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## ► To cite this version:

Guillaume Le Sant, Thomas Lecharte, Valentin Goreau, Antoine Nordez, Raphaël Gross, et al.. Motor performance, motor impairments, and quality of life after eccentric resistance training in neurological populations: A systematic review and meta-analysis. *NeuroRehabilitation*, 2023, pp.1-18. 10.3233/NRE-230035 . hal-04155975

**HAL Id: hal-04155975**

**<https://hal.science/hal-04155975v1>**

Submitted on 11 Jul 2023

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# Motor performance, motor impairments, and quality of life after eccentric resistance training in neurological populations: A systematic review and meta-analysis

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## Abstract.

**BACKGROUND:** Many overlapping factors impair motor performance and quality of life in neurological patients. Eccentric resistance training (ET) has potential benefits for improving motor performance and treating motor impairments better than some traditional rehabilitation approaches.

**OBJECTIVE:** To estimate the effect of ET in neurological settings.

**METHODS:** Seven databases were reviewed up to May 2022 according to PRSIMA guidelines to find randomized clinical trials involving adults with a neurological condition, who underwent ET as set by the American College of Sports Medicine. Motor performance (main outcome) was assessed as strength, power and capacities during activity. Secondary outcomes (impairments) were muscle structure, flexibility, muscle activity, tone, tremor, balance and fatigue. Tertiary outcomes were risk of fall, and self-reports of quality of life.

**RESULTS:** Ten trials were included, assessed using Risk of Bias 2.0 tool, and used to compute meta-analyses. Effective effects in favour of ET were found for strength and power, but not for capacities during activity. Mixed results were found for secondary and tertiary outcomes.

**CONCLUSION:** ET may be a promising intervention to better improve strength/power in neurological patients. More studies are needed to improve the quality of evidence underlying changes responsible for these results.

Keywords: Resistance training, physical therapy, exercise, neurological condition

## 1. Introduction

Degradation of motor performance is a major contributor to disability (WHO, 2011) and reduced

quality of life in individuals with neurological conditions (Eng et al., 2009; Ramari et al., 2020; Skinner et al., 2015). Naturally, recovering motor performance is rated as a top aspiration by people after a stroke (Stroke Association, 2021), Spinal Cord Injury (SCI) (van Middendorp et al., 2016), Cerebral Palsy (CP) (Cook et al., 2022), Parkinson Disease (PD) (Bowring et al., 2022), or Multiple Sclerosis (MS) (Chiu et al., 2019).

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Many overlapping factors impair motor performance in individuals with neurological conditions (Gracies, 2005a, 2005b; Graham et al., 2016; McLoughlin, 2018). Deficits in neural function and changes in motor unit properties (Klein et al., 2010; Thomas et al., 2014), involuntary muscle activity/spasms/tremor (McLoughlin, 2018), tissue remodelling and atrophy (Gorgey & Dudley, 2007; Handsfield et al., 2022; Hunnicutt & Gregory, 2017), decreases in joint mobility and muscle fascicle length due to contractures (Nuckolls et al., 2020) or rigidity (Wijemanne & Jankovic, 2019), and increased levels of fatigue (Kluger et al., 2013) worsen motor capacities over time.

Resistance training has turned into a key intervention of neuro-rehabilitation for a wide variety of conditions over time (Aravind et al., 2019; Hornby et al., 2020; National Institute for Health and Care Excellence, 2022; Osborne et al., 2022). Despite improving strength, 'conventional' programs using 'concentric' muscle contractions might have limited effects on aforementioned motor impairments. Recently, Davis et al. (2020) highlighted the potential relevance to use 'eccentric' muscle contractions in neurological settings. Eccentric resistance training (ET) has a greater positive effect on neuromuscular function (e.g. muscle activation), muscle size, fascicle length and joint flexibility compared to other types of exercises in healthy individuals (Blazevich, 2019; Diong et al., 2022; Douglas et al., 2017a, 2017b). Therefore, ET has a very large spectrum of plausible benefits that could be relevant to many individuals living with consequences of a neurological condition. The practice of ET provides a unique opportunity to improve motor performance while addressing major motor impairments simultaneously. For instance, ET is assumed to produce greater gains in muscle strength and volume (hypertrophy) while it may also regulate the balance between agonist/antagonist muscle neuromechanical output (i.e. paresis and hyperactivities). Moreover, because of the greater mechanical loading involved in active lengthening, ET exercises could be relevant in treating the relative shortness in muscle fascicle length and joint contractures. ET requires less metabolic demands for the same amount of work than concentric training, making it of particular interest for patients with neurological disorders experiencing high levels of fatigue and/or cardiorespiratory issues. Evidence suggests that ET can be used safely in neurological settings (Folkerts et al., 2017; LaS-tayo et al., 2014). Therefore, ET holds promise for improving motor performance and simultane-

ously addressing major motor impairments, during neuro-rehabilitation settings. However, the scientific evidence regarding its benefits for patients is not clear, yet.

This review primarily aimed to evaluate the effectiveness of ET on motor performance in neurological populations. This review also focused on the effectiveness of ET on motor impairments (secondary objective), and on patients' health-related quality of life (tertiary objective). We also aimed to evaluate effect modifiers such as the type of disease (neurological injury, neuro-degenerative disease), the initial motor capacities, and intervention delivery (e.g. standalone/included/added to rehabilitation, compliance with the American College of Sports Medicine (ACSM) position stand for resistance training interventions (American College of Sports Medicine, 2009).

## 2. Methodology

This systematic review was carried out according to the Cochrane Handbook (Higgins, 2022), and the Preferred Reporting Items for Systematic Reviews and Meta-analysis (Moher et al., 2009). This study, as a literature review, is exempt from Institutional Review Board approval. The protocol was pre-registered on PROSPERO database (n<sup>o</sup> CRD42021283908) for transparency.

### 2.1. Literature search

A PICOS (Patient, Intervention, Comparison, Outcomes, Study type) framework was used to develop literature-searching strategies and keywords. Seven databases were searched to find published, ongoing or unpublished trials (grey literature) from their inception with no time restriction, initially started by PubMed, and adapted for use in the other databases (PEDro, Embase, Cochrane Library, ClinicalTrials.gov, Scopus, Web of Science). Reference lists of published systematic reviews and authors' personal libraries were searched to confirm the retrieval of appropriate studies. An iterative process which involved team meetings was employed to define relevant search keywords that would capture relevant records. For that purpose, keywords, search strategies, and reference lists of included studies from relevant reviews from the field (resistance training in neurological populations, eccentric resistance training) were explored, so as authors' libraries to ensure

an optimal search strategy for each database. The keywords used for each criterion are listed in Table 1, and their association for each database (search strategy) is detailed in Supplementary File 1. Because all the objectives of this review might be answered by results from randomized clinical trials (RCT), we followed the recommendations of the Cochrane Handbook (Higgins, 2022) to restrict our research to RCT only. Trials were excluded if training corresponded to ‘functional or task oriented’ exercises (e.g. downhill walking), because these interventions tend to influence multiple parameters like motor control, skill, speed and endurance, which are not primary targeted by resistance training interventions.

## 2.2. Study selection

The selection was conducted on the open access online tool CADIMA (Kohl et al., 2018) in May 2022. Before initiating the selection, a random sample of 10 studies based on retrieved list of studies was screened by two reviewers (GLS and TL) to assess the consistency of criteria assessment, followed by a discussion between reviewers on the reasons for inclusion/exclusion, using the eligibility criteria list (Table 1). Then, the same reviewers independently removed duplicate, screened the titles and abstracts, and read the full-text of articles to determine their eligibility. At each stage of the process (titles/abstracts, full texts), every document was thoroughly examined to identify relevant information for inclusion/exclusion. In most cases, the eligibility criteria could be found in the methods section of the abstract or full-text, which provided details on the population, interventions/comparators, outcomes, and study methodology (RCT or not). At every stage of the process (duplicates, titles and abstract, full-text), a consistency check was done between both reviewers to reach a consensus. Discrepancies were resolved if required during a meeting with a third reviewer (TC) before proceeding to the next step.

## 2.3. Data extraction and synthesis

A data collection form adapted from Cochrane Collaboration (2022) was used for collecting data from retrieved studies. Information about eligibility, method (i.e., participants, intervention/comparator, outcomes) and results were extracted by two reviewers independently (GLS and TL) and cross-checked to produce a merged collection form. If information

was not available in the published papers, further precisions were requested from the corresponding author. Data extracted characterized the population, study protocol and outcomes for experimental and comparator groups. For a complete listing of collected parameters, please refer to Table 2. Because the effects of eccentric resistance training are of particular interest for a large variety of neurological conditions, and not specific to a particular situation, different populations were included and categorized as ‘neuro-injured’ (e.g. stroke) or ‘neuro-degenerative’ (e.g. multiple sclerosis). We used a customized form adapted from Hendrey et al. (2018) study to assess adherence to ACSM position stand for resistance training: frequency, intensity, type, repetitions, sets, progression, specificity and pattern, of the exercises used in the ET program (American College of Sports Medicine, 2009) (Supplementary File 5).

## 2.4. Assessment of characteristics of trials

The risk of bias was assessed using The Cochrane risk of bias (RoB) 2.0 tool (Sterne et al., 2019) independently by two reviewers (GLS and TL). A third reviewer was involved (TC) if a consensus could not be reached. RoB 2.0 is structured into signalling questions evaluating five bias domains in RCTs arising from: the randomisation process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The overall RoB for the study synthesizes the bias from each domain to an overall judgment qualified as ‘some concerns’, ‘low’ or ‘high’.

## 2.5. Data analysis

The replicability of the search strategy was assessed by the kappa statistic ( $\kappa$ ), with levels of agreements defined as: no agreement ( $0.00 < \kappa$ ), slight ( $0.00 \leq \kappa \leq 0.19$ ), fair ( $0.20 \leq \kappa \leq 0.39$ ), moderate ( $0.40 \leq \kappa \leq 0.59$ ), substantial ( $0.60 \leq \kappa \leq 0.79$ ), almost perfect ( $0.80 \leq \kappa \leq 1$ ) (Sim & Wright, 2005). For each outcome of each RCT, pre- and post-intervention scores were used. When multiple measures were reported for a same construct in a RCT, the one best reflecting the outcome was used (Higgins, 2022) (see Supplementary File 2). Data were converted when necessary (e.g. confidence intervals to standard deviation) using Cochrane RevMan software (The Cochrane Collaboration. Review Manager, RevMan, Version 5.4, 2020).

