Jiang et al. BMC Neurology (2025) 25:24
https://doi.org/10.1186/s12883-025-04035-5

BMC Neurology

SYSTEMATIC REVIEW

Open Access

Comparing the effectiveness of different exercise interventions on quality of life in stroke patients: a randomized controlled network meta-analysis

Liqun Jiang[1], Huimin Ding[1], Qishuai Ma[1], Shang Gao[1], Xinxin Zhang[1] and Buongo Chun[1*]

Abstract

Background This study evaluates the comprehensive impact of different exercise interventions on the quality of life in stroke patients through network meta-analysis, aiming to provide scientific evidence for developing more effective rehabilitation programs and improving patients' physical, psychological, and social functions.

Methods This systematic review, registered in PROSPERO (CRD42024541517) and following PRISMA guidelines, searched multiple databases (PubMed, Web of Science, EMbase, Cochrane, Ebsco) until November 1, 2024. Studies were selected based on the PICOS criteria, including RCTs on stroke and exercise. Methodological quality was assessed using RoB 2. Data analysis involved effect size calculations and network meta-analysis in Stata 17.0, with publication bias detected via funnel plots.

Results This meta-analysis included 41 studies (2,578 stroke patients) from 15 countries, published between 2002 and 2024. Participants aged 50–70 underwent interventions lasting 3 weeks to 6 months. DTOT (Dual-task oriented training)was most effective for Quality of Life, Mental Health, and Upper Limb Function; AQE (Aquatic Exercise) for Physical Health and Social Participation; ST(Strength Training) for Pain and Vitality; CIT(Constraint-Induced Therapy) for Mobility and Recovery; BCT for Memory and Thinking; ALCE(Aquatic and Land Combined Exercise) for Emotion and ADL; and ULT(Upper Limb Training) for Communication. No significant publication bias was found.

Conclusion This study indicates that different training methods have a significant impact on various dimensions of quality of life in stroke patients. Future research should focus on personalized rehabilitation programs, considering individual differences among patients, and explore multimodal integrated interventions to optimize outcomes. Long-term follow-up and outcome assessments should be strengthened to ensure the sustainability of interventions. Additionally, integrating mental health and social participation is essential to enhance overall quality of life. Emerging technologies such as VR, AI, and wearable devices can help optimize rehabilitation training. Interdisciplinary collaboration combining neuroscience, rehabilitation science, and psychology can provide more comprehensive rehabilitation solutions.

*Correspondence:
Buongo Chun
tianbingwu@mju.ac.kr

Full list of author information is available at the end of the article

Keywords Stroke, Exercise intervention, Quality of life, Network meta-analysis, Rehabilitation, Physical health, Mental health, Functional recovery, Patient outcomes

Introduction

Cerebrovascular diseases are caused by changes in the intracranial or extracranial blood vessels (arteries or veins) [1]. Stroke is the most common cerebrovascular disease. A stroke can be triggered when the arteries supplying the brain are blocked or ruptured [2]. Quality of life is a multidimensional concept, encompassing physical health, material health, social health, emotional health, and development and activities. It takes into account both objective and subjective indicators, as well as personal values, emphasizing the impact of individual differences [3]. Stroke patients often face a range of functional impairments, including limb paralysis, speech difficulties, and cognitive decline [4–6], These issues severely limit the patients' ability to perform daily activities [7]. At the same time, many patients experience emotional problems such as depression, anxiety, and emotional instability [8–10], further impacting their mental health. Due to functional impairments, many patients have to rely on others for care, losing their independence. This not only increases the burden on families and society but also exacerbates the psychological stress on patients [11]. Moreover, the high costs of long-term rehabilitation therapy place significant financial pressure on many families [12], while inadequate social support makes it difficult for patients to return to normal life [13]. Under the influence of these multiple factors, the quality of life of stroke patients significantly declines, with their physical, psychological, and social functioning severely affected.

Enhancing the quality of life for stroke patients is a key goal in promoting their health recovery and reducing the burden on healthcare systems. Current interventions, including pharmacological treatment, physical rehabilitation, and psychological therapy, can alleviate functional impairments and psychological stress caused by post-stroke sequelae to a certain extent [14–17]. Among these, exercise rehabilitation has emerged as a vital approach due to its benefits in improving overall health, boosting confidence, and promoting social participation, thereby significantly enhancing patients' quality of life [18] Traditional exercise rehabilitation focuses on precise restoration of impaired functions through systematic physical activities, helping patients overcome physical disabilities. However, with advancements in rehabilitation medicine, an increasing number of studies have highlighted the unique advantages of diverse exercise forms in improving patients' quality of life. Unlike traditional rehabilitation, other types of exercise interventions have demonstrated more pronounced effects in addressing functional impairments and improving life quality for stroke patients. For instance, aerobic walking has been shown to improve the quality of life and endurance of chronic stroke patients more effectively than routine massage therapy [19] ; strength training significantly enhances upper limb motor function and mobility in stroke patients [20] aquatic exercises are superior to conventional land-based physical therapy in improving mood and quality of life [21] ; and traditional Chinese exercises, such as Tai Chi and Baduanjin Qigong, exhibit remarkable benefits in enhancing aerobic endurance and reducing fall risks [22]. These diverse exercise modalities not only enhance cardiorespiratory endurance, flexibility, and balance but also help alleviate psychological issues, improve social participation, and reduce pain and other discomforts. Based on these findings, diverse exercise interventions are recognized as an essential strategy for improving the overall health and quality of life of stroke patients.

Although numerous studies have focused on the effects of individual exercise interventions on stroke patients, comprehensive comparisons among various exercise modalities remain relatively scarce. Network meta-analysis, an advanced statistical method, allows for the integration of multiple studies and the simultaneous comparison of various interventions across multiple outcome variables. For example, research by Anjos et al. demonstrated that high-intensity interval training was more effective than continuous aerobic training in improving patients' cardiorespiratory fitness, balance, and gait speed [23]. Domínguez-Téllez et al. found that game-based virtual reality interventions significantly enhanced upper limb motor function and quality of life [24]. A meta-analysis by Saquetto et al. revealed that aquatic exercises improved muscle strength, balance, aerobic endurance, and quality of life [25]. Similarly, Yi et al. reported that Qigong exercises positively impacted activities of daily living (ADL), neurological function, and quality of life [26].

However, most existing studies focus on the effects of a single exercise modality on quality of life or specific outcomes, lacking comprehensive comparisons across different interventions. For instance, Zhang et al. compared anaerobic exercises, resistance training, flexibility exercises, and multi-component exercises with traditional controls. They found that task-oriented exercise programs were most effective in improving social participation, while home-based mixed exercise interventions excelled in enhancing social engagement [27]. Yet, systematic research evaluating multiple exercise interventions remains limited, particularly in terms of outcome assessments, which often fail to comprehensively reflect the overall impact of different exercise modalities on stroke patients' quality of life.By employing network meta-analysis, which integrates data from various studies, it is possible to more comprehensively evaluate the effects of diverse exercise interventions. This approach can provide robust scientific evidence for developing more effective rehabilitation strategies.

Materials and methods

Study design and protocol registration

This systematic review was conducted in accordance with the recommendations of the Preferred Reporting Initiative for Systematic Reviews and Meta-Analyzes (PRISMA) [28]. The study was registered in the International Prospective Systematic Evaluation Registry (PROSPERO) in 2024 (CRD42024541517) and a detailed, pre-specified protocol is available on request.

