name, year of publication, study design, characteristics, sample sizes of intervention and control groups, type of intervention, type of control, selected acupoints, adverse events, and MEP amplitude (peak-to-peak). All data were organized and recorded using table forms.

Data were directly extracted when MEPs were reported as means and standard deviations. If data were presented as medians and interquartile ranges, medians were used as estimates for means, and standard deviations were estimated by dividing the interquartile range by 1.35 [26]. When data were presented in graphical form, the Plot Digitizer software was used to estimate values [27]. For studies missing essential data, attempts were made to contact the corresponding authors via email to obtain the information.

2.4. Data synthesis and analysis

A meta-analysis was conducted using RevMan 5.4.1 software (<https://revman.cochrane.org>) to compare the effectiveness of the different interventions on MEPs.

A random-effects meta-analysis was conducted to quantify the effect of acupuncture techniques on the amplitude of MEPs, utilizing mean difference (MD) and standardized mean difference (SMD) as the primary measurement tool. This approach may help to mitigate the impact of systematic influences and random errors across the collected studies. For clarity and precision in our findings, all SMD values were presented with their 95% confidence intervals (CIs). The SMD values were classified to indicate small (0.20–0.49), medium (0.50–0.79) and large (greater than 0.80) effect sizes [28]. In evaluating the impact of acupuncture treatments on MEPs, we centered on the use of SMD and MD along with 95% CIs, which was based on the consistency of the data and the uniformity of the measurement methodologies employed across studies.

To manage heterogeneity across studies, we used the I^2 statistic along with the Chi-squared test. This statistic helps identify the extent of variability among study findings that is due to differences beyond chance alone. The thresholds of 25%, 50% and 75% indicated low, moderate and high heterogeneity, respectively [29]. We opted for a fixed-effect model when heterogeneity was minimal to moderate ($I^2 \leq 50\%$ and $P \geq 0.1$). Statistical effects were considered to be significant at a P value of <0.05 across all tests. Z test is also used to assess the difference between the two groups.

2.5. Risk of bias and quality of evidence

The assessments were conducted independently by two reviewers, RL and WL. Any differences between their evaluations were settled through discussion or, if necessary, by consulting a third reviewer (AAKM). The studies selected for meta-analysis under-

went a thorough examination for potential biases using the Cochrane Collaboration’s Risk-of-Bias Tool (version 1) [30]. This evaluation considered seven specific domains that directly correlate with various types of biases. These domains include sequence generation, allocation concealment, blinding of participants, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other sources of bias, with each study receiving a designation of low, high or unclear risk across these categories.

3. Results

3.1. Literature search and study characteristics

The PRISMA flow diagram (Fig. 1) illustrates the steps employed for identifying, screening and assessing the eligibility of studies for inclusion. An initial comprehensive search across multiple databases revealed a total of 3284 studies. Subsequently, adhering to predetermined eligibility criteria, 34 studies were selected for inclusion in the meta-analysis including 15 studies from grey literature.

The collective sample size of these studies amounted to 1031 subjects, comprising 490 healthy individuals (aged between 18 and 65) and 541 patients with neurological disorders (aged between 23 and 65); in each study participants were divided into intervention and comparison groups. The publication years of these studies span from 2003 to 2024, with a notable observation that 31 out of the 34 studies (90%) were published between 2013

and 2024. Twenty-one of the 34 studies (62%) investigated the effects of EA, whereas the remaining 13 studies (38%) investigated MA. Detailed characteristics of the included studies are presented in Tables 2 and 3. Given that some studies examined multiple muscle groups, we eventually divided the initial set of 34 studies into 45 distinct studies for focused analysis. Among the selected publications, 37 studies evaluated the musculature of the upper limb (Table 2), including the first dorsal interosseous, abductor pollicis brevis, adductor digiti minimi, and flexor carpi radialis muscles.

Additionally, two studies [59,60] concentrated on the lower limb muscles, and 8 studies [31,42,45,56,57,61–63] investigated the muscles of the head and neck, encompassing the orbicularis oculi, geniohyoid muscle, mylohyoid muscle, and pharyngeal muscles (Table 3).

When considering all available studies, the 5 most frequently employed acupoints were LI4 (Hegu, 32 times), ST36 (Zusanli, 10 times), LI11 (Quchi, 7 times), TE5 (Waiguan, 6 times) and GB34 (Yanglingquan, 5 times). When the analysis was restricted to studies of the upper limb, the acupoints LI4 (26 times), LI11 (7 times), ST36 (7 times), TE5 (6 times) and LI10 (4 times) were the most frequently used acupoints. Conversely, the exploration of the lower limb reveals a predominant use of meridians (Du Meridian 1 time and Stomach Meridian 1 time).