Table 1  
Criteria used for inclusion of the studies

Category	Eligibility criteria
Population	Adults > 18 years old Diagnosis of a neurological injury or neuro-degenerative disease  <i>Corresponding keywords: "Demyelinating Autoimmune Diseases, CNS"[Mesh], "Central Nervous System Diseases"[Mesh], "Motor Neuron Disease"[Mesh], "Trauma, Nervous System"[Mesh]</i>
Intervention	Resistance training including eccentric contractions, defined as a progressive exercising program by the American College of Sports Medicine ( $\geq 4$ weeks, twice a week, against an external load)  <i>Corresponding keywords: Eccentric, "lengthening contraction", "lengthening exercise"</i>
Comparator	other forms of resistance programs (e.g. concentric), another form of rehabilitation (no progressive resistance program), or control (no rehabilitation)  <i>Corresponding keywords: rehab*, train*, exercise, physiother*</i>
Outcomes	Motor performance (primary objective) : maximal strength, maximal power, clinical exercises/tests (e.g. gait) Motor impairment (secondary objective): muscle structure, muscle activity, muscle tone, joint flexibility, fatigue Health-related quality of life (tertiary objective): risk of fall, and self-reports of health condition/behaviour  <i>Corresponding keywords : (none, left open to ensure the greatest possibility of finding results on outcomes)</i>
Design/study type	Randomized clinical trials
Other	Language: publications in English, French or Spanish Full/Published reports accessible for data extraction

Data were pooled to generate random-effects meta-analyses when at least two studies could be retrieved for an outcome. The critical value for statistical significance was set at 0.05. Analyses were reported as standardised mean differences (SMD) and 95% confidence interval (95% CI). The thresholds of the effect size of generated SMD were : 0.2 (small), 0.5 (medium), 0.8 (large). Subgroup analyses were performed based on aforementioned categorization (neuro-injured, neuro-degenerative) to explore the effect of the origin of central nervous system damage on the results. Heterogeneity between trials was examined using the  $I^2$  test with values of > 25% and 50% indicative of moderate and high heterogeneity, respectively (Higgins, 2022). When SMD for a trial was large, we explored the possible causes of heterogeneity by omitting one at a time individual studies, and stratifying by participants initial motor capacities (Higgins, 2022). Results were summarised descriptively when data could not be pooled.

The quality of evidence (QoE) in relation to each outcome was rated using the approach developed by the GRADE collaboration (GRADE, 2013). Six domains are evaluated through GRADE approach: study design, RoB, indirectness, inconsistency, imprecision and publication bias. Four levels of evidence can be attributed: 'high', 'moderate', 'low', and 'very low'. For each outcome, a sequential analysis

system was used (Balslem et al., 2011) (described in Supplementary File 3).

### 3. Results

The review followed the registered protocol except that effect modifiers that were examined as categorical factors in sensitivity analyses.

#### 3.1. Flow of trials through the review

The search identified a total of  $n=407$  papers (310 excluding duplicates). After screening titles and abstracts, we identified 42 studies as potentially eligible ( $n=3$  awaiting classification) ( $\kappa=0.94$ ). After inspecting the full reports, 10 RCTs were found eligible for inclusion ( $\kappa=0.94$ ) (Fig. 1). The reasons for exclusion have been summarised in Supplementary File 4.

#### 3.2. Characteristics of the included trials

Detailed characteristics of the studies are depicted in Table 2.

Table 2  
Main characteristics of the included studies

Study	Condition	Population (n of participants)	Intervention: Eccentric Training (ET)	Comparator (COMP)	Relevant outcome measures
Lattouf (2021)	Stroke	Setting: patients in an outpatient service (country: np)	Muscles: KE, KF	usual rehabilitation	Participation: -
		ET (19) Delay from injury: 11.6 ± 4.1 months Age: 65.1 ± 11.2 y Initial characteristics: 0.84 ± 0.76 (MAS) Initial motor capacities: 0.46 ± 0.69 <sup>a</sup> (max-selected walking speed, 10mWT), coded 'moderate' <sup>b</sup>	Format: added to usual rehabilitation  Content: horizontal leg press concentric phase (both legs)+eccentric phase (paretic leg only); velocity: np.  Dose: session: 2 sets x [5 reps x 40% 1RM]+1 set x [5 reps x 60% 1RM] frequency: 3/wk duration: 4 wks	- Prevention of complications - Stimulation of motor skills - Management of spasticity - Transfers, balance displacement and functional acquisition - Therapeutic education	Activity: gait Function: strength, spasticity Structure: -
Kadkhodaie (2020)	Parkinson's Disease	Setting: patients in an outpatient service (Iran)	Muscles: EF, WF, WE	no intervention (control)	Participation: -
		ET (11) Delay from diagnostic: 61.2 ± 38.4 months Age: 67.8 ± 9.6 y Initial characteristics: 2.3 ± 1.0 (H&Y) Initial motor capacities : -	Format: standalone  Content: weighted training balls fixed to participants hand or forearm Eccentric only (concentric performed by therapist)		Activity: - Function: amplitude of hand tremor Structure: -
		COMP (10) Delay from diagnostic: 67.2 ± 70.8 months Age: 67.4 ± 6.8 y Initial characteristics: 2.3 ± 0.8 (H&Y) Initial motor capacities : -	Dose: session: 3 sets x 10 reps 1 session (RPE = 10–11) 2 sessions (RPE = 12–14) frequency: 3/wk duration: 6 wks  Range of movement for training: np  Velocity of movement: np  Progressivity: heavier weights to keep a constant intensity level		

(Continued)

Table 2  
(Continued)

Study	Condition	Population (n of participants)	Intervention: Eccentric Training (ET)	Comparator (COMP)	Relevant outcome measures
Dibble (2015)	Parkinson's Disease	<p>Setting: patients in an outpatient service (USA)</p> <p>ET (20)            Delay from diagnostic: 96.0 ± 53.8 months            Age: 66.0 ± 14.8 y            Initial characteristics: 2.0 (2 to 4) (H&amp;Y On)            Initial motor capacities: 558.07 ± 182.49 m (6MWT), coded 'good'<sup>b</sup></p> <p>COMP (21)            Delay from diagnostic: 68.4 ± 50.8 months            Age: 70.7 ± 9.2 y            Initial characteristics: 2.0 (1 to 4) (H&amp;Y On)            Initial motor capacities: 485.99 ± 158.95 m (6MWT), coded 'good'<sup>b</sup></p>	<p>Muscles: HE, KE, AE</p> <p>Format: included in a multi-component rehabilitation program</p> <p>Content: COMP, with eccentric training on ergometer targeting lower extremity extensors</p> <p>Dose:            session: 15 minutes            frequency: 2/wk            duration: 12 wks</p> <p>Range of movement for training: np</p> <p>Progressivity: variation in workload to maintain a RPE at 13</p>	<p>multi-component rehabilitation program</p> <p>– warm-up exercises (bicycle or treadmill)</p> <p>– flexibility training (mobility exercises)</p> <p>– balance training (static/dynamic stability training)</p> <p>– upper extremity concentric resistance training (exercise machine)</p> <p>– concentric ergometer training (NuStep)</p>	<p>Participation: health status</p> <p>Activity: gait</p> <p>Function: strength</p> <p>Structure: quadriceps volume</p>
Clark (2013)	Stroke	<p>Setting: np (USA)</p> <p>ET (18)            Delay from injury: 13.3 ± 4.9 months            Age: 63.2 ± 10.6 y            Initial characteristics: 77.3 ± 9.4 (F-M)            Initial motor capacities: 0.37 ± 0.18 m/s (self-selected walking speed), coded 'moderate'<sup>b</sup></p> <p>COMP (17)            Delay from injury: 12.8 ± 4.7 months            Age: 59.7 ± 10.9 y            Initial characteristics: 80.9 ± 7.1 (F-M)            Initial motor capacities: 0.39 ± 0.25 m/s (self-selected walking speed), coded 'moderate'<sup>b</sup></p>	<p>Muscles: HE, HF, KE, KF, AE, AF</p> <p>Format: standalone</p> <p>Content: isokinetic training<sup>c</sup></p> <p>Dose:            session: sets of 10 repetitions            wk 1 : 9 sets (3x30°/s, 3x90°/s, 3x150°/s)            wk 2 : 9 sets (3x 60°/s, 3x 120°/s, 3x180°/s)            wk 3 : 12 sets (4x90°/s, 4x150°/s, 4x210°/s)            wk 4 : 9 sets (3x60°/s, 3x150°/s, 3x210°/s)            wk 5 : 9 sets (3x30°/s, 3x90°/s, 3x150°/s)            frequency: 3/wk            duration: 5 wks</p> <p>Range of movement for training: np</p> <p>Velocity of movement: see dose</p> <p>Progressivity : np</p>	<p>concentric resistance training (using the same dose as ET)</p>	<p>Participation: -</p> <p>Activity: gait</p> <p>Function: strength, power, muscle activity</p> <p>Structure: -</p>