Literature retrieval

From the inception of the databases to November 1, 2024, a search was conducted across four databases—PubMed, Web of Science, EMbase, and The Cochrane Library, as well as Ebsco—using a combination of subject terms (e.g., Stroke, Exercise, Quality of Life, randomized controlled trial) and free-text terms (e.g., Strokes, Cerebrovascular Accident, Physical Activity, Aerobic exercise, Aquatic Therapy, Taiji, controlled clinical trial, RCT, etc.). The detailed search strategy is provided in Appendix 3, specifically in Table S3.1–Table S3.5.

Eligibility criteria

Inclusion Criteria: Literature was included strictly based on the PICOS framework: P (Population): Participants aged over 18 years, clinically and neuroradiologically (via CT or MRI) diagnosed with stroke.I (Intervention): Any form of exercise intervention.C (Comparison): Comparison of the effects between different types of exercise interventions.O (Outcomes): Outcome measures focused on quality of life.S (Study Design): Randomized controlled trials (RCTs).

Exclusion Criteria:1.Studies where both the experimental and control groups received the same type of intervention.2.Reviews, case reports, study protocols, or conference abstracts.3.Duplicate publications, studies without accessible full texts, or studies with incomplete data.

Data extraction

Two researchers independently performed literature screening and data extraction, ensuring consistency through cross-checking. Discrepancies were resolved through mutual consultation. The literature screening process involved an initial exclusion of irrelevant studies based on titles and abstracts, followed by a thorough review of the full text to determine eligibility according to inclusion criteria. The extracted data included key information such as: the first author's name, the country and year of the study, basic characteristics of participants (e.g., age, gender, type of stroke), sample sizes in the experimental and control groups, frequency and duration of interventions, intervention measures for both experimental and control groups, outcome indicators, and result data.

Risk of bias

This study used the standards from the Cochrane Handbook for Systematic Reviews of Interventions version 6.3 (2022) to assess the risk of bias in the included studies. The bias assessment was conducted using the Revised Cochrane Risk-of-Bias Tool for Randomized Trials (RoB 2), which covers different study designs such as parallel, crossover, and cluster designs, and clarifies concepts that may lead to confounding. The assessment items include: ① bias from the randomization process; ② bias from deviations from the intended interventions; ③ bias due to missing outcome data; ④ bias in outcome measurement; ⑤ bias from selective reporting of results. Two researchers independently assessed each signal question as "Y" (Yes), "PY" (Probably Yes), "N" (No), "PN" (Probably No), or "NI" (No Information) and summarized the findings into categories of high risk, low risk, or some risk of bias. The final overall risk of bias for the included studies was then determined [29].

Data analysis

This study evaluates the average summary estimate of the differences in changes between the two groups by calculating the effect size of each intervention. To partially adjust for variability among subjects, the analysis uses change scores relative to baseline. When the mean and standard deviation ($M \pm SD$) are available, the change scores are directly extracted. If the change values cannot be obtained, a baseline-to-endpoint correlation coefficient (R) of 0.5 is assumed for calculations between the baseline and endpoint measurements. For data where the standard deviation (SD) is not reported, the p-value or confidence interval (CI) is used for estimation. If the data are provided in the form of medians with interquartile ranges or medians with the maximum and minimum values, a conversion method based on the five-number summary and sample size is used to transform the data into ($M \pm SD$) to adjust for skewed distributions and address skewness issues [30, 31]. In the network meta-analysis, the network relationship diagram is first drawn using the gemtc package in R 4.3.3 software to show the direct and indirect comparisons between interventions [32]. Then, consistency testing (network meta c) and inconsistency testing (network meta i) are performed in Stata 17.0. If the p-value is less than 0.05, the inconsistency model is selected; otherwise, the consistency model is used. Local consistency is tested using the node splitting method to examine the consistency between direct and indirect comparisons within a specific loop. If the p-value is greater than 0.05, it indicates consistency between direct and indirect results, which is generally considered to be good consistency. The SUCRA ranking method is used to assess the effectiveness of interventions, generating a priority ranking and creating a ranking of overall interventions. The effectiveness of each intervention is intuitively compared through the forest plots and league tables of pairwise comparisons. The significance of the effect size is assessed using the 95% CI, with both the upper and lower limits greater than 0 indicating positive significance, and both less than 0 indicating negative significance [33]. Finally, funnel plots are used to detect publication bias and small sample effects [34].

Results

Literature search process and results

During the literature search, a total of 5602 articles were initially identified. After preliminary screening, duplicate articles, systematic reviews, and study protocols were excluded, leaving 1954 articles. After further reviewing the titles or abstracts, 173 articles were selected. Finally, after reading the full texts, articles that could not provide valid outcome data or were not randomized controlled trials (RCTs) were excluded, and 49 articles that met the inclusion criteria were retained for analysis (The specific screening process is shown in Fig. 1).

Characteristics of the included studies

Appendix 4 Table S4 details the baseline characteristics of 49 studies, involving 2,578 stroke patients from 15 countries. Published between 2002 and 2024, the studies included 4 three-arm trials with sample sizes from 15 to 243 patients, and participants' average age ranged from 50 to 70 years. Interventions varied in frequency (1 to 5 times per week), duration (20 min to 2 h per session), and length (3 weeks to 6 months). Two studies did not distinguish gender. There were 24 intervention measures and 13 outcome indicators, including total quality of life score (SIS scale total score, SS-QOL scale total score, EQ-5D scale total score, WHOQOL-BREF total score, SF-12 total score, SF-36 total score, effect size was SMD), physical health (SIS subscale physical domain total score, SF-12 subscale physical domain total score, SF-36 subscale physical domain total score, WHOQOL-BREF subscale Physical Healthy, effect size was SMD), mental health (SF-12 subscale psychological domain total score, SF-36 subscale psychological domain total score), social participation (SF-36 subscale Social Function, WHOQOL-BREF subscale Social Relationship, SIS subscale participation, SS-QOL subscale Social Role, effect size is SMD), daily activities (SF-36 subscale Role-Physical, SS-QOL subscale Work/Practivity, SIS subscale ADL, effect size is SMD), pain (SF-36 subscale Body pain, SIS subscale pain, SS-QOL subscale pain), mental state (SF-36 subscale vitality, SS-QOL subscale energy, effect size is SMD), emotion (SF-36 subscale Role-emotion, SIS subscale emotion, SS-QOL subscale Mood, effect size is SMD), memory and thinking (SIS subscale memory and thinking, SS-QOL subscale thinking, effect size is SMD), communication (SIS subscale Communication, SS-QOL subscale Communication, effect size is SMD), mobility (SIS subscale Mobility, SS-QOL subscale Mobility, effect size is SMD), upper limb function (SIS subscale Hand Function, SS-QOL subscale Upper Extremity), physical recovery (SIS subscale Recovery), Bias risk assessment in Fig. 2 highlighted lack of blinding as a primary source of bias, affecting data authenticity. Ultimately, 49 studies were included, with no selective reporting bias identified. Detailed bias assessments for each study are in Appendix 8 Figure S2.1.

Network meta-analysis results

Quality of life

A total of 23 studies assessed overall quality of life (QoL) scores. The network evidence diagram (Figure S3.1) formed a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. The local inconsistency test (Table S5.1) showed no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.1) indicated that DTOT (SUCRA = 95.6) and CT(Cognitive Training) (SUCRA = 78.3) were the most effective interventions for improving QoL, while BT(Boxing Training) (SUCRA = 12.0) was likely the least effective. Pairwise comparisons showed significant differences: DTOT vs. CIT (1.71 [0.51, 2.91], $P<0.05$), DTOT vs. BT (2.38 [0.56, 4.21], $P<0.05$), and CT vs. BT (1.47 [0.02, 2.91], $P<0.05$). Additional significant results are presented in Figure S4.1 and Table S6.1. The funnel plot (Figure S6.1) did not reveal evidence of significant publication bias.