3.2. Adverse events

Adverse events in the included studies are presented in Table S2. Among the studies, 47% (16 out of 34 studies) reported data related

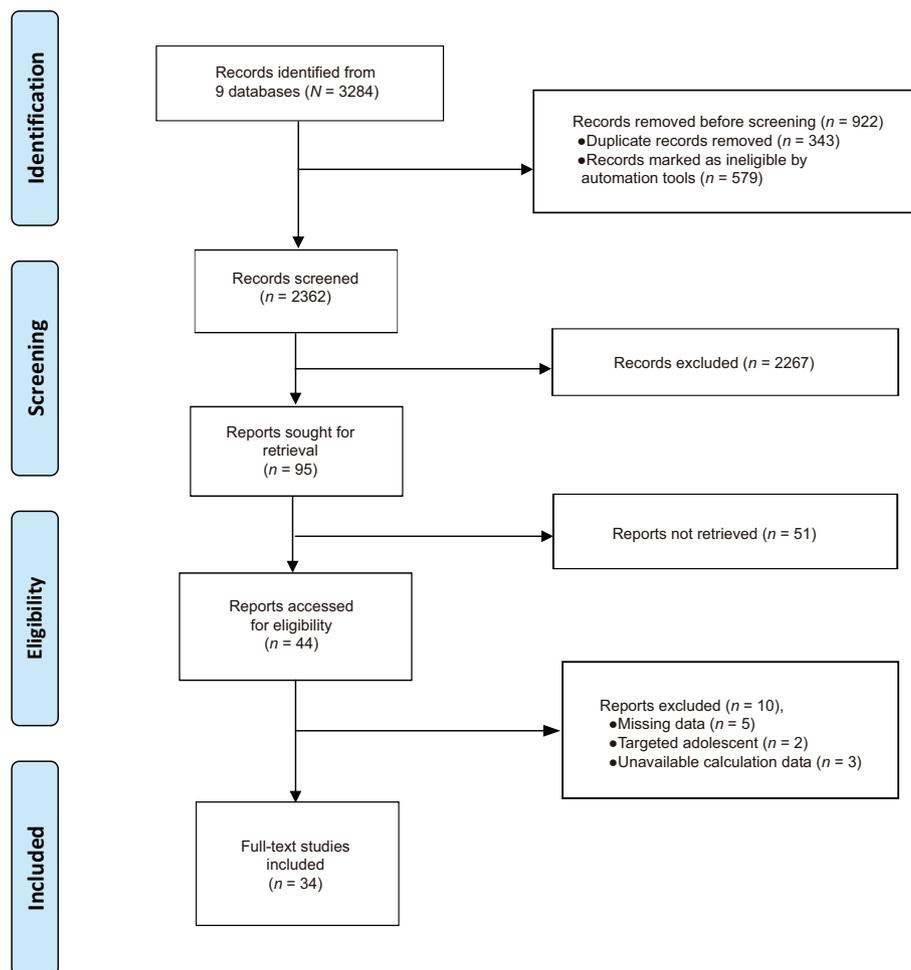


Fig. 1. Flowchart of the study selection using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines.

Table 2
The effects of acupuncture on CSE: upper limb muscles.

Author and year	Study design	Total participants	Intervention(s)	Comparison	Target muscle	Acupoint(s)	CSE
Healthy subjects							
Lin 2024 [31]	Crossover design	20	EA	MT	First dorsal interosseous	LI4	↑
Xie 2023 [32]	Crossover design	15	1. EA once; 2. EA twice within 1 day; 3. EA twice on alternative days	Baseline	First dorsal interosseous	LI4	1. ↑; 2. ↑; 3. ↑
Cheng 2023 [33]	Crossover design	15	1. EA LI4; 2. EA LU6	Sham acupoint	First dorsal interosseous	LI4 and LU6	1. ↑; 2. ↑
Zou 2022 [34]	Crossover design	20	EA	EA + rTMS	First dorsal interosseous	LI4	↑
Liang 2022 [35]	Crossover design	20	EA	Sham needle	First dorsal interosseous	LI4	↑
Xu 2022 [36]	RCT	80	1. 2 Hz EA; 2. 50 Hz EA; 3. 100 Hz EA	Streibberger needle	Abductor pollicis brevis	LI11, LI4, ST36 and ST42	1. ↑; 2. ↑; 3. ↑
Li 2021 [37]	Crossover design	25	EA	Baseline	First dorsal interosseous	LI4	↑
Sun 2020 [38]	RCT	18	MA	Baseline	First dorsal interosseous	LI11 and TE5	↑
Peng 2020 [39]	Crossover design	20	EA	Sham needle	First dorsal interosseous	TE5	↑
Zhong 2020 [40]	Crossover design	10	EA	Sham point	First dorsal interosseous	LI4	↑
Li 2019 [41]	Crossover design	17	EA	Baseline	First dorsal interosseous	LI4	↑
He 2019 [42]	Crossover design	18	MA	Sham needle	First dorsal interosseous	LI11 and TE5	↑
He 2019 [43]	Crossover design	22	EA	Sham needle	First dorsal interosseous	LI4 and ST2	↑
Alana 2019 [44]	Crossover design	10	MA	Sham needle	First dorsal interosseous	LI4	–
Sun 2019 [45]	Crossover design	20	MA	Sham point	First dorsal interosseous	ST36	↑
Yang 2017 [46]	Crossover design	10	MA	No stimulation	First dorsal interosseous	LI4, LI10, LI11, TE5, ST36, GB34, SP6 and EX-UE9	↑
Wang 2016 [47]	Crossover design	15	1. 2 Hz EA 5 min; 2. 2 Hz EA 15 min; 3. 2 Hz EA 30 min; 4. 100 Hz EA 5 min; 5. 100 Hz EA 15 min; 6. 100 Hz EA 30 min	Baseline	Abductor pollicis brevis	DU16 and RN23	↑
Lin 2014 [48]	Crossover design	10	EA	Baseline	First dorsal interosseous	ST6 and LI4	↓
Maioli 2006 [49]	Crossover design	15	1. MA LI4; 2. MA ST38	Sham point	First dorsal interosseous	LI4 and ST38	1. ↑; 2. ↑
Yew 2005 [50]	Crossover design	8	1. MA 5 min; 2. MA 10 min; 3. MA 15 min	Sham point	First dorsal interosseous	LI10	1. –; 2. ↑; 3. ↑
Yew 2003 [51]	Crossover design	9	MA	Sham point	Adductor digiti minimi	LI4	↓
Patients with clinical conditions							
Yan 2023 [52]	RCT of comorbid depression and insomnia	60	EA	Sham needle	First dorsal interosseous	GV20, EX-HN3, LR3, LI4, BL62, KI6, CV12, CV10, CV6 and CV4	↑
Lei 2023 [53]	RCT of stroke	62	Regular acupoints + Jiaji point + MT	Regular acupoints + MT	Abductor pollicis brevis	Jiaji point, LI5, LI11, LI10, TE5, LI4, GB34, ST36, GB30, GB31, BL40 and LR3	↑
Li 2022 [54]	RCT of chronic fatigue syndrome	72	EA	Sham point	First dorsal interosseous	BL13, BL15, BL18, BL20 and BL23	↑
Li 2021 [55]	RCT of stroke	32	1. MA MEP(+); 2. MA MEP(–)	Sham point	First dorsal interosseous	LI11, LI4, PC6, ST36, GB34 and SP6	1. ↑; 2. ↑
Li 2020 [56]	Crossover design of postparalytic facial syndrome	60	1. EA LI4; 2. EA regular acupoints	Sham needle	First dorsal interosseous	ST4, ST6, LI20, EX-HN5, GB14 and LI4	1. ↑; 2. ↑
Zhao 2016 [57]	Crossover design of peripheral facial paralysis	20	EA	Baseline	First dorsal interosseous	LI4	↑
Jun 2016 [58]	Crossover design of chronic disorders of consciousness	14	MA	No treatments	Abductor pollicis brevis	GV26, EX-HN3, LI4 and ST36	↑