Hayes (2011)	Multiple Sclerosis	<p>Setting: patients in an outpatient service (USA)</p> <p>ET (10)            Delay from diagnostic: 149.9 ± 113.8 months            Age: 48.0 ± 11.9 y            Initial characteristics: 5.2 ± 1.0 (EDSS)            Initial motor capacities: 248 ± 169 m (6MWT), coded 'good'<sup>b</sup></p> <p>COMP (9)            Delay from diagnostic: 142.2 ± 87.6 months            Age: 49.7 ± 11.0 y            Initial characteristics: 5.3 ± 1.0 (EDSS)            Initial motor capacities: 372 ± 266 m (6MWT), coded 'good'<sup>b</sup></p>	<p>Muscles: HE, KE, AE</p> <p>Format: added to usual rehabilitation</p> <p>Content: eccentric training on ergometer targeting lower extremity extensors (eccentron)</p> <p>Dose:            session: 45 to 60 minutes            wk 1 : 1–5 min (RPE = 7)            wk 2 : 1–5 min (RPE = 9)            wk 3 : 11–14 min (RPE = 11)            last 8 wks: 11–14 min (RPE = 13)            frequency: 3/wk            duration: 12 wks</p> <p>Range of movement for training: from 10° to 90° of knee flexion</p> <p>Velocity of movement: pedal cadence: 15 to 20 rotations per minute</p> <p>Progressivity: variation in workload to maintain a RPE from 11 to 13</p>	<p>usual rehabilitation</p> <ul style="list-style-type: none"> <li>– aerobic training (NuStep, horizontal stepper)</li> <li>– lower extremity stretching (hamstring, quads, triceps surae)</li> <li>– upper extremity strength training (machines and free weights)</li> <li>– balance exercises (standing on a wobble board while maintaining balance for both a side-to-side and front-to-back perturbation)</li> </ul>	<p>Participation: -</p> <p>Activity: gait, risk of fall</p> <p>Function: strength, balance, fatigue</p> <p>Structure: -</p>
Dibble (2009)	Parkinson's Disease	<p>Setting: patients in an outpatient service (USA)</p> <p>ET (10)            Delay from diagnostic: 73.2 ± 46.8 months            Age: 64.3 ± 9.6 y            Initial characteristics: 2.5 ± 0.5 (H&amp;Y)            Initial motor capacities: 1.74 ± 0.33 m/s (max-selected walking speed, 10mWT), coded 'good'<sup>b</sup></p> <p>COMP (9)            Delay from diagnostic: 78.0 ± 51.6 months            Age: 67.0 ± 10.2 y            Initial characteristics: 2.5 ± 0.7 (H&amp;Y)            Initial motor capacities: 1.71 ± 0.34 m/s (max-selected walking speed, 10mWT), coded 'good'<sup>b</sup></p>	<p>Muscles: HE, KE</p> <p>Format: included in a multi-component rehabilitation program</p> <p>Content: eccentric training on ergometer targeting lower extremity extensors (eccentron)</p> <p>Dose:            session: 5 to 30 minutes            wk1 : 2/wk, 3–5 min (RPE = 7)            wk2 : 3/wk, 5 min (RPE = 9)            wk3 : 3/wk, 5–10 min (RPE = 11)            wk4 : 3/wk, 10–15 min (RPE = 11–13)            wk 5–12 : 3/wk, 15–30 min (RPE = 13)            frequency: 2–3/wk            duration: 12 wks</p> <p>Range of movement for training: np</p> <p>Velocity of movement: np</p> <p>Progressivity: variation in workload to obtain a RPE = 13 (wk 5 to 12)</p>	<p>multi-component rehabilitation program</p> <ul style="list-style-type: none"> <li>– warm-up exercises (bicycle or treadmill)</li> <li>– flexibility training (mobility exercises)</li> <li>– balance training (static/dynamic stability training)</li> <li>– upper extremity concentric resistance training (exercise machine)</li> <li>– concentric ergometer training (NuStep)</li> </ul>	<p>Participation: quality of life</p> <p>Activity: gait, risk of fall</p> <p>Function: strength</p> <p>Structure: -</p>

(Continued)

Table 2  
(Continued)

Dibble (2006)	Parkinson's Disease	<p>Setting: patients in an outpatient service (USA)</p> <p>ET (10)            Delay from diagnostic: 73.2 ± 46.8 months            Age: 64.3 ± 9.6 y            Initial characteristics: 2.5 ± 0.5 (H&amp;Y)            Initial motor capacities: 575.12 ± 142.37 m (6MWT), coded 'good'<sup>b</sup></p> <p>COMP (9)            Delay from diagnostic: 78.0 ± 51.6 months            Age: 67.0 ± 10.2 y            Initial characteristics: 2.5 ± 0.7 (H&amp;Y)            Initial motor capacities: 544.72 ± 133.13 m (6MWT), coded 'good'<sup>b</sup></p>	<p>Muscles: HE, KE</p> <p>Format: included in a multi-component rehabilitation program</p> <p>Content: eccentric training on ergometer targeting lower extremity extensors (eccentron)</p> <p>Dose:            session: 5 to 30 minutes            wk1 : 2/wk, 3–5 min (RPE = 7)            wk2 : 3/wk, 5 min (RPE = 9)            wk3 : 3/wk, 5–10 min (RPE = 11)            wk4 : 3/wk, 10–15 min (RPE = 11–13)            wk 5–12 : 3/wk, 15–30 min (RPE = 13)            frequency: 2–3/wk            duration: 12 wks</p> <p>Range of movement for training: np</p> <p>Velocity of movement: np</p> <p>Progressivity: variation in workload to obtain a RPE = 13 (wk 5 to 12)</p>	<p>multi-component rehabilitation program</p> <ul style="list-style-type: none"> <li>– warm-up exercises (bicycle or treadmill)</li> <li>– flexibility training (mobility exercises)</li> <li>– balance training (static/dynamic stability training)</li> <li>– upper extremity concentric resistance training (exercise machine)</li> <li>– concentric ergometer training (NuStep)</li> </ul>	<p>Participation: -</p> <p>Activity: gait</p> <p>Function: strength</p> <p>Structure: quadriceps volume</p>
Engardt (1995)	Stroke	<p>Setting: patients in an outpatient service (Sweden)</p> <p>ET (10)            Delay from injury: 26.5 ± 10.3 months            Age: 62.2 ± 7.6 y            Initial characteristics: 81 (68 to 97) (F-M)            Initial motor capacities: 0.81 ± 0.18 m/s (self-selected walking speed, 30mWT), coded 'good'<sup>b</sup></p> <p>COMP (10)            Delay from injury: 27.8 ± 12.0 months            Age: 64.6 ± 6.2 y            Initial characteristics: 78 (70 to 86) (F-M)            Initial motor capacities: 0.65 ± 0.20 m/s (self-selected walking speed, 30mWT), coded 'moderate'<sup>b</sup></p>	<p>Muscles: KE</p> <p>Format: standalone</p> <p>Content: eccentric training on isokinetic dynamometer (exclusively on knee extensors)</p> <p>Dose:            session: up to 15 sets of 10 reps            angular velocities: pyramidal (60, 120, 180, 120, 60)            frequency: 2/wk            duration: 6 wks</p> <p>Range of movement for training: from 10° to 100° of knee flexion</p> <p>Velocity of movement: see dose</p> <p>Progressivity: variation in workload to obtain a RPE = 13 (wk 5 to 12)</p>	<p>concentric resistance training (using the same dose as ET)</p>	<p>Participation: -</p> <p>Activity: gait</p> <p>Function: strength, balance/posture, muscle activity</p> <p>Structure: -</p>

Fernandez-Gonzalo (2016)	Stroke	Setting: np (Spain)  ET (16) Delay from injury: 42 ± 43.2 months Age: 61.2 ± 9.8 y Initial characteristics: 28.1 ± 1.8 (MMSE) Initial motor capacities: 20.3 ± 14.5 s (TUG), coded 'severe'  COMP (16) Delay from injury: 51.6 ± 58.8 months Age : 65.7 ± 12.7 y Initial characteristics : 27.7 ± 2.3 (MMSE) Initial motor capacities: 17.6 ± 14.8 s (TUG), coded 'severe' <sup>b</sup>	Muscles: KE  Format: standalone  Content: eccentric training on eccentric ergometer (YoYo)  Dose: session: 4 sets x 7 reps Angular velocities : pyramidal (60, 120, 180, 120, 60) frequency: 2/wk duration: 12 wks  Range of movement for training: from 0° to 70° of knee flexion  Velocity of movement: see dose  Progressivity: variation of the workload to maintain maximal intensity	no intervention (control)	Participation: quality of life Activity: balance, risk of fall Function: strength, spasticity Structure: quadriceps volume
Lee (2013)	Stroke	Setting: patients in an inpatient service (Korea)  ET (10) Delay from injury: np Age: 53.40 ± 9.71 y Initial characteristics: np Initial motor capacities: 0.37 ± 0.33 m/s (self-selected walking speed), coded 'moderate' <sup>b</sup>  COMP (10) Delay from injury: np Age: 53.86 ± 10.56 y Initial characteristics: np Initial motor capacities: 0.41 ± 0.19 m/s (self-selected walking speed), coded 'moderate' <sup>b</sup>	Muscles: HF, HE  Format: added to usual rehabilitation  Content: Eccentric training on isokinetic dynamometer  Dose: session: 60 minutes (5 minutes warm up) 4 sets x 8 reps frequency: 3/wk duration: 6 wks  Range of movement for training: np  Velocity of movement: see dose  Progressivity: np	usual rehabilitation (not described)	Participation: - Activity: risk of fall, gait Function: strength Structure: -

Abbreviations: Muscle groups: AE/AF ankle extensors/flexors, EE/EF elbow flexors/extensors, KE/KF knee extensors/flexors, HE/HF hip extensors/flexors, WE/WF wrist extensors/flexors; BBS: Berg Balance Scale; EDSS: Expanded Disability Status Scale; FAC: Functional Ambulation Category; F-M: Fugl-Meyer assessment of sensorimotor function; FSS: Fatigue Severity Scale ; H&Y: Hoehn & Yahr Scale; MAS: Modified Ashworth; MDS-UPDRS III: Movement Disorders Society Unified Parkinson's Disease Rating Scale; MMSE: mini mental state examination; MRI: Magnetic Resonance Imaging; MVC: maximum voluntary contraction; np: non precised; rep: repetitions; RM: repetition maximum; RPE: rating of perceived exertion; SF-36: Short-Form 36; TUG: timed-up and go test; VAS: visual analogue scale; wk: week; y: years; 10mWT: 10 Metres Walk Test; 30mWT: 30 Metres Walk Test; 6MWT: 6 Minutes Walk Test. a: Calculated from time values provided in the original paper (speed = 10/time). b: Previous research in neurological populations (Kubo et al., 2020; Moore et al., 2018; Quinn et al., 2013) had proposed cuts-offs to reflect 'good', 'moderate', and 'severe' motor performance capacities for 10mWT ('good' > 0.8 m/s, 'moderate' between 0.4 and 0.8 m/s, 'severe' < 0.4 m/s), 6MWT ('good' > 448 m, 'moderate' between 225 m and 448 m, 'severe' < 225 m), TUG ('good' < 12 sec, 'moderate' between 12 s and 14 s, 'severe' < 14 sec), respectively. c: The study of Clark (2013) was a staged intervention: part 1 (resistance training, 5 weeks) followed by part 2 (gait training, 3 weeks). Only data from part 1 were considered. Kubo, H., et al. (2020). Reference value of 6-minute walk distance in patients with sub-acute stroke. *Top Stroke Rehabil*, 27(5), 337-343. doi: 10.1080/10749357.2019.1704372. Moore, J. L., et al. (2018). A Core Set of Outcome Measures for Adults With Neurologic Conditions Undergoing Rehabilitation: A CLINICAL PRACTICE GUIDELINE. *J Neurol Phys Ther*, 42(3), 174-220. doi: 10.1097/NPT.0000000000000229. Quinn, L., et al. Outcome Measures Subgroup of the European Huntington's Disease, N. (2013). Reliability and minimal detectable change of physical performance measures in individuals with pre-manifest and manifest Huntington disease. *Phys Ther*, 93(7), 942-956. doi: 10.2522/ptj.20130032.