Physical health

A total of 24 studies evaluated Physical Health. The network evidence diagram (Figure S3.1) formed a closed loop, and a fixed-effect model was used for subsequent network meta-analysis. The local inconsistency test (Table S5.2) indicated no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.2) showed that AQE (SUCRA = 90.5) and BST (Balance and Stability Training)(SUCRA = 83.4) were the most effective interventions for improving Physical Health, while CS(Community Sports) (SUCRA = 7.1) was likely the least effective. Significant pairwise comparisons

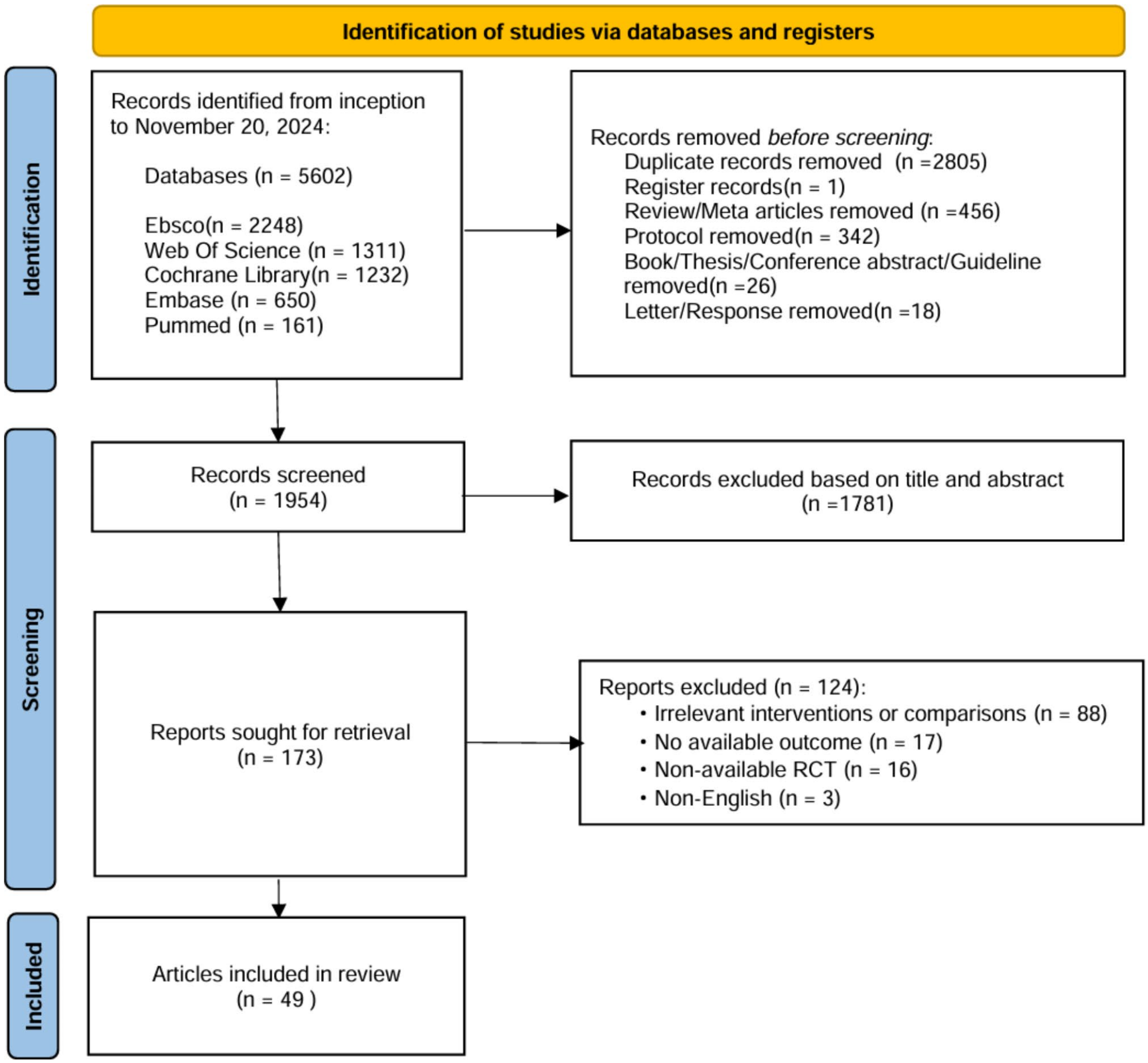

Fig. 1 Literature screening flow chart

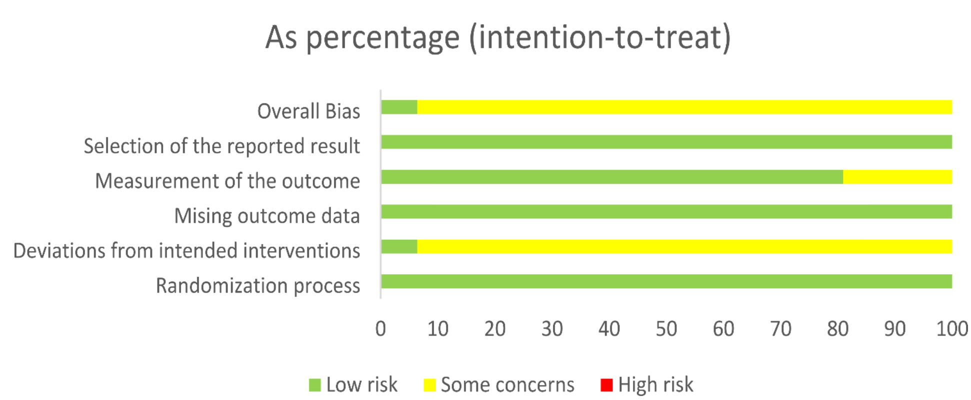

Fig. 2 Cochrane risk of bias percentile chart

included CS vs. AQE (-2.89 [-4.50, -1.28], $P<0.05$), S vs. AQE (-1.73 [-2.96, -0.49], $P<0.05$), and S vs. BST (-1.33 [-2.32, -0.33], $P<0.05$). Additional significant results are presented in Figure S4.2 and Table S6.2, and the funnel plot (Figure S6.2) showed no evidence of significant publication bias.

Mental health

A total of 19 studies evaluated Mental Health. The network evidence diagram (Figure S3.3) formed a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. The local inconsistency test (Table S5.3) showed no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.3) indicated that DTOT (SUCRA = 85.8) and AQE (SUCRA = 80.4) were the most effective interventions for improving Mental Health, while HIVT(High-intensity vibration training) (SUCRA = 24.0) was likely the least effective. In pairwise comparisons, DTOT vs. CIT showed a significant effect size (1.55 [0.27, 2.83], $P<0.05$). Additional comparative results can be found in Figure S4.3 and Table S6.3. The funnel plot (Figure S6.3) did not indicate evidence of significant publication bias.

Social participation

A total of 21 studies assessed Social Participation. The network evidence diagram (Figure S3.4) formed a closed loop, and a fixed-effect model was used for subsequent network meta-analysis. The local inconsistency test (Table S5.4) showed no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.4) indicated that AQE (SUCRA = 91.1) and BCT (SUCRA = 75.5) were the most effective interventions for improving Social Participation, while ULT (SUCRA = 12.5) was likely the least effective. Pairwise comparisons showed significant effects for ULT vs. AQE (-1.10 [-1.92, -0.29], $P<0.05$), S vs. AQE (-0.75 [-1.28, -0.23], $P<0.05$), and CS vs. AQE (-0.73 [-1.31, -0.16], $P<0.05$). Additional results are presented in Figure S4.4 and Table S6.4, and the funnel plot (Figure S6.4) showed no evidence of significant publication bias.