CSE: corticospinal excitability; EA: electroacupuncture; MA: manual acupuncture; MEP: motor-evoked potential; MT: motor training; RCT: randomized control trial; rTMS: repetitive transcranial magnetic stimulation; ↑: increase; ↓: decrease; –: not significant; (+): participants who can elicit the maximum amplitude of MEP under high-intensity TMS; (–): participants who are unable to elicit MEP even at the maximum stimulation intensity of the TMS.

Table 3
The effects of acupuncture on CSE: studies of other muscles.

Author and year	Study design	Total participants	Intervention(s)	Comparison	Acupoint(s)	CSE
Tibialis anterior Niu 2022 [59]	Crossover design	90, incomplete spinal cord injury	1. EA; 2. EA + MT	MT	DU14 and DU4	1. ↑ 2. ↑
Li 2016 [60]	RCT	21, healthy subjects	EA	No stimulation	ST36 and ST39	–
Mylohyoid muscle Tang 2022 [61]	RCT	40, healthy subjects	EA	Streitberger needle	CV23 and GV16	↑
Pharyngeal muscle Wang 2016 [47]	Crossover design	15, healthy subjects	1. 2 Hz EA 5 min; 2. 2 Hz EA 15 min; 3. 2 Hz EA 30 min; 4. 100 Hz EA 5 min; 5. 100 Hz EA 15 min; 6. 100 Hz EA 30 min	Baseline	DU16 and RN23	1. ↑; 2. ↑; 3. ↑; 4. ↑; 5. ↑; 6. ↑
Yang 2016 [62]	Crossover design	15, healthy subjects	EA	Baseline	DU16 and RN23	↑
Geniohyoid muscle Wang 2019 [63]	RCT	59, stroke	MA	MT	GV20, EX-HN5, BL37, BL38, GB33, GB34, ST36, ST38 and LR3	↑
Anal external sphincter Zhang 2015 [64]	Crossover design	30, functional defecation disorders	MA	Baseline	ST25, CV6, ST37, ST36, GV20, BL33, BL54, BL25, BL23, BL20 and GV11	↓
Orbicularis oculi Zhong 2020 [40]	Crossover design	10, healthy subjects	EA	Sham point	LI4	↓
Li 2020 [56]	Crossover design	60, post-paralytic facial syndrome	1. EA LI4; 2. EA regular acupoints	Sham needle	ST4, ST6, LI20, EX-HN5, GB14 and LI4	1. ↓; 2. ↓
He 2019 [43]	Crossover design	22, healthy subjects	EA	Sham needle	LI4 and ST2	↓
Zhao 2016 [57]	Crossover design	20, healthy subjects	MA	Baseline	LI4	↓
Lin 2014 [48]	Crossover design	10, healthy subjects	EA	Baseline	ST6 and LI4	↓

CSE: corticospinal excitability; EA: electroacupuncture; MA: manual acupuncture; MT: motor training; RCT: randomized control trial; ↑: increase; ↓: decrease; –: not significant.

to adverse events [31,36,39,42–45,47,48,52,53,55,58,61–63]. One study [55] documented mild reactions including subcutaneous bleeding and hematoma following acupuncture, while no adverse events were documented in the other 15 studies. The remaining studies examined in our meta-analysis and systematic review did not provide any information on adverse events. These findings suggest the favorable safety profile of acupuncture in CSE treatment.