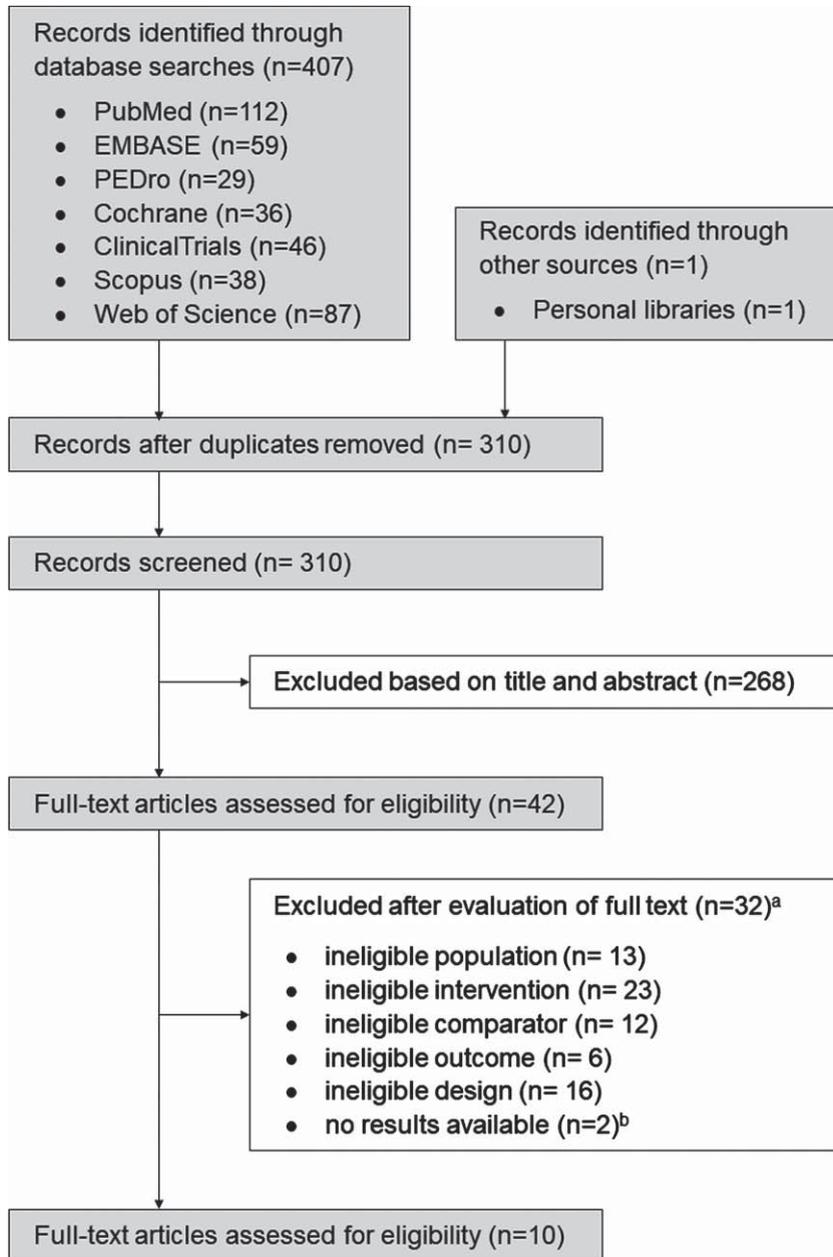


Fig. 1. Flow of trials through the review. a Some trials displayed multiple reasons for exclusion. b Authors contacted with no responses.

### 3.2.1. Participants

The 10 RCTs involved 260 participants, mean age ranged from 48.0 to 70.7 years, at chronic stages of their respective condition (11.6 to 149.9 months): a neurological injury (stroke,  $n = 141$ ) (Clark & Patten, 2013; Engardt et al., 1995; Fernandez-Gonzalo et al., 2016; Lattouf et al., 2021; Lee & Kang, 2013); a degenerative condition: PD ( $n = 100$ ) (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009; Kad-

khodaie et al., 2020), and MS ( $n = 19$ ) (Hayes et al., 2011). All participants were followed in a trial during which they could be assigned prospectively to a group allocating to a single intervention (ET or comparative intervention).

### 3.2.2. Intervention

ET targeted the lower limb in 9 studies (Clark & Patten, 2013; Dibble et al., 2015; Dibble et al., 2006;

Dibble et al., 2009; Engardt et al., 1995; Fernandez-Gonzalo et al., 2016; Hayes et al., 2011; Lattouf et al., 2021; Lee & Kang, 2013), and the upper limb in 1 study (Kadkhodaie et al., 2020). ET was multi-segmental in 7 studies (Clark & Patten, 2013; Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009; Hayes et al., 2011; Kadkhodaie et al., 2020; Lattouf et al., 2021), and targeted one joint in 3 studies (Engardt et al., 1995; Fernandez-Gonzalo et al., 2016; Lee & Kang, 2013). Exercises were performed on an isokinetic dynamometer in 3 studies (Clark & Patten, 2013; Engardt et al., 1995; Lee & Kang, 2013), a fitness/exercise machine in 6 studies (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009; Fernandez-Gonzalo et al., 2016; Hayes et al., 2011; Lattouf et al., 2021), and free-weights in 1 study (Kadkhodaie et al., 2020). ET was added (Hayes et al., 2011; Lattouf et al., 2021; Lee & Kang, 2013) or included (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009) to rehabilitation care in 6 studies, or proposed as a standalone intervention in 4 studies: compared to concentric training (Clark & Patten, 2013; Engardt et al., 1995) or to control (no intervention) (Fernandez-Gonzalo et al., 2016; Kadkhodaie et al., 2020). The ET program lasted from 4 to 12 weeks, with a frequency of 2.5 sessions/week. However, the trials remained unclear in their description and manipulation of exercise variables: repetitions of movement to failure or not, velocity and range of movement at which exercise were performed (Table 2 and Supplementary File 5).

### 3.2.3. Outcome measures

Motor performance was assessed as maximal strength by measuring force or torque in 8 studies [isometrically (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009; Fernandez-Gonzalo et al., 2016; Hayes et al., 2011); or dynamically (Engardt et al., 1995; Fernandez-Gonzalo et al., 2016; Lattouf et al., 2021; Lee & Kang, 2013)], power in 2 studies (Clark & Patten, 2013; Fernandez-Gonzalo et al., 2016), and gait capacities in 8 studies [distance (Dibble et al., 2015; Dibble et al., 2006; Hayes et al., 2011; Lattouf et al., 2021); velocity (Clark & Patten, 2013; Dibble et al., 2009; Engardt et al., 1995; Hayes et al., 2011; Lattouf et al., 2021; Lee & Kang, 2013)]. Regarding motor impairments, muscle structure was quantified using MRI in 3 studies as muscle size (Dibble et al., 2015) or volume (Dibble et al., 2006; Fernandez-Gonzalo et al., 2016); muscle activity using surface electromyography (sEMG) in 2 studies (Clark & Patten, 2013; Engardt et al., 1995), muscle tone in 2

studies via modified Ashworth Scale (Fernandez-Gonzalo et al., 2016; Lattouf et al., 2021), frequency of hand tremor in one study (Kadkhodaie et al., 2020), balance in 3 studies [bodyweight distribution (Hayes et al., 2011) or Berg Balance Test (Engardt et al., 1995; Fernandez-Gonzalo et al., 2016)] and fatigue in one study [Fatigue Severity Scale, Hayes et al. (2011)]. Finally, the risk of fall was measured in 4 studies using Time Up and Go test (Dibble et al., 2009; Fernandez-Gonzalo et al., 2016; Hayes et al., 2011; Lee & Kang, 2013), and 3 trials reported a self-measurement of global health status [using the generic Short-Form 36 scale Fernandez-Gonzalo et al. (2016); or disease-specific Parkinson's Disease Questionnaire-39 (Dibble et al., 2015; Dibble et al., 2009)] (Supplementary File 2).

### 3.2.4. Quality of included trials

The RoB was variable for each domain as described in Fig. 2. Globally, only 20% of the studies reported an overall 'low' RoB ( $\kappa=1.00$ ) (Fig. 2).

### 3.3. Effect of ET on motor performance

The effect of ET on strength was examined by pooling data from 8 studies: 4 studies in persons with stroke (Engardt et al., 1995; Fernandez-Gonzalo et al., 2016; Lattouf et al., 2021; Lee & Kang, 2013), and 4 studies in neuro-degenerative conditions: 3 in PD (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009), and 1 in MS (Hayes et al., 2011). The effect size was moderate (SMD 0.58, CI95% 0.30 to 0.87,  $p < 0.0001$ ;  $I^2=0\%$ ) in favour of ET, with no effect of the subgroup (Fig. 3A). When stratifying by the type of ET delivery, the effect of ET on strength was still significant: ET as a standalone intervention (SMD 0.79, CI95% -0.13 to 1.08,  $p = 0.009$ ;  $I^2=0\%$ ) or ET included/added into a rehabilitation program (SMD 0.52, CI95% 0.20 to 0.84,  $p = 0.002$ ;  $I^2=0\%$ ). Without the trial reporting a large effect size (Fernandez-Gonzalo et al., 2016), ET still improved strength (SMD 0.53, CI95% 0.23 to 0.84,  $p = 0.0005$ ;  $I^2 = 0\%$ ). The QoE was very low for the effect of ET on strength (Supplementary File 2).