ADL

A total of 14 studies assessed ADL. The network evidence diagram (Figure S3.5) formed a closed loop, and a fixed-effect model was used for subsequent network meta-analysis. The local inconsistency test (Table S5.5) showed no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.5) indicated that ALCE (SUCRA = 86.9) and AQE (SUCRA = 83.9) were the most effective interventions for improving ADL, while S(Control, Standard Care, and Conventional Rehabilitation Training) (SUCRA = 25.2) was likely the least effective. Pairwise comparisons showed significant effects for S vs. AQE (-1.26 [-2.27, -0.24], $P<0.05$) and S vs. ALCE (-1.47 [-2.83, -0.12], $P<0.05$). Additional results can be found in Figure S4.5 and Table S6.5, and the funnel plot (Figure S6.5) showed no evidence of significant publication bias.

Pain

A total of 7 studies assessed Pain. The network evidence diagram (Figure S3.6) formed a closed loop, and a random-effects model was used for the subsequent network meta-analysis. The local inconsistency test (Table S5.6) showed differences between direct and indirect comparisons for AQE vs. BST ($P<0.05$), AQE vs. S ($P<0.05$), and BST vs. S ($P<0.05$). SUCRA rankings (Figure S5.6) indicated that ST (SUCRA = 95.9) and TCMT (Traditional Chinese Medicine Exercise Therapy)(SUCRA = 83.8) were the most effective interventions for managing pain, while AQE (SUCRA = 2.3) was likely the least effective. Significant pairwise comparisons included ST vs. S (1.42 [0.37, 2.47], $P<0.05$), ST vs. AQE (4.24 [2.61, 5.88], $P<0.05$), and TCMT vs. AQE (3.67 [2.05, 5.28], $P<0.05$). Additional significant results can be found in Figure S4.6 and Table S6.6, and the funnel plot (Figure S6.6) showed no evidence of significant publication bias.

Vitality

A total of 9 studies assessed Vitality. The network evidence diagram (Figure S3.7) formed a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. The local inconsistency test (Table S5.1) showed differences between direct and indirect comparisons for AQE vs. BST ($P<0.05$), AQE vs. S ($P<0.05$), and BST vs. S ($P<0.05$). SUCRA rankings (Figure S5.7) indicated that ST (SUCRA = 96.7) and MST(Multidisciplinary supervised training) (SUCRA = 68.9) were the most effective interventions for improving vitality, while ALCE (SUCRA = 9.4) was likely the least effective. Significant pairwise comparisons included ST vs. S (1.05 [0.17, 1.92], $P<0.05$), ST vs. AQE (1.57 [0.41, 2.73], $P<0.05$), and TCMT vs. ALCE (1.74 [0.58, 2.91], $P<0.05$). Additional significant results can be found in Figure S4.7 and Table S6.7, and the funnel plot (Figure S6.7) showed no evidence of significant publication bias.

Emotion

A total of 16 studies assessed Emotion. The network evidence diagram (Figure S3.8) formed a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. The local inconsistency test (Table S5.8) showed no significant differences between direct and indirect comparisons ($P>0.05$). SUCRA rankings (Figure S5.8) indicated that ALCE (SUCRA = 73.3) and AQE (SUCRA = 63.7) were the most effective interventions for improving emotion, while BST (SUCRA = 17.2) was likely the least effective. No significant differences were found in the pairwise comparisons, with additional results presented in Figure S4.8 and Table S6.8. The funnel plot (Figure S6.8) showed no evidence of significant publication bias.

Memory and thinking

A total of 9 studies assessed Memory and Thinking. The network evidence diagram (Figure S3.9) did not form a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. SUCRA rankings (Figure S5.1) indicated that BCT (SUCRA = 86.9) and TCMT (SUCRA = 85.2) were the most effective interventions for improving memory and thinking, while CIST(Circuit Station Training) (SUCRA = 19.7) was likely the least effective. In pairwise comparisons, a significant effect was found between TCMT and CIST (0.77 (0.04, 1.51), $p < 0.05$). Additional results are presented in Figure S4.9 and Table S6.9. The funnel plot (Figure S6.9) showed no evidence of significant publication bias.

Communicate

A total of 9 studies assessed Communication. The network evidence diagram (Figure S3.10) did not form a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. SUCRA rankings (Figure S5.10) showed that ULT (SUCRA = 67.9) and CIT (SUCRA = 67.7) were the most effective interventions for improving communication, while CIST (SUCRA = 24.5) was likely the least effective. No significant differences were observed in pairwise comparisons. Additional results can be found in Figure S4.10 and Table S6.10. The funnel plot (Figure S6.10) showed no evidence of significant publication bias.

Mobility

A total of 9 studies assessed Mobility. The network evidence diagram (Figure S3.11) did not form a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. SUCRA rankings (Figure S5.11) showed that CIT (SUCRA = 75.9) and TCMT (SUCRA = 72.5) were the most effective interventions for improving mobility, while S (SUCRA = 27.0) was likely the least effective. No significant differences were observed in pairwise comparisons. Additional results can be found in Figure S4.11 and Table S6.11. The funnel plot (Figure S6.11) showed no evidence of significant publication bias.

Upper limb function

A total of 8 studies assessed BBS balance ability. The network evidence diagram (Figure S3.12) did not form a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. SUCRA rankings (Figure S5.12) indicated that DTOT (SUCRA = 84.1) and CIT (SUCRA = 72.1) were the most effective interventions for improving balance ability, while CIST (SUCRA = 30.0) was likely the least effective. No significant differences were observed in pairwise comparisons. Additional results can be found in Figure S4.12 and Table S6.12. The funnel plot (Figure S6.12) showed no evidence of significant publication bias.

Recover

A total of 6 studies assessed Recovery. The network evidence diagram (Figure S3.13) did not form a closed loop, and a fixed-effect model was used for the subsequent network meta-analysis. The SUCRA rankings (Figure S5.13) showed that CIT (SUCRA = 81.5) and CS (SUCRA = 67.2) were the most effective interventions for improving recovery, while CIST (SUCRA = 19.4) was likely the least effective. No significant differences were found in pairwise comparisons. Additional results can be found in Figure S4.13 and Table S6.13. The funnel plot (Figure S6.13) showed no evidence of significant publication bias.

Discussion

This study conducted a network meta-analysis on the effects of different training methods on various dimensions of quality of life, systematically evaluating 13 dimensions, including Quality of Life, Physical Health, Mental Health, and others. The results showed that DTOT had the best effect on Quality of Life, Mental Health, and Upper Limb Function; AQE was most effective for Physical Health and Social Participation; ST had the best effect on Pain and Vitality; CIT was most effective for Mobility and Recovery; BCT showed the best results for Memory and Thinking; ALCE was most effective for Emotion and ADL; and ULT had the best effect on Communication.