3.3. Risk of bias and quality of evidence

The risk of bias assessments are shown in Table 4. Most trials (30/34, 88%) were at risk for bias for at least one domain. Twenty-four studies (70%) adequately documented how allocation randomization was achieved, and 16 (48%) did not have sufficient information on allocation. Regarding blinding of participants and outcome assessment, only three studies were noted to have a high risk of bias. Yet, several studies provided unclear reporting of the blinding process or failed to describe it. Most trials (32/34, 94%) were ranked as having a low risk of bias due to missing or incomplete outcome data. Lastly, nearly all studies have reported the outcome data addressed and provided a low risk of bias within the selective reporting domain.

3.4. Meta-analysis results

3.4.1. Effects of EA for CSE

Our meta-analysis indicated a positive effect of EA in enhancing CSE, with a mean MEP of 0.53 ($I^2 = 0\%$, $P < 0.00001$), suggesting that EA may contribute to increased CSE across studies (Fig. 2). Specifically, the analysis also showed a positive effect of EA in enhancing CSE in individuals with pathological conditions, with a mean MEP

of 0.56 ($I^2 = 37\%$, $P = 0.002$). Furthermore, EA was found to enhance CSE in healthy individuals, with a mean MEP of 0.51 ($I^2 = 0\%$, $P = 0.0008$). The Chi^2 test for subgroup differences yielded a value of 0.05 ($df = 1$, $P = 0.83$, $I^2 = 0\%$), suggesting no statistically significant difference in effect sizes between the subgroups.

3.4.2. The effects of MA for CSE

Our meta-analysis indicated a positive effect of MA in enhancing CSE in individuals with different clinical conditions, with mean MEPs of 0.43 ($I^2 = 23\%$, $P < 0.00001$). Specifically, a positive effect of MA in enhancing CSE in individuals with pathological conditions, with mean MEPs of 0.43 ($I^2 = 46\%$, $P < 0.0001$) was observed (Fig. 3). Furthermore, the results showed that MA could also enhance CSE in healthy individuals with mean MEPs of 0.44 ($I^2 = 8\%$, $P = 0.0002$). The Chi^2 for subgroup differences is 0.01 ($df = 1$, $P = 0.94$, and $I^2 = 0\%$), suggesting that there was no statistically significant difference in effect size between the pathology and healthy subgroups.

3.4.3. The effects of acupuncture techniques on different muscle groups

Furthermore, acupuncture's influence on the upper limb's CSE manifested a statistically significant improvement over the control group ($P < 0.0001$). The effect size calculated to be 0.52, with a 95% CI of [0.29, 0.75]. A moderate level of heterogeneity ($I^2 = 71\%$) was observed. Conversely, for lower limb assessments, the effect size was determined to be 0.47, with a 95% CI of [-1.63, 2.57]. A high level of heterogeneity ($I^2 = 97\%$) was revealed, coupled with a Z test for overall effect yielding a value of 0.44 ($P > 0.05$). As for the muscle group of the head and neck, the effect size was 0.49, with a 95% CI of [-0.28, 1.26]. The test for heterogeneity indicated a high level of heterogeneity ($I^2 = 89\%$, $P > 0.05$) (Fig. 4).

Table 4
Risk of bias assessment for included studies.

Study	Sequence generation	Allocation concealment	Blinding of participants	Blinding of outcome assessment	Incomplete outcome data	Selective outcome reporting	Other bias
Lin 2024 [31]	Low	Low	Unclear	Low	Low	Low	Low
Lei 2023 [53]	Low	Unclear	Unclear	Low	Low	Low	Low
Yan 2023 [52]	Low	Low	Low	Low	Low	Low	Low
Xie 2023 [32]	Low	Unclear	Unclear	Low	Low	Low	Low
Cheng 2023 [33]	Low	Low	Low	Low	Low	Low	Low
Xu 2022 [36]	Low	Low	Low	Low	Low	Low	Low
Niu 2022 [59]	Low	Unclear	Unclear	Low	Low	Low	Low
Zou 2022 [34]	Low	Low	Unclear	Low	Low	Low	Low
Tang 2022 [61]	Low	Low	Low	Low	Low	Low	Low
Li 2022 [54]	Low	Low	High	Low	Low	Low	Low
Liang 2022 [35]	Low	Low	Unclear	Low	Low	Low	Low
Li 2021 [37]	Unclear	Unclear	Unclear	Low	Low	Low	Low
Li 2021 [55]	Low	Low	Low	Low	Low	High	Low
Zhong 2020 [40]	Low	Low	Unclear	Low	Low	Low	Low
Sun 2020 [38]	Low	Unclear	Unclear	Low	Low	Low	Low
Li 2020 [56]	Low	Low	Unclear	Low	Low	Low	Low
Peng 2020 [39]	Low	Low	Unclear	Low	Low	Unclear	Low
Alana 2019 [44]	Unclear	Unclear	Low	Low	Low	Unclear	Low
Wang 2019 [63]	Low	Low	Unclear	Low	Low	Low	Low
He 2019 [42]	Low	Low	Unclear	Unclear	Low	Unclear	Low
He 2019 [43]	Low	Unclear	Unclear	Unclear	Low	Low	Low
Li 2019 [41]	Low	Low	Unclear	Unclear	Low	Low	Low
Sun 2019 [45]	Low	Low	Unclear	Unclear	Low	Low	Low
Yang 2017 [46]	Unclear	Unclear	Unclear	Unclear	Low	Low	Low
Zhao 2016 [57]	Unclear	Unclear	Unclear	Unclear	Low	Low	Low
Yang 2016 [62]	Unclear	Unclear	High	Low	Low	Unclear	Low
Jun 2016 [58]	Unclear	Low	Unclear	Unclear	Low	Low	Low
Li 2016 [60]	Low	Unclear	Unclear	Unclear	Low	Low	Low
Wang 2016 [47]	Unclear	Unclear	High	Low	Low	Low	Low
Zhang 2015 [64]	Unclear	Unclear	Unclear	Unclear	Low	Unclear	Low
Lin 2014 [48]	Unclear	Unclear	Unclear	Unclear	Low	Unclear	Low
Maioli 2006 [49]	Low	Low	Unclear	Unclear	Low	Unclear	Low
Yew 2005 [50]	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Low
Yew 2003 [51]	Low	Unclear	Unclear	Unclear	Unclear	Unclear	Low