The effect of ET on power was examined by pooling outcomes from 2 studies in persons with stroke delivering ET as a standalone intervention (Clark & Patten, 2013; Fernandez-Gonzalo et al., 2016). The effect size was large (SMD 0.98, CI95% 0.32 to 1.63,  $p = 0.003$ ;  $I^2 = 0\%$ ) in favour of ET (Fig. 3B). It was not possible to test the effect of subgroup, the type of ET delivery, or initial motor capacities due to the

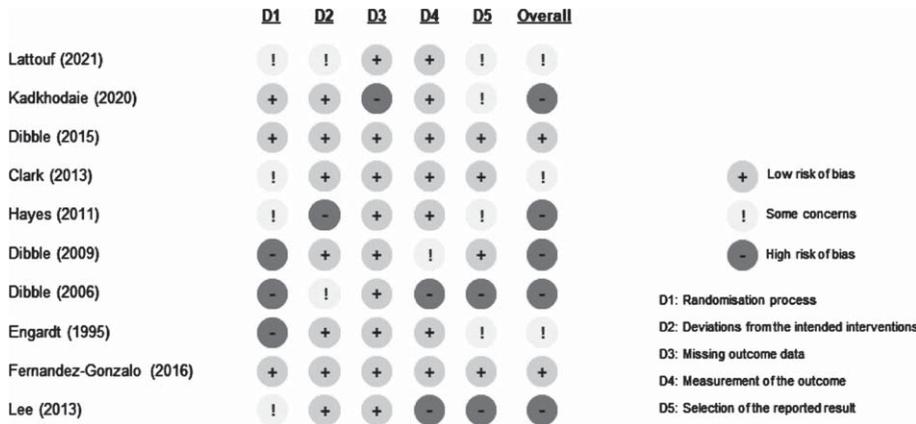


Fig. 2. Risk of Bias of the included trials assessed using the Cochrane Risk of Bias 2 tool.

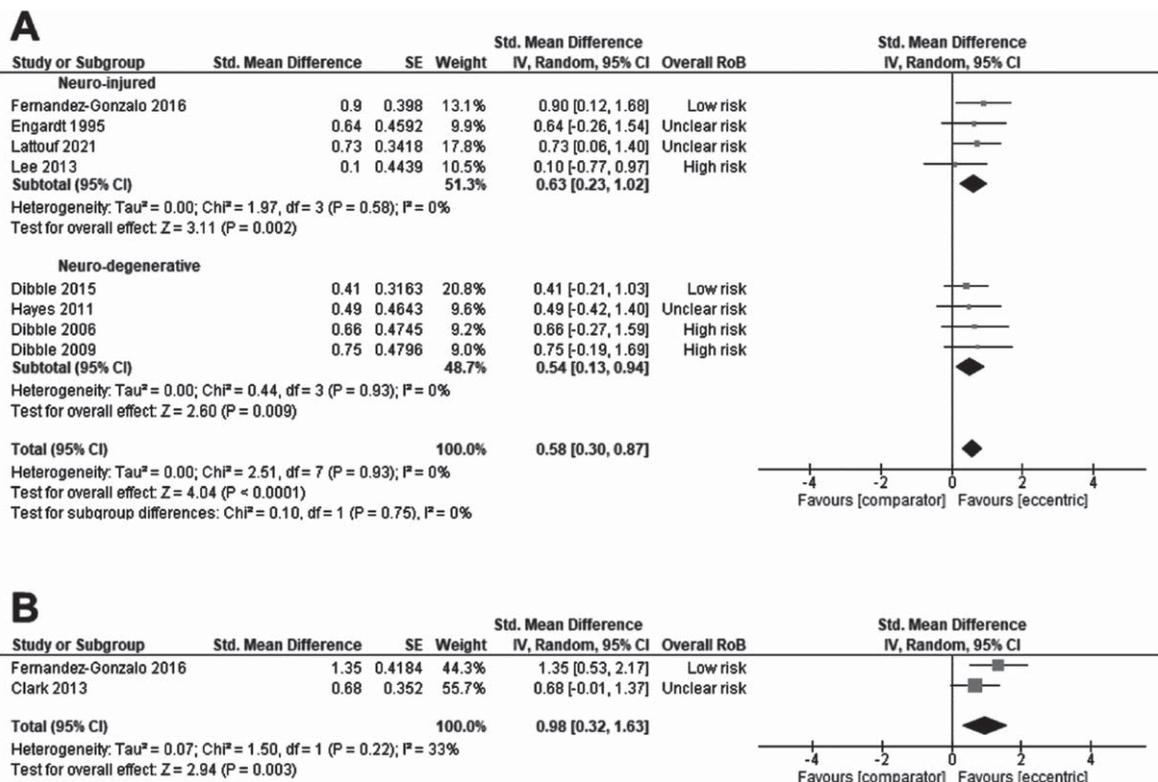


Fig. 3. Standardised mean difference (95% CI) of effect of eccentric resistance training versus comparator (usual rehabilitation, or control) on strength ( $n = 194$ ) (A) or power ( $n = 63$ ) (B) immediately after the intervention ( $n = 194$ ).

number of studies. The QoE was rated as very low for the effect of ET on power (Supplementary File 3).

The effect of ET on gait was examined by pooling outcomes from 8 studies: 4 studies in persons with stroke (Clark & Patten, 2013; Engardt et al., 1995; Lattouf et al., 2021; Lee & Kang, 2013) and 4 studies in patients with MS (Dibble et al., 2015; Dibble et al., 2006; Dibble et al., 2009; Hayes et al.,

2011). The effect size was 0.27 (CI95% -0.22 to 0.75,  $p = 0.28$ ;  $I^2 = 65\%$ ) which was not significant (Fig. 4). There was no effect of the subgroup, the initial motor capacities on the result: participants with 'moderate' capacities (SMD 0.28, CI95% -0.47 to 1.02,  $p = 0.46$ ;  $I^2 = 73\%$ ) or 'good' capacities (SMD 0.25, CI95% -0.48 to 0.99,  $p = 0.67$ ;  $I^2 = 67\%$ ). There was no effect of the type of ET delivery on the result: ET as stan-

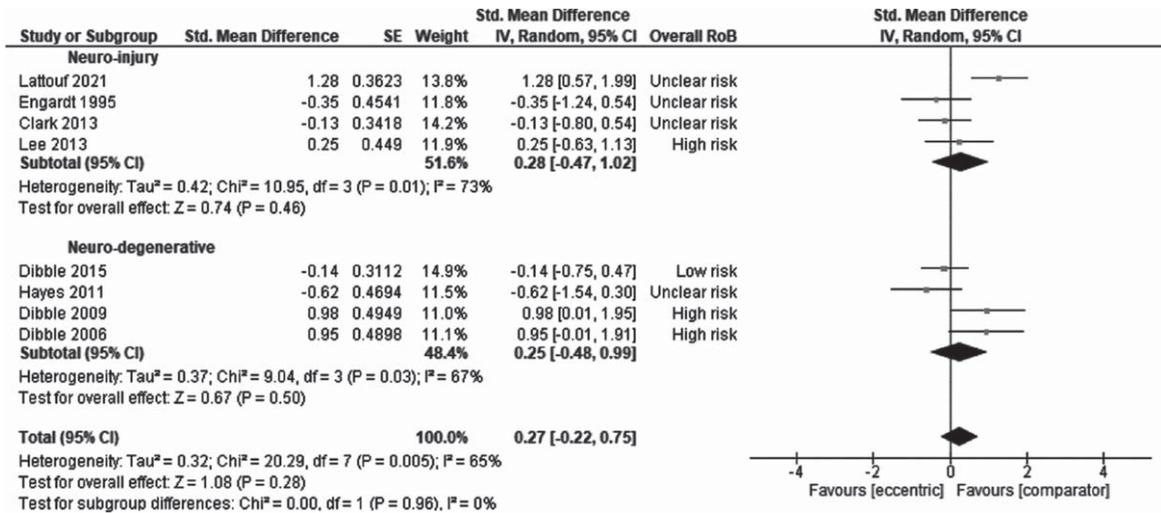


Fig. 4. Standardised mean difference (95% CI) of effect of eccentric resistance training versus comparator (usual rehabilitation, or control) on gait immediately after the intervention ( $n = 209$ ).

alone intervention (SMD  $-0.21$ , CI95%  $-0.74$  to  $0.33$ ,  $p = 0.44$ ;  $I^2 = 70\%$ ) or ET included/added into a rehabilitation program (SMD  $0.44$ , CI95%  $-0.17$  to  $1.05$ ,  $p = 0.70$ ;  $I^2 = 69\%$ ). The QoE was rated as very low for the effect of ET on gait (Supplementary File 3).

### 3.4. Effect of ET on secondary outcomes

The effect of ET on muscle structure was examined by pooling outcomes from 3 studies in persons with stroke (Fernandez-Gonzalo et al., 2016) and with MS (Dibble et al., 2015; Dibble et al., 2006). The effect size was  $0.79$  (CI95%  $-0.02$  to  $1.60$ ,  $p = 0.06$ ;  $I^2 = 66\%$ ) which was not significant. There was no effect of the subgroup on the result (Supplementary File 6A). It was not possible to test the effect of the type of ET delivery, or initial motor capacities due to the number of studies. The QoE was rated as very low for the effect of ET on muscle structure (Supplementary File 3).

The effect of ET on knee extensors sEMG activity during maximal knee extensions was examined by pooling outcomes from 2 studies in persons with stroke (Clark & Patten, 2013; Engardt et al., 1995). The effect size was  $0.67$  (CI95%  $-0.26$  to  $1.59$ ,  $p = 0.16$ ;  $I^2 = 63\%$ ) which was not significant (Supplementary File 6B). It was not possible to test the effect modifiers due to the number of studies. The QoE was rated as very low for the effect of ET on muscle activity (Supplementary File 3). Additionally, the study of Engardt et al. (1995) did not find differences

in knee flexors' muscle activity during maximal knee extensions (i.e., acting as antagonists).