Stroke patients experience a significant decline in quality of life due to neurological impairments, manifested in worsening psychological health issues and the impact of upper limb dysfunction on daily activities and independence. Previous meta-analyses have indicated that Dual-task-oriented training (DTOT) is an effective intervention that can significantly improve postural stability and gait function in stroke patients, especially in chronic stroke patients, with notable improvements in balance, gait patterns, and upper limb function [35–37]. The results of this study show that DTOT has the best effect in improving quality of life, psychological health, and upper limb function. DTOT involves simultaneous cognitive tasks (such as memory, attention, decision-making, etc.) and motor tasks (such as gait, balance, coordination, etc.), promoting dynamic brain network reorganization, enhancing neural plasticity and executive function, thereby optimizing resource allocation, and enabling patients to better handle unexpected situations in complex daily tasks [38, 39]. Moreover, continuous dual-task training can effectively manage cognitive load, reduce stress and anxiety caused by improper resource allocation, particularly enhancing multitasking and attention [40, 41], making patients more adept in multitasking situations, thus improving daily activity efficiency, confidence, and life satisfaction. In contrast, Constraint-Induced Therapy (CIT) is a single-task training method that restricts the use of the healthy limb, forcing patients to repeatedly use the affected limb to complete specific tasks [42]. This training aims to promote functional activity of the affected limb by strengthening the motor cortex remodeling, thereby improving motor control and functional performance of the affected limb [43, 44]. Previous studies have shown that CIT has a positive effect on muscle strength, gait-related activities, and upper limb functions (such as arm movement ability) in stroke patients, drawing similar conclusions [45–47]. However, this study further found that CIT not only significantly improves mobility but also shows significant differences in overall physical recovery. This is because CIT enhances the functional activity of the affected limb, significantly activating proprioceptive feedback mechanisms, improving foot load perception, as well as step stability and coordination [48–50]. Additionally, by strengthening the lower limb strength and balance ability [51], and indirectly activating the core muscle group, CIT further optimizes standing and walking abilities [52]. In real-life scenarios, CIT helps patients incorporate the recovery of the affected limb into daily activities, such as gait training and mobility tasks, gradually improving their independence in home, community, and social environments.

In recent years, AQE (Aquatic Exercise) has emerged as an innovative treatment method and is increasingly applied in stroke rehabilitation [53, 54]. Studies have shown that AQE has the most significant effect on physical health and social participation. Previous meta-analyses indicated that compared to land-based interventions, water therapy has shown superior effects in balance, muscle strength, proprioception, health-related quality of life, physiological indicators, and cardiovascular health [25, 55]. This study also found significant advantages in social participation, primarily due to the unique physical properties of the water environment and its combined effects on neural plasticity and psychosocial function. The buoyancy of water can significantly reduce the patient's body weight load, lowering exercise stress, making it easier to perform movements, reducing the risk of injury, and promoting muscle strength recovery and motor pattern reshaping. The viscous resistance of water provides uniform load, enhancing core muscle strength and balance ability. Warm water temperature and water pressure improve blood circulation, relieve spasms, and enhance cardiovascular function [54]. Moreover, water-based exercises combined with repetitive functional movement training can stimulate neural network remodeling, enhance axonal connection density, and improve synaptic transmission efficiency, which improves the brain's control over muscles [56]. Additionally, multimodal inputs from touch, temperature, and pressure promote sensory integration and recovery of motor perception [57]. The buoyant properties of water reduce the risk of falls [58], enhance the patient's sense of safety, exercise confidence, and willingness to participate, while group water exercise sessions reduce feelings of loneliness through social interaction, strengthening a sense of belonging and social support [59]. As exercise ability improves, patients gradually regain their ability to participate in family and community activities, improving quality of life. Aquatic-Land Combined Exercise (ALCE) combines water-based exercises with land-based training to provide a multidimensional approach to functional recovery for stroke patients. This study found that ALCE was particularly effective in improving mood (Emotion) and daily activity abilities (ADL), because land-based training focuses on restoring the patient's practical daily functions, such as standing, walking, and climbing stairs, strengthening the affected limb's muscle strength, standing stability, and upper limb grip ability, thereby enhancing the patient's ability to live independently [60]. The complementary training approach of ALCE maximizes the physical functional recovery of stroke patients, improving their emotional stability and daily living capabilities.

Strength Training (ST) is a rehabilitation method that enhances muscle strength and endurance through high-intensity, repetitive weight-bearing or resistance exercises. In recent years, the role of ST in stroke rehabilitation has garnered increasing attention. This study found significant effects on pain management and mental health improvement, aligning with conclusions from previous studies [61, 62]. Stroke patients often experience pain in the shoulder, lower back, and joints due to hemiplegia, muscle weakness, and muscle imbalance [63]. ST alleviates pain by strengthening muscles, improving joint dynamic stability, and correcting movement patterns [64], thereby reducing joint overload and pain caused by abnormal movements. It also balances the tension between spastic muscles and weak antagonist muscles, optimizing the body's adaptation to external forces and gravity [65], and mitigating pain from muscle imbalance. Additionally, ST increases local blood flow, improves metabolic states, and accelerates waste clearance [66], effectively relieving chronic pain. By modulating central nervous system sensitivity, ST activates endogenous analgesic systems, such as the release of endorphins and serotonin [67, 68], significantly reducing pain perception. Regarding mental health, ST promotes the secretion of dopamine, serotonin, and endorphins [68], markedly enhancing emotional regulation, and alleviating anxiety, depression, and mood swings. Its role in promoting neuroplasticity improves axonal connectivity and interregional brain coordination [69], particularly activating the prefrontal cortex and hippocampus [70, 71], which substantially enhances emotional control and cognitive function.ST also offers positive feedback by quantifying progress indicators, boosting patient confidence and rehabilitation adherence. Moreover, it lowers stress hormone levels, alleviating anxiety and tension. Consequently, ST provides broader benefits for pain relief and mental health improvement.

Breathing Coordination Training (BCT) effectively regulates the brain's autonomic nervous system through deep breathing and coordination exercises, balancing sympathetic and parasympathetic activity to promote brain function recovery. This study found that BCT had the most significant effects on memory and thinking, consistent with previous findings [72, 73]. Deep breathing helps increase oxygen supply to the brain, enhancing cerebral blood flow and oxygenation, which improves neuronal activity in central brain regions, including the limbic system, hypothalamus, and medulla [74]. Additionally, the improved sympathetic and vagal outflow enhances cerebral circulation and cognitive abilities [75], particularly memory and thinking [76] BCT significantly improves memory by strengthening brain network connectivity. Improvements in verbal memory are linked to enhanced connectivity within the Default Mode Network (DMN), specifically in areas like the medial frontal cortex and anterior cingulate cortex, as well as increased collaboration in the language processing network involving the left inferior frontal gyrus. Visual-spatial memory improvements are associated with reduced connectivity in the superior parietal network and medial parietal cortex, reflecting more efficient information processing mechanisms. By optimizing neural interactions related to language and visual-spatial memory, BCT enhances cognitive functions [77] For stroke patients, BCT stimulates high-order cognitive regions of the cerebral cortex, improving decision-making, attention, and short-term memory. Previous studies have shown that upper limb training not only restores motor control [78] but also enhances non-verbal communication abilities, such as gestures and facial expressions [79], facilitating clearer interactions with others. Furthermore, upper limb exercises indirectly activate brain areas associated with language processing, promoting language function recovery [80],. This is especially beneficial for patients with speech difficulties due to stroke, as improved upper limb motor skills play a crucial role in restoring language fluency. Additionally, upper limb training enhances patients' motor abilities, boosting their self-efficacy and confidence, encouraging active participation in social interactions and improving language communication efficiency [81].

Limitations of this study

The strengths of this study are the large evidence base (49 RCT studies, 2578 patients), reliable statistical methods with multiple intervention modalities and outcome indicators. To ensure a good level of evidence, we followed strict inclusion and exclusion criteria. Our study is the first reticulated meta-study comparing different exercise interventions with regard to quality of life in stroke patients, providing a basis for further detailed research in this area. There are also some limitations to this study. Firstly, the intensity, duration, frequency and timing of the exercise interventions included in the study were inconsistent, potentially limiting the results. Further subgroup analyzes based on the intensity, duration, frequency and timing of the intervention are needed in the future. Secondly, too little literature on quality of life subscales was included. Finally, adverse events may not be captured accurately enough in the included randomized controlled trials. Therefore, the safety of exercise interventions needs further investigation.