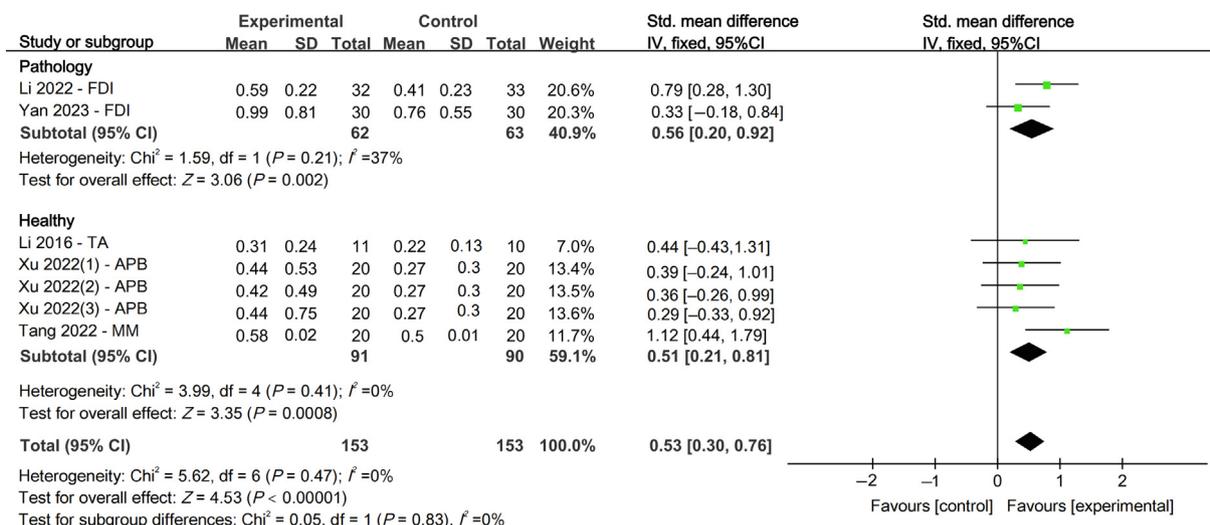


Fig. 2. The forest plot for the effect of EA on CSE. APB: abductor pollicis brevis; CI: confidence interval; CSE: corticospinal excitability; EA: electroacupuncture; ES: effect size; FDI: first dorsal interosseous; MM: mylohyoid muscle; SD: standard deviation; TA: tibialis anterior.