The effect of ET on spasticity was examined by pooling outcomes from 2 studies in persons with stroke (Fernandez-Gonzalo et al., 2016; Lattouf et al., 2021). The effect size was  $-0.15$  (CI95%  $-0.63$  to  $0.33$ ,  $p = 0.55$ ;  $I^2 = 0\%$ ) which was not significant (Supplementary File 6C). It was not possible to test the effect modifiers due to the number of studies. The QoE was rated as very low for the effect of ET on muscle spasticity (Supplementary File 3). Kadhodaie et al. (2020) did not report between-group differences on hand tremor in PD (SMD  $0.83$ , CI95%  $-0.07$  to  $1.73$ ).

The effect of ET on balance was examined by pooling outcomes from 3 studies in persons with stroke (Engardt et al., 1995; Fernandez-Gonzalo et al., 2016) and persons with MS (Hayes et al., 2011). The effect size was  $0.66$  (CI95%  $-1.33$  to  $2.66$ ,  $p = 0.51$ ;  $I^2 = 93\%$ ) which was not significant. There was no 'subgroup' effect on the result (Supplementary File 6D). The QoE was rated as very low for the effect of ET on balance (Supplementary File 3).

Finally, Hayes et al. (2011) did not report between-group differences in self-perceived fatigue on daily function in people with MS (Fatigue Severity Scale, MD =  $0.44$ , CI95%  $-0.36$  to  $1.24$ ).

### 3.5. Effect of ET on tertiary outcomes

The effect of ET on risk of fall was examined by pooling outcomes from 2 studies in persons with

stroke (Fernandez-Gonzalo et al., 2016; Lee & Kang, 2013), 1 study in patients with PD (Dibble et al., 2009), and 1 study in patients with MS (Hayes et al., 2011). The effect size was medium (SMD  $-0.67$ , CI95%  $-1.11$  to  $-0.23$ ,  $p=0.003$ ;  $I^2=0\%$ ) in favour of ET (Supplementary File 6E). There was no ‘sub-group’ effect of the on the result. The effect size was improved when participants had a ‘severe’ or ‘moderate’ motor impairment (SMD  $-0.82$ , CI95%  $-1.41$  to  $-0.23$ ,  $p=0.007$ ;  $I^2=0\%$ ) and not significant when participants had ‘good’ initial motor capacities (SMD  $-0.49$ , CI95%  $-1.30$  to  $0.31$ ,  $p=0.23$ ;  $I^2=33\%$ ). When trials with a large effect size were omitted one-by-one (Dibble et al., 2009; Fernandez-Gonzalo et al., 2016; Lee & Kang, 2013), the overall result was reduced but still in favour of ET (all SMD and CI95%  $<-0.60$ ,  $-1.13$  to  $-0.07$ , all  $p$ -values  $<0.01$ ). However, the result was not significant when at least two of these trials were omitted (see Supplementary File 6E for further details). The QoE was rated as very low for the effect of ET on risk of fall (Supplementary File 3).

Three trials (Dibble et al., 2015; Dibble et al., 2009; Fernandez-Gonzalo et al., 2016) assessed participants’ perceptions of their quality of life in relation to their health status. It was not possible to pool their data. Qualitatively, the ‘perception of pain’ on SF-36 scale was better improved after ET in persons with stroke (SMD  $0.96$ , CI95%  $0.16$  to  $1.74$ ) (Fernandez-Gonzalo et al., 2016). In people with PD, Dibble et al. (2009) reported that ET improved the ‘global index’ subsection of Parkinson Disease Questionnaire (PDQ-39) (SMD  $-1.26$ , CI95%  $-2.26$  to  $-0.25$ ), but this result was not confirmed in a later study (no data reported) (Dibble et al., 2015).

#### 4. Discussion

This systematic review provided evidence that ET improves motor performance, especially maximal strength and power, in neurological populations. The effect of ET on secondary outcomes (motor impairments) and tertiary outcomes (health-related quality of life) were not consistent. However, the overall QoE was very low due to a high RoB, small sample sizes generating imprecisions across the studies. The moderate to large effect size for strength is in accordance with conclusions of previous reviews applying ‘conventional’ resistance training programs in neurological populations : stroke injury [SMD  $=0.99$ , CI95%  $0.28$  to  $1.70$  Veldema and Jansen (2020);

$0.98$ , 95% CI  $0.67$  to  $1.29$ , Dorsch et al. (2018)]; CP [ $0.26$ , CI95%  $0.04$  to  $0.48$ , Merino-Andres et al. (2022)]; MS [ $0.36$ ,  $0.18$  to  $0.55$ , Andreu-Caravaca et al. (2022)];  $0.45$ , CI95%  $0.18$  to  $0.72$ , Jorgensen et al. (2017)]; PD [ $1.9$ , CI95%  $0.55$  to  $3.24$ , Yang and Wang (2023)].

Also, gait was the only activity assessed in the retrieved studies of this review ( $n=8/10$ ). We did not find evidence of superiority of ET over the comparator in improving gait, which is consistent with the findings from previous reviews in neurological populations where either distance or velocity were not better improved after a ‘conventional’ resistance training program (Braz de Oliveira et al., 2021; Dorsch et al., 2018; Merino-Andres et al., 2022; Veldema & Jansen, 2020). However, a recent review in PD populations reported a better positive effect on a disease-specific impairment: freezing during gait [SMD  $=0.55$ , CI95%  $0.16$  to  $0.95$ , Yang and Wang (2023)]. We did not retrieve trials assessing changes in freezing in PD, after ET. However, when considering their initial gait capacities (distance or velocity), the participants of the trials of the present review were probably at a too ‘moderate-to-low’ degree of walking disability (Table 2) to expect a carry-over of strength on activity (Dorsch et al., 2021). Another reason might be related to the specificity of the intervention to target the most important muscle groups for walking and/or not using fast-enough muscle contractions to match the physiological needs for gait (Williams et al., 2019).

Resistance training is a complex intervention with many variables that can affect its benefits through different neural and structural adaptations. For instance, performing rapid muscle contractions might be more beneficial for optimizing neural plasticity and muscle activation while slow muscle contractions would better promote hypertrophy (Coratella, 2022; Scott et al., 2016). An optimal program would ideally fit individual needs and impairments. It is difficult to appreciate to in the present review in which extent the intervention optimized neural or structural adaptations for improving strength was related to the initial impairments of the participants. For instance, different movement velocities could be used among the retrieved studies’ protocols (Table 2). Also, motor impairments were not consistently followed in the retrieved studies (30% only). The trial of Fernandez-Gonzalo et al. (2016) in persons with stroke was the only trial assessing neural and structural outcomes in addition to strength. This study reported increases of strength and muscle volume in favor of the ET

group, while muscle tone remained unchanged for both groups. These findings would mean that ET would be of particular interest to promote hypertrophy for improving strength. Dibble et al. (2006) also reported a better increase after ET in quadriceps muscle size of patients with PD in addition to strength gain. However, this result was not confirmed later (Dibble et al., 2015) and muscle activity was not measured in those trials. A trial conducted in children with CP (not included in this review) (Reid et al., 2010) reported strength gains after ET associated with a decrease in antagonist muscle co-activation. Taken together, different mechanisms (neural, structural) could be involved to improve strength after ET.

Muscle tone and balance were not better improved after ET (Supplementary File 5), like found in 'conventional' resistance training programs (Merino-Andres et al., 2022; Veldema & Jansen, 2020). Surprisingly, no trials investigated joint flexibility, muscle length or stiffness despite the popularity of contractures and rigidity in individuals with neurological conditions, that are associated with changes in musculo-tendinous structure and/or mechanical properties (intrinsic level of stiffness) (Diong et al., 2012; Hoang et al., 2021; Kwah et al., 2012; Le Sant et al., 2019; Lieber & Friden, 2019). Once developed, contractures enhance the overall degradation of motor performance and disability (Ada et al., 2000; Barber et al., 2017). These features are difficult to address in neuro-rehabilitation where classical approaches using stretching exercises fail to produce clinical worthwhile results (Harvey et al., 2017; Lecharte et al., 2020; Svane et al., 2021). A recent review reported that ET offer an opportunity to improve joint range of motion and muscle fascicle length in healthy populations (Diong et al., 2022). A feasibility study in a small sample of MS patients reported clinical gains in joint flexibility after an ET (Manca et al., 2020). These preliminary results need to be confirmed in future studies, in order to identify the morphological and biomechanical adaptations underpinning the clinical outcomes.

In order to provide evidence-based strategies in clinical contexts future studies should include neurophysiological and structural outcomes in their assessments to understand how adaptations following ET: i) differ/conform to 'conventional' resistance training programs; ii) influence the severity of motor impairments and disability. A greater understanding of the distinct neurological and/or architectural adaptations following strength training would lead

to more personalized exercise prescription for this population.

The main strength of this review was to comprehensively examine motor performance, motor impairments, and disability across different neurological conditions, by considering a person's functioning in terms of body functions and structures, activities and participations (health-related quality of life), rather than just strength. We also considered ACSM guideline for resistance training to determine an 'optimal' program that would increase strength (Supplementary File 5). However, the studies focused on the lower limb (90% of the trials) and for individuals at chronic phases of their condition (Table 2). Based on that, it is not possible to conclude on the effects of ET on upper limb motor performance, for acute/subacute populations, or in patients with different conditions (e.g. CP, SCI). Moreover, despite positive results for strength after ET, the precise estimate of the mode of delivery (and comparator) is difficult to appreciate, because of the number of studies retrieved. Future trials are needed to estimate how much more (or less) effective eccentric training is than usual rehabilitation, and to determine its optimal dose-effect. Finally, we excluded trials using task-oriented exercises such as backward gait-training (Hosl et al., 2018), whose tend to influence motor control, skill, speed, endurance, and not only strength. Ballistic training offers opportunities (Williams et al., 2022) but might be more suitable when the goal of training is to improve the rate of force production (Williams et al., 2019). Also, ballistic training might not isolate the specific effect of ET which was beyond the scope of this review. Future trials should compare different types of resistance training regarding the specific needs of the activity, in order to determine to most effective approach of resistance training.