Conclusions

This study conducted a network meta-analysis to evaluate the effects of different training methods on various dimensions of quality of life in stroke patients and drew several important conclusions. Future research should focus on the development of personalized rehabilitation plans, taking into account factors such as the patient's disease course, severity of damage, age, and other individual differences, in order to tailor the most appropriate intervention measures to further improve rehabilitation outcomes. At the same time, multimodal integrated interventions should be further explored, as combining various training methods (such as DTOT with CIT, ST with BCT) may produce greater synergistic effects and optimize overall rehabilitation outcomes. Moreover, stroke rehabilitation is a long-term process, and future research should strengthen long-term follow-up and effectiveness assessments to understand the durability of interventions and ensure that rehabilitation outcomes are not diminished over time. On the other hand, mental health and social participation should progress alongside physical function recovery. Future research should focus more on how to integrate mental health interventions with social participation to improve the overall quality of life of patients. With advancements in technology, the application of emerging technologies such as virtual reality (VR), artificial intelligence (AI), and wearable devices holds great promise. Future research could combine these technologies to optimize rehabilitation training and enhance patients' self-management abilities. Finally, stroke rehabilitation involves multiple disciplines, and future research should strengthen interdisciplinary cooperation, integrating knowledge from neuroscience, exercise rehabilitation, and psychology, to provide more comprehensive and scientific rehabilitation solutions for patients.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12883-025-04035-5.

Supplementary Material 1

Acknowledgements
Not applicable.

Author contributions
Conceptualization: [Liqun Jiang]; Methodology: [Liqun Jiang]; Software: [Liqun Jiang, Huimin Ding, Xinxin Zhang]; Validation: [Liqun Jiang, Huimin Ding, Qishuai Ma, Shang Gao, Xinxin Zhang]; Formal analysis: [Liqun Jiang]; Investigation: [Liqun Jiang, Qishuai Ma, Shang Gao, Xinxin Zhang]; Resources: [Liqun Jiang]; Data Curation: [Liqun Jiang]; Writing - Original Draft: [Liqun Jiang]Writing - Review & Editing: [Buongo Chun]; Visualization: [Liqun Jiang, Huimin Ding]; Supervision: [Buongo Chun]; Project administration: [Buongo Chun], and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors have read and approved the final manuscript. They have provided their consent for the publication of this manuscript in BMC Neurology.

Competing interests
The authors declare no competing interests.

Author details
[1]Graduate School of Physical Education, Myongji University, Mingzhi Road, Churen District, Yongin 17058, Gyeonggi Province, Republic of Korea

Received: 15 September 2024 / Accepted: 14 January 2025
Published online: 17 January 2025

References

1. Murie-Fernández M, Irimia P, Martínez-Vila E, John Meyer M, Teasell R. [Neuro-rehabilitation after stroke]. Neurologia. 2010;25(3):189–96.
2. Portegies ML, Koudstaal PJ, Ikram MA. Cerebrovascular disease. Handb Clin Neurol. 2016;138:239–61. https://doi.org/10.1016/b978-0-12-802973-2.00014-8
3. Felce D, Perry J. Quality of life: its definition and measurement. Res Dev Disabil. 1995;16(1):51–74. https://doi.org/10.1016/0891-4222(94)00028-8
4. Ward AB. A literature review of the pathophysiology and onset of post-stroke spasticity. Eur J Neurol. 2012;19(1):21–7. https://doi.org/10.1111/j.1468-1331.2011.03448.x.
5. Sinanović O, Mrkonjić Z, Zukić S, Vidović M, Imamović K. Post-stroke language disorders. Acta Clin Croatica. 2011;50(1):79–94.
6. Einstad MS, Saltvedt I, Lydersen S, Ursin MH, Munthe-Kaas R, Ihle-Hansen H, et al. Associations between post-stroke motor and cognitive function: a cross-sectional study. BMC Geriatr. 2021;21(1):103. https://doi.org/10.1186/s12877-021-02055-7
7. Heshmatollah A, Dommershuijsen LJ, Fani L, Koudstaal PJ, Ikram MA, Ikram MK. Long-term trajectories of decline in cognition and daily functioning before and after stroke. J Neurol Neurosurg Psychiatry. 2021;92(11):1158–63. https://doi.org/10.1111/j.1468-1331.2011.03448.x
8. Medeiros GC, Roy D, Kontos N, Beach SR. Post-stroke depression: a 2020 updated review. Gen Hosp Psychiatry. 2020;66:70–80. https://doi.org/10.1016/j.genhosppsych.2020.06.011
9. Rafsten L, Danielsson A, Sunnerhagen KS. Anxiety after stroke: a systematic review and meta-analysis. J Rehabil Med. 2018;50(9):769–78. https://doi.org/10.2340/16501977-2384
10. Damsbo AG, Kraglund KL, Buttenschøn HN, Johnsen SP, Andersen G, Mortensen JK. Predictors for wellbeing and characteristics of mental health after stroke. J Affect Disord. 2020;264:358–64. https://doi.org/10.1016/j.jad.2019.12.032
11. Grant JS, Glandon GL, Elliott TR, Giger JN, Weaver M. Caregiving problems and feelings experienced by family caregivers of stroke survivors the first month after discharge. Int J Rehabilitation Res Int Z fur Rehabilitationsforschung Revue Int De recherches de Readaptation. 2004;27(2):105–11. https://doi.org/10.1097/01.mrr.0000127639.47494.e3
12. Camak DJ. Addressing the burden of stroke caregivers: a literature review. J Clin Nurs. 2015;24(17–18):2376–82. https://doi.org/10.1111/jocn.12884
13. Salter K, Foley N, Teasell R. Social support interventions and mood status post stroke: a review. Int J Nurs Stud. 2010;47(5):616–25. https://doi.org/10.1016/j.ijnurstu.2009.12.002
14. Hohmann C, Klotz JM, Radziwill R, Jacobs AH, Kissel T. Pharmaceutical care for patients with ischemic stroke: improving the patients quality of life. Pharm World Science: PWS. 2009;31(5):550–8. https://doi.org/10.1007/s11096-009-9315-y
15. Hopman WM, Verner J. Quality of life during and after inpatient stroke rehabilitation. Stroke. 2003;34(3):801. https://doi.org/10.1161/01.Str.0000057978.15397.6f
16. Zhao B, Yao Y, Gao T. The effect of psychological intervention on the quality of life and rehabilitation outcome of stroke patients with anxiety and depression: a systematic review. Medicine. 2024;103(45):e40439. https://doi.org/10.1097/md.0000000000040439
17. Carod-Artal FJ, Egido JA. Quality of life after stroke: the importance of a good recovery. Cerebrovasc Dis. 2009;27(Suppl 1):204–14. https://doi.org/10.1159/000200461
18. Mennell J. The tradition of physical medicine. Annals Phys Med. 1953;1(5):151–5. https://doi.org/10.1093/rheumatology/1.5.151
19. Gordon CD, Wilks R, McCaw-Binns A. Effect of aerobic exercise (walking) training on functional status and health-related quality of life in chronic stroke survivors: a randomized controlled trial. Stroke. 2013;44(4):1179–81. https://doi.org/10.1161/strokeaha.111.000642
20. Bastola P, Singh P, Pinto D. A comparison of the Effect of Resistance Training on Upper Extremity Motor function, Motor Recovery, and quality of life in Sub-acute Stroke participants. Med J Dr DY Patil Vidyapeeth. 2021;14(2):219–25. https://doi.org/10.4103/mjdrdypu.mjdrdypu_227_19
21. Pérez-de la Cruz S. Influence of an aquatic therapy program on Perceived Pain, stress, and Quality of Life in Chronic Stroke patients: a Randomized Trial. Int J Environ Res Public Health. 2020;17(13). https://doi.org/10.3390/ijerph17134796
22. Taylor-Piliae RE, Hoke TM, Hepworth JT, Latt LD, Najafi B, Coull BM. Effect of Tai Chi on physical function, fall rates and quality of life among older stroke survivors. Arch Phys Med Rehabil. 2014;95(5):816–24. https://doi.org/10.1016/j.apmr.2014.01.001
23. Anjos JM, Neto MG, Dos Santos FS, Almeida KO, Bocchi EA, Lima Bitar YS, et al. The impact of high-intensity interval training on functioning and health-related quality of life in post-stroke patients: a systematic review with meta-analysis. Clin Rehabil. 2022;36(6):726–39. https://doi.org/10.1177/02692155221087082
24. Domínguez-Téllez P, Moral-Muñoz JA, Salazar A, Casado-Fernández E, Lucena-Antón D. Game-based virtual reality interventions to improve Upper Limb