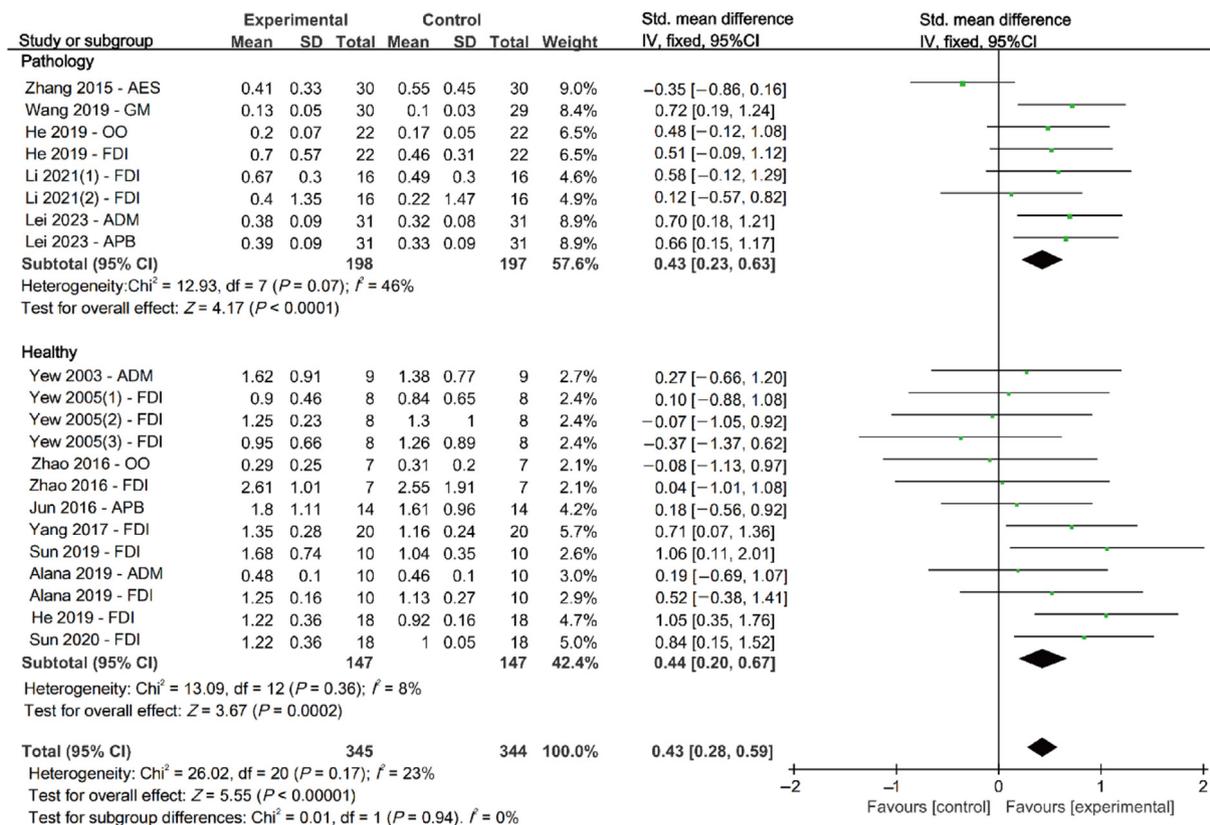


Fig. 3. The forest plot for the effect of MA on CSE. ADM: adductor digiti minimi; AES: anal external sphincter; APB: abductor pollicis brevis; CI: confidence interval; CSE: corticospinal excitability; ES: effect size; FCR: flexor carpi radialis; FDI: first dorsal interosseous; GM: geniohyoid muscle; MA: manual acupuncture; MM: mylohyoid muscle; OO: orbicularis oculi; PM: pharyngeal muscle; SD: standard deviation; TA: tibialis anterior.

3.5. Gaps in the literature

The findings suggest that both MA and EA improve CSE, with EA demonstrating superior effects compared to MA. However, several significant gaps in the literature remain which include: (1) limited exploration of other acupuncture techniques, (2) limited outcome measurements of motor function, (3) limited research on the selection and diversity of acupoints, (4) limited use of TMS in

acupuncture research, and (5) limited research on specific populations.

4. Discussion

The current systematic review and meta-analysis aimed to identify the effects of MA and EA of motor-related acupoints on CSE