## 5. Conclusion

This systematic review shows that ET is likely to improve motor performance in neurological conditions. Because this result is based on a very-low quality of evidence, future studies are needed to provide robust evidence and to precise the magnitude of this finding. These studies would use larger samples of participants, and test ET in acute populations and/or with more severe capacities. The effect of ET on clinical parameters that have useful implications in neurologically-impaired populations, such as joint flexibility also needs further investigation.

## Conflict of interest

GLS is supported by a grant from the French Ministry of Health (PHRIP, n° PHRIP-21-0031). Funders had no role in design and conduct of the research; collection, management, data analysis and interpretation; and preparation; review, or approval of the manuscript or the decision to submit for publication. None of the other authors have any competing interests.

## Acknowledgments

The authors have no acknowledgments.

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## **Supplementary File 1. Search strategy, by database.**

### ***Search Strategy for PubMed***

1. "Demyelinating Autoimmune Diseases, CNS"[Mesh]
2. "Central Nervous System Diseases"[Mesh]
3. "Motor Neuron Disease"[Mesh]
4. "Trauma, Nervous System"[Mesh]
5. OR 1-4
6. Eccentric
7. "lengthening contraction"
8. "lengthening exercise"
9. OR 6-8
10. Rehab\*
11. Train\*
12. Exercise
13. Physiother\*
14. OR 10-13
15. 5 AND 9 AND 14

### ***Search Strategy for PEDro***

1. eccentric ti.ab
2. neurology sub.
3. 1 AND 2

### ***Search Strategy for EMBASE***

1. 'eccentric muscle contraction'/exp
2. 'eccentric muscle contraction'
3. OR 1-2
4. 'central nervous system disease'/exp
5. 'central nervous system disease'
6. 'motor neuron disease'/exp
7. 'motor neuron disease'
8. 'nervous system injury'/exp
9. 'nervous system injury'
10. 'demyelinating disease'/exp
11. 'demyelinating disease'
12. OR 4-11
13. 'rehabilitation'/exp
14. 'rehabilitation'
15. 'training'/exp
16. 'training'
17. 'exercise'/exp
18. 'exercise'
19. 'physiotherapy'/exp
20. 'physiotherapy'
21. OR 13-20
22. 3 AND 12 AND 21

### ***Search Strategy for Cochrane***

1. Eccentric

2. MeSH descriptor: [Rehabilitation] explode all trees
3. MeSH descriptor: [Demyelinating Autoimmune Diseases, CNS] explode all trees
4. MeSH descriptor: [Central Nervous System Diseases] explode all trees
5. MeSH descriptor: [Motor Neuron Disease] explode all trees
6. MeSH descriptor: [Trauma, Nervous System] explode all trees
7. OR 2-6
8. MeSH descriptor: [Neurological Rehabilitation] explode all trees
9. Exercise
10. Train\*
11. OR 8-10
12. 1 AND 7 AND 11

***Search Strategy for Scopus***

1. Eccentric
2. Neurological
3. Train\*
4. Exercise
5. Rehab\*
6. OR 3-5
7. 1 AND 2 AND 5

***Search Strategy for Web of Science***

1. ALL=(eccentric)
2. ALL=(exercise)
3. ALL=(training)
4. ALL=(rehabilitation)
5. OR 2-4
6. ALL=(neurological)
7. 1 AND 5 AND 6

***Search Strategy for ClinicalTrials registry***

1. Condition or disease : Neurological Diseases or Conditions
2. Intervention/treatment : eccentric
3. Eligibility criteria : adult/older adult
4. Study type: interventional (clinical trial)
5. 1 AND 2 AND 3 AND 4 AND 5

**Supplementary File 2.** Rationale to reduce comparisons within studies.

	<b>Outcomes (tools/scales used for assessment)</b>		
<b>Study</b>	<b>Motor Performance</b>	<b>Motor impairments</b>	<b>Health related quality of life</b>
Lattouf (2021)	<b>KE strength more+less affected side (1 RM estimated)</b> <b>Gait (10mWT, 6MWT)</b> [keep : 10mWT as most recommended tool]	<b>Spasticity (Modified Ahsworth Scale)<sup>a</sup></b>	
Kadkhodaie (2020)		<b>Hand tremor (frequency, at rest, most symptomatic hand)</b>	
Dibble (2015)	<b>KE strength phase ON/FF, more affected side (isometric MVC)</b> [keep: phase ON] <b>Gait (6MWT, Functional Gait Assessment)</b> [keep : 6MWT as most recommended tool]	<b>QF CSA (MRI)</b>	<b>Health status (PDQ-39)</b>
Clark (2013)	<b>KE Power (60°/sec,120°/sec,180°/sec, eccentric/concentric)</b> [keep : 60°/sec eccentric, as most usual velocity used] <b>Gait (6 Gait cycles, self/max velocity)</b> [keep : max velocity as most recommended tool]	<b>RF, VM muscle activity (EMG 60°/sec,120°/sec,180°/sec, eccentric/concentric)</b> [keep : VM muscle activity as most related to strengthening intervention, -60°/sec]	
Hayes (2011)	<b>KF/KE, HF/HE, DF, sum of lower-limb muscles strength (MVC, bilateral)</b> [keep : sum of lower-limb muscles] <b>Gait (10mWT self/max velocity, 6MWT)</b> [keep : 10mWT max velocity as most recommended tool]	<b>Balance (BBS)</b>	<b>Risk of Fall (TUG)</b> <b>Fatigue (FSS)</b>
Dibble (2009)	<b>KE strength more/less affected side (isometric MVC)</b> [keep : more affected side] <b>Gait (10mWT)</b>		<b>Health status (PDQ-39)</b>
Dibble (2006)	<b>KE strength more/less affected side (isometric MVC)</b> [keep : more affected side] <b>Gait (6MWT)</b>	<b>QF, RF, VI, VL, VM Volume (MRI)</b> [keep : QF volume]	<b>Risk of Fall (TUG)</b>
Engardt (1995)	<b>KE strength more affected side (MVC 60°/sec,120°/sec,180°/sec, eccentric/concentric)</b> [keep : 60°/sec eccentric, as most usual velocity used] <b>Gait (30 m self/max velocity)</b> [keep : max velocity as most recommended tool]	<b>KE/KF muscle activity (EMG 60°/sec,120°/sec,180°/sec, eccentric/concentric)</b> [keep : 60°/sec eccentric, as most usual velocity used] <b>Posture rising/sitting down (body weight distribution)</b> [keep : rising]	
Fernandez-Gonzalo (2016)	<b>KE+HE strength more/less affected side (isometric and dynamic MVC)</b> [keep : more affected side, dynamic]	<b>QF Volume (MRI) QF average/maximal CSA (MRI)</b> [keep: QF average CSA] <b>Spasticity (Modified Ahsworth Scale)</b>	<b>Risk of Fall (TUG, talking while walking test)</b> [keep : TUG as most recommended tool]

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	<b>KE+HE power more/less affected side</b> [keep : more affected side]	<b>Balance (BBS)</b> <b>Spasticity (MAS)</b>	<b>Health status (SF-36)</b>
Lee (2013)	<b>HF/HE strength more affected (dynamic MVC, 90°/sec)</b> [keep : within-study analysis : HF/HE] <b>Gait (velocity)</b>		<b>Risk of Fall (TUG)</b>

Abbreviations: BBS: Berg Balance Scale ; CSA: cross sectional area; DF: dorsiflexors; FSS: Fatigue Severity Scale; HE/HF: hip extensors/flexors; KE/KF: knee extensors/flexors; MRI: magnetic resonance imaging; MVC: Maximum Voluntary Contraction; PDQ-39: Parkinson's Disease Questionnaire-39; QF: *quadriceps femoris*; RF: *rectus femoris*; RM: Repetition Maximum; SF-36: Short-Form 36 health survey; TUG: Time Up and Go test; VI: *vastus intermedius*; VL: *vastus lateralis* VM: *vastus medialis*; 6MWT: 6 minutes walk test; 10mWT: 10 metre walk test.

<sup>a</sup> data provided by the authors

### **Supplementary File 3.** Level of evidence according to the GRADE

Six domains are evaluated through GRADE approach: study design, RoB, indirectness, inconsistency, imprecision and publication bias.

Four levels of evidence can be attributed: 'high', 'moderate', 'low', and 'very low'.

For each outcome, a sequential analysis system was used.

Each outcome was initially as 'high' since only RCTs were included in this review.

The QoE was downgraded to 'moderate', 'low' or 'very low' level using the categories:

- i) RoB:  $\geq 50\%$  of trials had a RoB 2.0 overall judgment as 'high' (-2 levels) or 'some concerns' (-1 level);
- ii) inconsistency: substantial heterogeneity by a visual inspection in the forest plots ( $I^2$  statistic value  $> 50\%$  meaning substantial heterogeneity) (-1 level);
- iii) indirectness: substantial differences exist between the target population and samples from RCTs included in this review about the population, the intervention, or the outcomes measured (-1 level);
- iv) imprecision: a wide confidence interval of the averaged result (-1 level) or based on a total sample size  $< 800$  participants (-1 level);
- v) publication bias: by visualisation of the funnel plot (-1 level).

GRADE. Handbook for grading the quality of evidence and the strength of recommendations using the GRADE approach. 2013.

Balshem H, Helfand M, Schunemann HJ, et al. GRADE guidelines: 3. Rating the quality of evidence. *Journal of clinical epidemiology* 2011; 64(4):401-406.