Motor function and quality of Life after Stroke: systematic review and Meta-analysis. Games Health J. 2020;9(1):1–10. https://doi.org/10.1089/g4h.2019.0043
25. Saquetto MB, da Silva CM, Martinez BP, Sena CDC, Pontes SS, da Paixão MTC, et al. Water-based Exercise on Functioning and Quality of Life in Poststroke persons: a systematic review and Meta-analysis. J Stroke Cerebrovasc Diseases: Official J Natl Stroke Association. 2019;28(11):104341. https://doi.org/10.1016/j.jstrokecerebrovasdis.2019.104341
26. Lan Y, You Q, Jiang Q, Peng X, Cao S, Sun J. Effect of Qigong exercise on non-motor function and life quality in stroke patients: a systematic review and meta-analysis. Brain Behav. 2023;13(11):e3246. https://doi.org/10.1002/brb3.3246
27. Zhang Q, Schwade M, Smith Y, Wood R, Young L. Exercise-based interventions for post-stroke social participation: a systematic review and network meta-analysis. Int J Nurs Stud. 2020;111:103738. https://doi.org/10.1016/j.ijnurstu.2020.103738
28. Panic N, Leoncini E, de Belvis G, Ricciardi W, Boccia S. Evaluation of the endorsement of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement on the quality of published systematic review and meta-analyses. PLoS ONE. 2013;8(12):e83138. https://doi.org/10.1371/journal.pone.0083138
29. Jpt H. Cochrane handbook for systematic reviews of interventions. https://www.cochrane-handbook.org; 2008.
30. Higgins JP, Li T, Deeks J. Choosing effect measures and computing estimates of effect. Cochrane handbook for systematic reviews of interventions. 2019:143 – 76.
31. Shi J, Luo D, Wan X, Liu Y, Liu J, Bian Z, et al. Detecting the skewness of data from the five-number summary and its application in meta-analysis. Stat Methods Med Res. 2023;32(7):1338–60. https://doi.org/10.1177/09622802231172043
32. Shim SR, Kim SJ, Lee J, Rücker G. Network meta-analysis: application and practice using R software. Epidemiol Health. 2019;41:e2019013. https://doi.org/10.4178/epih.e2019013
33. Shim S, Yoon BH, Shin IS, Bae JM. Network meta-analysis: application and practice using Stata. Epidemiol Health. 2017;39:e2017047. https://doi.org/10.4178/epih.e2017047
34. Song F, Khan KS, Dinnes J, Sutton AJ. Asymmetric funnel plots and publication bias in meta-analyses of diagnostic accuracy. Int J Epidemiol. 2002;31(1):88–95. https://doi.org/10.1093/ije/31.1.88
35. Zhang X, Xu F, Shi H, Liu R, Wan X. Effects of dual-task training on gait and balance in stroke patients: a meta-analysis. Clin Rehabil. 2022;36(9):1186–98. https://doi.org/10.1177/02692155221097033
36. Zhou Q, Yang H, Zhou Q, Pan H. Effects of cognitive motor dual-task training on stroke patients: a RCT-based meta-analysis. J Clin Neuroscience: Official J Neurosurgical Soc Australasia. 2021;92:175–82. https://doi.org/10.1016/j.jocn.2021.08.009
37. Ghai S, Ghai I, Effenberg AO. Effects of dual tasks and dual-task training on postural stability: a systematic review and meta-analysis. Clin Interv Aging. 2017;12:557–77. https://doi.org/10.2147/cia.S125201
38. Bowen A, Wenman R, Mickelborough J, Foster J, Hill E, Tallis R. Dual-task effects of talking while walking on velocity and balance following a stroke. Age Ageing. 2001;30(4):319–23. https://doi.org/10.1093/ageing/30.4.319
39. Alavash M, Thiel CM, Gießing C. Dynamic coupling of complex brain networks and dual-task behavior. NeuroImage. 2016;129:233–46. https://doi.org/10.1016/j.neuroimage.2016.01.028
40. Anguera JA, Boccanfuso J, Rintoul JL, Al-Hashimi O, Faraji F, Janowich J, et al. Video game training enhances cognitive control in older adults. Nature. 2013;501(7465):97–101. https://doi.org/10.1038/nature12486
41. Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou LS, Mayr U, et al. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. Arch Phys Med Rehabil. 2009;90(3):381–7. https://doi.org/10.1016/j.apmr.2008.09.559
42. Psychouli P. Modified constraint-induced movement therapy in children with congenital hemiplegic cerebral palsy. University of Southampton; 2008.
43. Winstein CJ, Wolf SL, Schweighofer N. Task-oriented training to promote upper extremity recovery. Stroke Recovery Rehabilitation. 2008;2:320–43.
44. Xu J, Chen M, Wang X, Cai Z, Wang Y, Luo X. Global research hotspots and trends in constraint-induced movement therapy in rehabilitation over the past 30 years: a bibliometric and visualization study. Front Neurol. 2024;15:1375855. https://doi.org/10.3389/fneur.2024.1375855
45. Jeon BJ, Kim WH, Park EY. Effect of task-oriented training for people with stroke: a meta-analysis focused on repetitive or circuit training. Top Stroke Rehabil. 2015;22(1):34–43. https://doi.org/10.1179/1074935714z.0000000035
46. da Silva ESM, Ocamoto GN, Santos-Maia GLD, de Fátima CM, Padovez R, Trevisan C, de Noronha MA, et al. The Effect of Priming on outcomes of Task-oriented training for the Upper Extremity in Chronic Stroke: a systematic review and Meta-analysis. Neurorehabilit Neural Repair. 2020;34(6):479–504. https://doi.org/10.1177/1545968320912760
47. Timmermans AA, Lemmens RJ, Monfrance M, Geers RP, Bakx W, Smeets RJ, et al. Effects of task-oriented robot training on arm function, activity, and quality of life in chronic stroke patients: a randomized controlled trial. J Neuroeng Rehabil. 2014;11:45. https://doi.org/10.1186/1743-0003-11-45
48. Windhorst U. Muscle proprioceptive feedback and spinal networks. Brain Res Bull. 2007;73(4–6):155–202. https://doi.org/10.1016/j.brainresbull.2007.03.010
49. Smarandache CR, Daur N, Hedrich UB, Stein W. Regulation of motor pattern frequency by reversals in proprioceptive feedback. Eur J Neurosci. 2008;28(3):460–74. https://doi.org/10.1111/j.1460-9568.2008.06357.x
50. Ergen E, Ulkar B. Proprioception and coordination. Clinical sports medicine. 2007:237 – 45.
51. Fernandes B, Ferreira MJ, Batista F, Evangelista I, Prates L, Silveira-Sérgio J. Task-oriented training and lower limb strengthening to improve balance and function after stroke: a pilot study. Eur J Physiotherapy. 2015;17(2):74–80.
52. Au MK, Chan WM, Lee L, Chen TM, Chau RM, Pang MY. Core stability exercise is as effective as task-oriented motor training in improving motor proficiency in children with developmental coordination disorder: a randomized controlled pilot study. Clin Rehabil. 2014;28(10):992–1003. https://doi.org/10.1177/0269215514527596
53. Cole A. Comprehensive aquatic therapy. Butterworth Heinemann; 2004.
54. Kopack JK. Aquatic therapy. Principles of Therapeutic Exercise for the physical therapist Assistant. Routledge; 2024. pp. 223–40.
55. Veldema J, Jansen P. Aquatic therapy in stroke rehabilitation: systematic review and meta-analysis. Acta Neurol Scand. 2021;143(3):221–41. https://doi.org/10.1111/ane.13371
56. Carr JH, Shepherd RB. Neurological rehabilitation: optimizing motor performance. Elsevier Health Sciences; 2010.
57. Ackerley R, Borich M, Oddo CM, Ionta S. Insights and perspectives on sensory-motor integration and rehabilitation. Multisensory Res. 2016;29(6–7):607–33.
58. Hoogenboom BJ, Lomax NE. Aquatic therapy in rehabilitation. Rehabilitation techniques for sports medicine and athletic training. Routledge; 2024. pp. 379–404.
59. Alaniz ML, Rosenberg SS, Beard NR, Rosario ER. The effectiveness of Aquatic Group Therapy for Improving Water Safety and Social Interactions in children with Autism Spectrum disorder: a Pilot Program. J Autism Dev Disord. 2017;47(12):4006–17. https://doi.org/10.1007/s10803-017-3264-4
60. Motta M. The effects of aquatic and land-based exercise on balance and gait in people post stroke. California State University, Northridge; 2012.
61. Assa T, Geva N, Zarkh Y, Defrin R. The type of sport matters: Pain perception of endurance athletes versus strength athletes. Eur J Pain. 2019;23(4):686–96. https://doi.org/10.1002/ejp.1335
62. Harris JE, Eng JJ. Strength training improves upper-limb function in individuals with stroke: a meta-analysis. Stroke. 2010;41(1):136–40. https://doi.org/10.1161/strokeaha.109.567438
63. Teasell R, editor. Editor Musculoskeletal complications of hemiplegia following stroke. Seminars in arthritis and rheumatism. Elsevier; 1991.
64. Blackburn T, Guskiewicz KM, Petschauer MA, Prentice WE. Balance and joint stability: the relative contributions of proprioception and muscular strength. J Sport Rehabilitation. 2000;9(4):315–28.
65. Ivchenko A, Kanygina S, Cherepok O. Rehabilitation of diseases and lesions of the musculoskeletal system. 2023.
66. Coyle EF. Physical activity as a metabolic stressor. Am J Clin Nutr. 2000;72(2):S512–20.
67. Basbaum AI, Fields HL. Endogenous pain control mechanisms: review and hypothesis. Ann Neurol. 1978;4(5):451–62. https://doi.org/10.1002/ana.410040511
68. Hamedinia M, Sharifi M, Hosseini-Kakhak A. The effect of eight weeks of aerobic, anaerobic and resistance training on some factor of endocannabinoid system, serotonin, beta-endorphin and BDNF in young men. Biosci Biotechnol Res Asia. 2017;14(3):1201.
69. Carroll TJ, Riek S, Carson RG. Neural adaptations to resistance training: implications for movement control. Sports medicine (Auckland, NZ). 2001;31(12):829–40https://doi.org/10.2165/00007256-200131120-00001