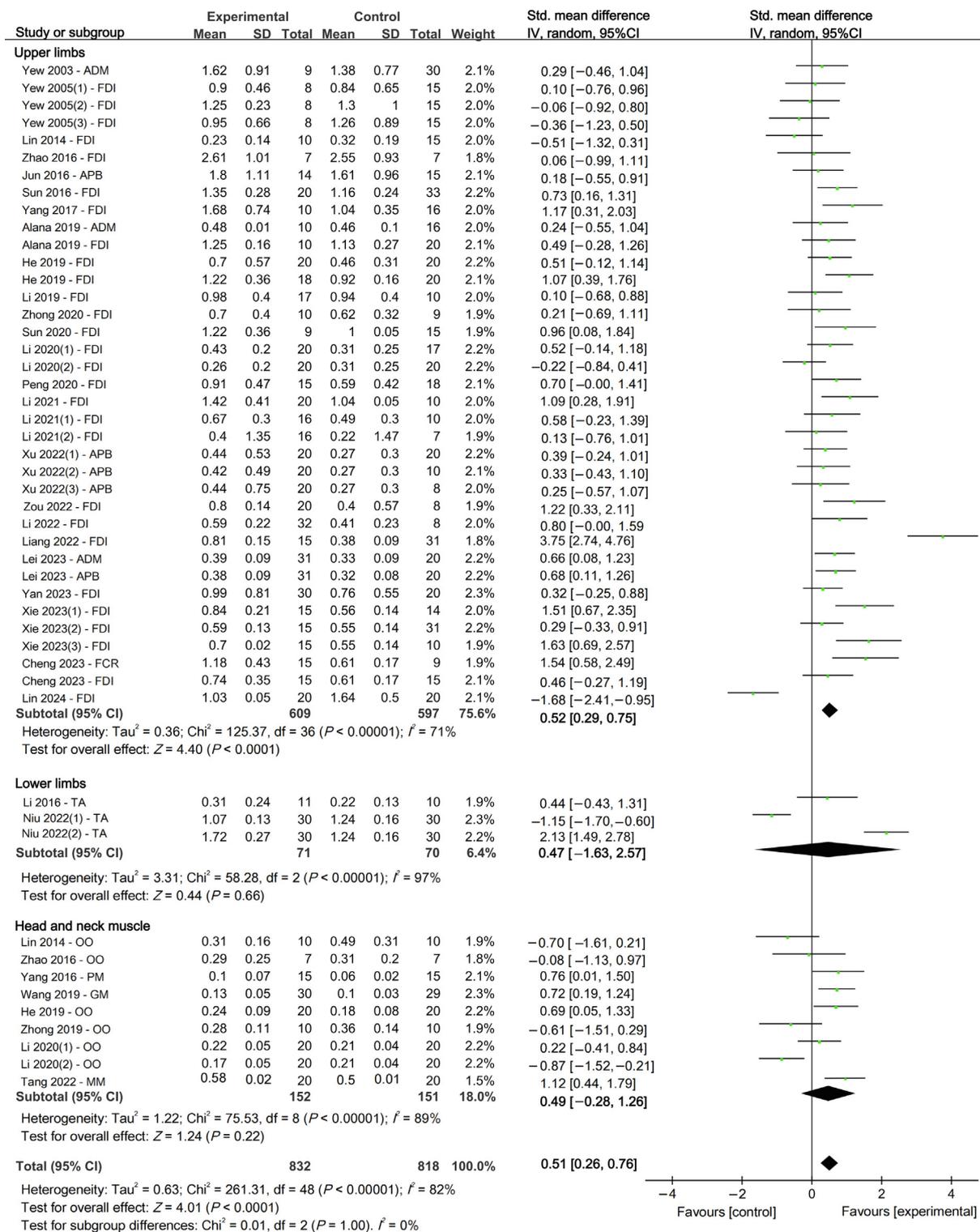


Fig. 4. The forest plot for the effect of EA or MA on CSE across different muscle groups. ADM: adductor digiti minimi; AES: anal external sphincter; APB: abductor pollicis brevis; CI: confidence interval; CSE: corticospinal excitability; EA: electroacupuncture; ES: effect size; FCR: flexor carpi radialis; FDI: first dorsal interosseous; GM: geniohyoid muscle; MA: manual acupuncture; MM: mylohyoid muscle; OO: orbicularis oculi; PM: pharyngeal muscle; SD: standard deviation; TA: tibialis anterior.

and to find the gaps in the literature. The findings suggest that: (1) both MA and EA improve CSE with a low incidence of adverse events; (2) EA demonstrates superior effects compared to MA; (3) the commonly used acupoints for motor rehabilitation include LI4, ST36, LI11, TE5 and GB34; and (4) key gaps in current acupuncture research were identified, emphasizing the need for future studies to explore new techniques, optimize measurement methods, clarify acupoint selection, and incorporate TMS measurements.

EA is an extension of MA; it acts by introducing pulsed electrical currents to acupoints, enhancing stimulation to achieve therapeutic effects [65]. Our results suggest that EA significantly enhances CSE and has superior effects than MA. This superior efficacy can be attributed to the precise control over stimulation parameters that EA offers, such as the inter-pulse interval, intensity, frequency, waveform and pulse duration [66]. This precision allows for accurate adjustment of therapeutic effects, reducing total needling time

for acupuncturists and effectively saving human resources [67]. Unlike MA, where the effectiveness can vary due to the manual skills of the practitioner, EA allows for the standardization of treatment through controlled electrical stimulation.

EA enhances CSE through several mechanisms, including neural modulation and enhanced neural plasticity. The electrical currents used in EA stimulate sensory nerve endings, which transmit signals to the central nervous system. Furthermore, enhanced CSE by EA generally indicates more effective communication between the M1 and target muscles, which is crucial for motor control and strength development. The stimulation of acupoints with EA can impact related neural pathways and thus potentially alter the excitability of the M1 [68,69]. For example, acupuncture may promote or inhibit the release of neurotransmitters (such as serotonin and endorphins), which can modulate neuronal excitability [70]. Long-term acupuncture treatment is believed to enhance neural plasticity, the ability of the nervous system to adjust its structure and function in response to environmental changes or new learning experiences. Furthermore, acupuncture might activate reflex mechanisms at the spinal level, indirectly affecting the activity of motor neurons [71].

EA's ability to provide precise and strong stimulation directly to the nervous system makes it a valuable tool in clinical practice. Conditions such as stroke, spinal cord injuries and Parkinson's disease, where enhancing CSE is beneficial, may particularly benefit from EA treatments.

MA is a traditional technique that involves manual manipulations of acupuncture needles (such as rotation, twirling, lifting and thrusting) to achieve its therapeutic effects. Our systematic review and meta-analysis indicate that MA also enhances CSE. MA can be operator-dependent, and acupuncturists need to apply manipulations on acupoints adequately, so as to achieve therapeutic effects [72]. Consequently, there is a higher chance of variability in treatment effectiveness among different acupuncturists, making it difficult to standardize and replicate treatment outcomes [73].

The mechanical stimulation provided by MA is similar to EA and can also influence neuronal excitability. MA stimulates the tissues in and near acupoints through manipulations of the filiform needle. This generates direct or indirect mechanical forces, which are transmitted as mechanical waves to cells or other receptors, transforming into biochemical signals. These signals then modulate the body's neuro-endocrine-immune network, exerting therapeutic effects [74,75]. Therefore, MA stimulation is fundamentally a mechanical and physical stimulation of acupoints.

Of note, acupuncture-related adverse events reported across all studies were infrequent and mild, further supporting the safety profile of acupuncture therapies in enhancing CSE.

The human body has over 300 acupoints, each with its own therapeutic effects. The selection of different acupoints can influence the outcome of the treatment. Selecting appropriate acupoints is critical for maximizing the therapeutic efficacy of acupuncture interventions, particularly in enhancing their clinical utility for improving motor functions in neurological disorders. Despite its central importance, the identification of the most effective acupoints is an issue of concern and can limit the therapeutic outcomes and broader application of acupuncture. To address this, an analysis was conducted on the frequency of acupoint usage in acupuncture treatments aimed at improving motor function. This analysis revealed that LI4, ST36, LI11, TE5 and GB34 are the most frequently utilized acupoints. These acupoints are associated with the Lung Meridian, Stomach Meridian, Bladder Meridian and Triple Energizer Meridian, all of which are distributed along the limbs of the human body. The predominance of acupoints associated with the upper limbs (LI4, LI11 and TE5) in the present study mirrors the focus of most of the included literature on measuring CSE related to the muscles of the upper limbs. Furthermore, the inclu-

sion of ST36 aligns with TCM practices, particularly the strategy of exclusively utilizing Yangming Meridian acupoints for treating muscle atrophy or weakness. GB34 (Yanglingquan) is acknowledged for its roles in soothing and strengthening the sinews, marking it as a pivotal acupoint in the treatment of muscle weakness and improving motor function, especially in the context of neurological impairments affecting the limbs based on its "Jinhui" function [76,77].