70. Chang H, Kim K, Jung YJ, Kato M. Effects of acute high-intensity resistance exercise on cognitive function and oxygenation in prefrontal cortex. J Exerc Nutr Biochem. 2017;21(2):1–8. https://doi.org/10.20463/jenb.2017.0012
71. Aksu I, Topcu A, Camsari UM, Acikgoz O. Effect of acute and chronic exercise on oxidant-antioxidant equilibrium in rat hippocampus, prefrontal cortex and striatum. Neurosci Lett. 2009;452(3):281–5. https://doi.org/10.1016/j.neulet.2008.09.029
72. Zhang Y, Li C, Zou L, Liu X, Song W. The effects of mind-body Exercise on Cognitive Performance in Elderly: a systematic review and Meta-analysis. Int J Environ Res Public Health. 2018;15(12). https://doi.org/10.3390/ijerph15122791
73. Silveira K, Smart CM. Cognitive, physical, and psychological benefits of yoga for acquired brain injuries: a systematic review of recent findings. Neuropsychological Rehabilitation. 2020;30(7):1388–407. https://doi.org/10.1080/09602011.2019.1583114
74. Pal GJIJCEP. Effects of pranayama on cardiovascular health. 2016;3(3):57–8.
75. Abdullahi A, Wong TW, Ng SS. Efficacy of diaphragmatic breathing exercise on respiratory, cognitive, and motor function outcomes in patients with stroke: a systematic review and meta-analysis. Front Neurol. 2023;14:1233408. https://doi.org/10.3389/fneur.2023.1233408
76. Eisenbeck N, Luciano C, Valdivia-Salas S. Effects of a focused breathing mindfulness exercise on attention, memory, and mood: the importance of task characteristics. Behav Change. 2018;35(1):54–70.
77. Eyre HA, Acevedo B, Yang H, Siddarth P, Van Dyk K, Ercoli L, et al. Changes in neural connectivity and memory following a yoga intervention for older adults: a pilot study. J Alzheimer's Disease: JAD. 2016;52(2):673–84. https://doi.org/10.3233/jad-150653
78. Chen PM, Kwong PWH, Lai CKY, Ng SSM. Comparison of bilateral and unilateral upper limb training in people with stroke: a systematic review and meta-analysis. PLoS ONE. 2019;14(5):e0216357. https://doi.org/10.1371/journal.pone.0216357
79. Palermo E, Hayes DR, Russo EF, Calabrò RS, Pacilli A, Filoni S. Translational effects of robot-mediated therapy in subacute stroke patients: an experimental evaluation of upper limb motor recovery. PeerJ. 2018;6:e5544. https://doi.org/10.7717/peerj.5544
80. Hunter SM, Johansen-Berg H, Ward N, Kennedy NC, Chandler E, Weir CJ, et al. Functional Strength Training and Movement Performance Therapy for Upper Limb Recovery Early Poststroke-Efficacy, neural correlates, predictive markers, and Cost-Effectiveness: FAST-INdiCATE trial. Front Neurol. 2017;8:733. https://doi.org/10.3389/fneur.2017.00733
81. Covey MK, McAuley E, Kapella MC, Collins EG, Alex CG, Berbaum ML, et al. Upper-Body Resistance Training and Self-Efficacy Enhancement in COPD. J Pulmonary Respiratory Med. 2012;001. https://doi.org/10.4172/2161-105x.S9-001. Suppl 9:.

Publisher's note