Despite the growing body of evidence supporting the efficacy of EA and MA in enhancing CSE, several critical gaps persist in the literature that still need further investigation. Firstly, to date, there has been little exploration of alternative acupuncture techniques, which may offer different or complementary mechanisms of action. Secondly, there is a lack of direct evidence for measuring motor function. Although there is evidence supporting the relationship between changes in CSE and motor function improvements, specific measurement tools such as the Pegboard or Choice Task remain underutilized, limiting the comprehensiveness of assessing acupuncture's effects. The Pegboard assesses fine motor skills and dexterity, while the Choice Task measures decision-making speed and accuracy, both of which could contribute to evaluating motor and cognitive functions. Thirdly, while certain acupoints are frequently used in clinical practice, the optimal combinations and the specific effects of individual versus combined acupoints are not well defined. Fourthly, there is a need for more studies utilizing TMS measurements, including both single-pulse and paired-pulse TMS, to better understand the cortico-cortical excitatory mechanisms underlying acupuncture's effects on the brain. Addressing these gaps through rigorous, standardized research could significantly advance our understanding of acupuncture's full therapeutic potential and its application in motor function. Lastly, it is also a very important finding that there is a lack of studies that have probed the motor functions to acupuncture therapies in older adults.

There is substantial evidence supporting the relationship between changes in CSE and improvement in motor function. Numerous studies have demonstrated correlations between measures of CSE, such as MEPs elicited by TMS, and various motor outcomes. First, clinical studies in participants with neurological disorders, including stroke, spinal cord injuries or Parkinson's disease, have uncovered the correlations between measures of CSE and the severity of motor impairments or dysfunctional outcomes. Changes in CSE frequently align with improvements in motor function after rehabilitation efforts in these patients, indicating that modulation of CSE is a critical step in improving the quality of life and restoring motor functions in patients with neurological disorders. Secondly, longitudinal studies that track changes in CSE and motor function over time provide further evidence of their relationship. Specifically, studies assessing CSE and motor outcomes before and after rehabilitation interventions or during recovery from neurological injuries often report concurrent changes in both measures [7,78,79]. Lastly, cross-sectional studies investigating the relationship between CSE measures and motor performance in healthy individuals or clinical populations have consistently found correlations between these variables. Overall, the evidence from clinical studies, longitudinal studies and correlational studies collectively supports the notion that changes in CSE are closely linked to improvements in motor function. This relationship underscores the importance of CSE as a biomarker of motor system integrity and responsiveness to interventions in both healthy individuals and clinical populations with motor impairments.

This study has some limitations which need to be considered when interpreting the main findings. First, some of the included studies have a high risk of bias in several domains (e.g., selective outcome reporting and blinding), which may lead to overestimation of the effects. Second, the parameters of EA and MA varied among the included studies, which need further investigation

and classification. Third, most studies had small sample sizes, and large-scale, multi-center randomized controlled trials are needed to reinforce the data. Moreover, methodological limitations such as body region studied or different types of muscle need to be considered for the underlying neural mechanisms.

Our results suggest some areas for future research. Firstly, future studies should focus more on TMS-based measurements (not only single-pulse TMS but also paired-pulse TMS) which could help to explain the underlying corticospinal excitatory mechanisms. By addressing these research gaps, studies will be able to provide a comprehensive understanding of the corticospinal-motoneuronal responses to acupuncture in adults.

Secondly, future studies should focus on investigating acupuncture instrument parameters, exploring the functions of acupoints (including studies on single acupoints versus combination acupoints, as well as local versus distal effects). In addition to traditional acupuncture and EA, it is essential to identify and study additional types of acupuncture instruments, such as laser acupuncture.

To our knowledge, this is the first meta-analysis to combine existing literature on the effect of acupuncture interventions in improving CSE in both healthy and diseased adults. Our results can be generalized since we included 34 studies from different countries with different types of participants, like healthy subjects and diseased subjects. Furthermore, our study provides reliable and high-quality evidence that acupuncture is effective and safe as a complementary and alternative intervention. It shows potential advantages in specific research applications such as enhancing motor function and reducing spasticity [31,63].

5. Conclusion

This systematic review provides a comprehensive quantitative assessment of the impact of acupuncture therapies on CSE in adults. The analysis demonstrated that both EA and MA could enhance CSE in healthy individuals as well as those with clinical conditions. Notably, EA showed a greater effect in CSE enhancement compared to MA. LI4 (Hegu), ST36 (Zusanli), LI11 (Quchi), TE5 (Waiguan) and GB34 (Yanglingquan) were identified as the most frequently utilized acupoints for CSE enhancement. Additionally, the assessment of adverse events confirmed that acupuncture therapies were generally well tolerated, supporting their safe application across healthy and clinical populations. Based on existing evidence, there is a need for further investigation into alternative acupuncture techniques, single-pulse and paired-pulse TMS measurements, specific motor function measurement tools, clarifying acupoint selection, and researching high-risk populations.

CRedit authorship contribution statement

RL contributed to conceptualization, data curation, formal analysis, investigation, methodology, writing original draft, and review & editing. **AAKM** contributed to supervision, and review & editing. **WL** contributed to data curation and methodology. **MZ** contributed to supervision, and review & editing. **SJ** contributed to conceptualization, formal analysis, methodology, supervision, and review & editing. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary material to this article can be found online at <https://doi.org/10.1016/j.joim.2025.02.004>.

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