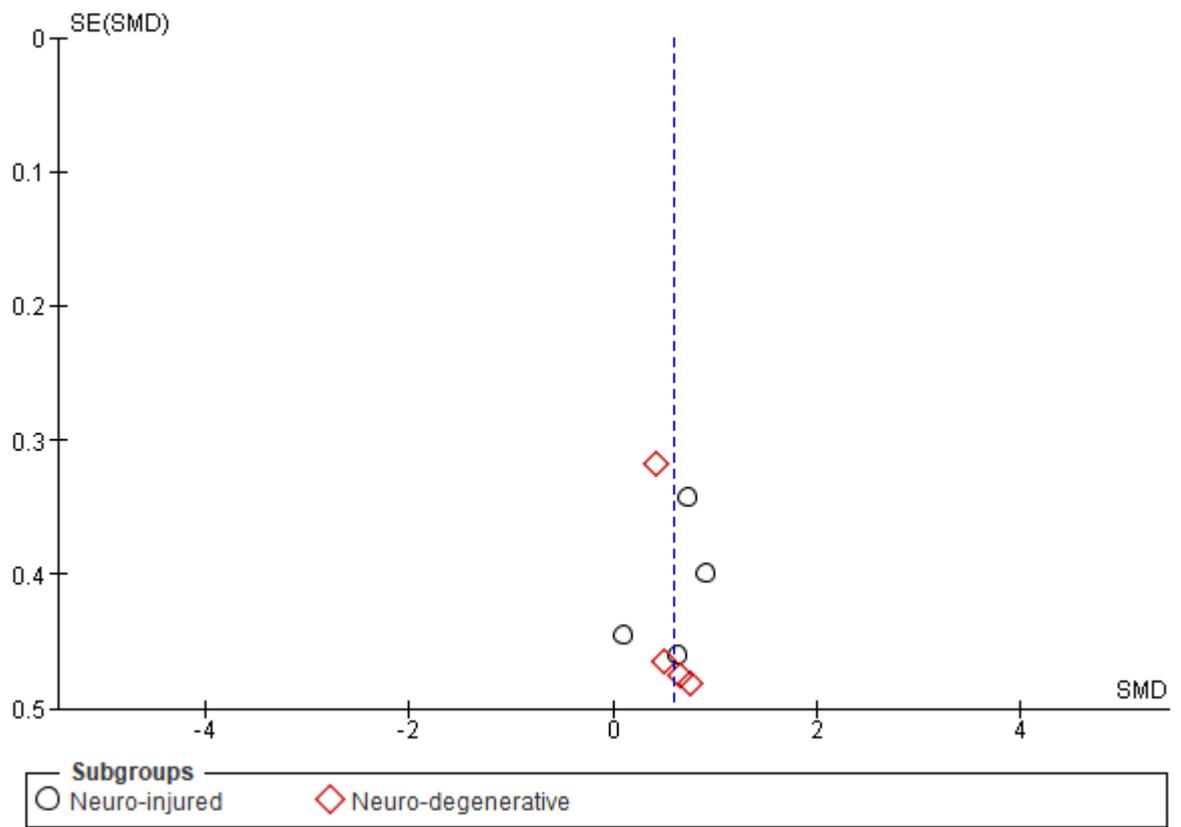
Guyatt G, Oxman AD, Kunz R, et al. Corrigendum to GRADE guidelines 6. Rating the quality of evidence-impresion. *J Clin Epidemiol* 2011;64:1283-1293. *Journal of clinical epidemiology* 2021; 137:265.

### **Eccentric resistance training vs comparator on physical function: strength**

The GRADE approach was applied to the pooled analysis of 8 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on the strength of muscles ( $P < 0.0001$  ; pooled standardised mean difference: 0.58; 95% CI 0.30 to 0.87).

<b>Overall result:</b> eccentric resistance training may improve muscle strength in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 6/8 (75%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’ or ‘high’.
<b>Inconsistency of results</b>	We did not downgrade the evidence due to heterogeneity of included studies as the heterogeneity between trials was not significant ( $P = 0.93$ , $I^2 = 0\%$ ).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had $n = 164 < 800$ participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

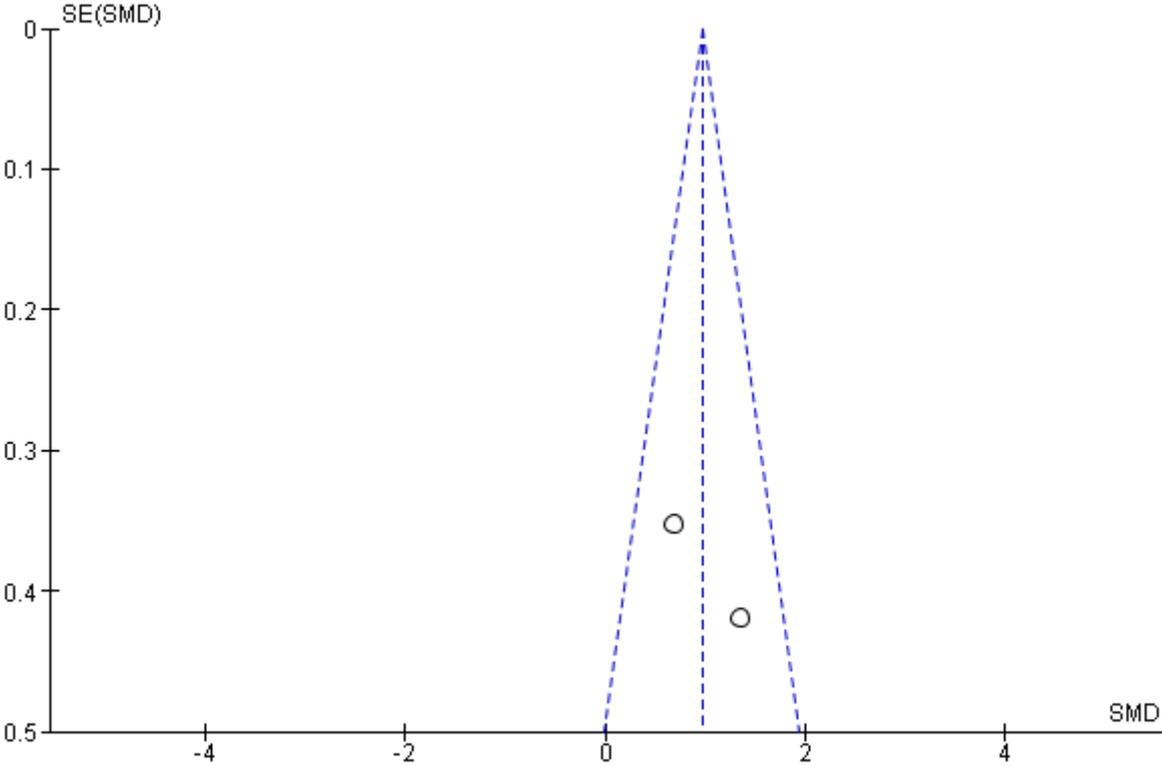


### **Eccentric resistance training vs comparator on muscle function: power**

The GRADE approach was applied to the pooled analysis of 2 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on the power of muscles (P=0.003; pooled standardised mean difference: 0.98; 95% CI 0.32 to 1.63).

<b>Overall result:</b> eccentric resistance training may improve muscle power in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 1/2 (50%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’.
<b>Inconsistency of results</b>	We did not downgrade the evidence due to heterogeneity of included studies as the heterogeneity between trials was not significant (P=0.22, I <sup>2</sup> =33%).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had n=63<800 participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

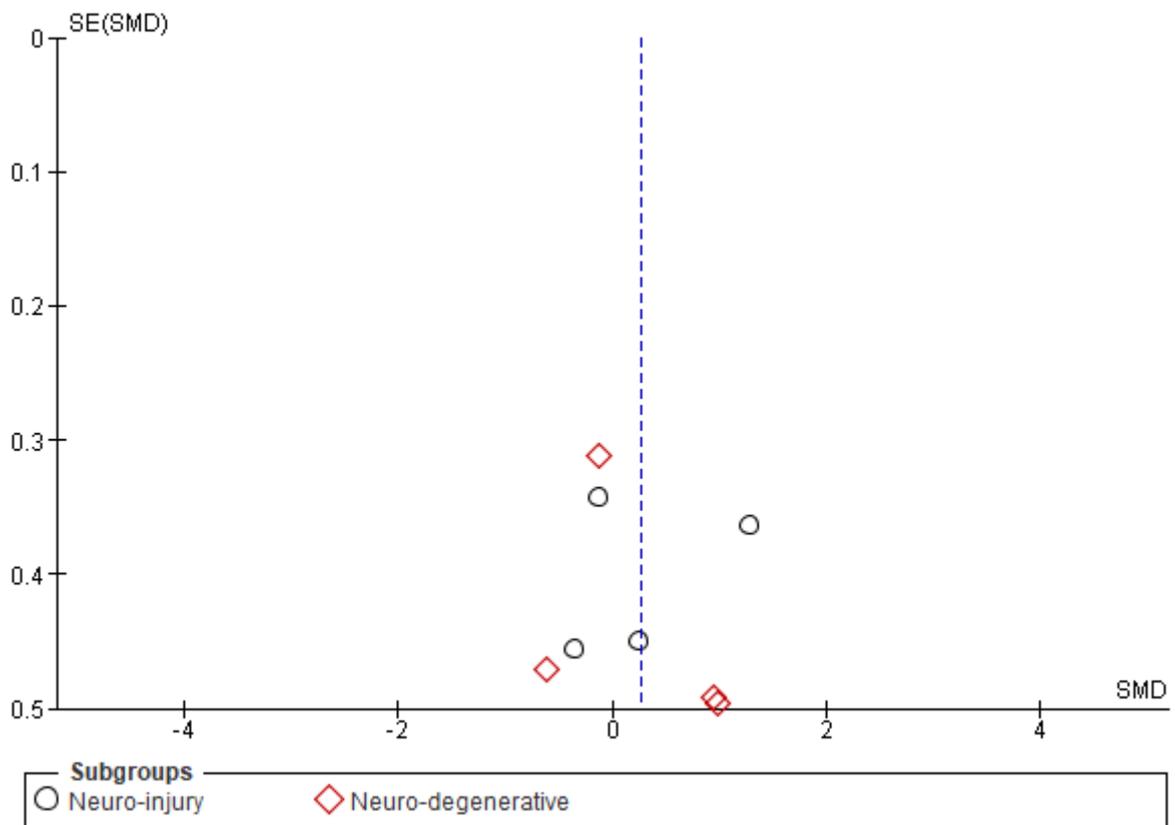


### **Eccentric resistance training vs comparator on gait**

The GRADE approach was applied to the pooled analysis of 8 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on gait (P=0.28; pooled standardised mean difference: 0.27; 95% CI -0.22 to 0.75).

<b>Overall result:</b> eccentric resistance training may not improve gait in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 7/8 (100%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’ or ‘high’.
<b>Inconsistency of results</b>	We downgraded the evidence due to heterogeneity of included studies as the heterogeneity between trials was high (p=0.005; I <sup>2</sup> =65%).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had n=209<800 participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

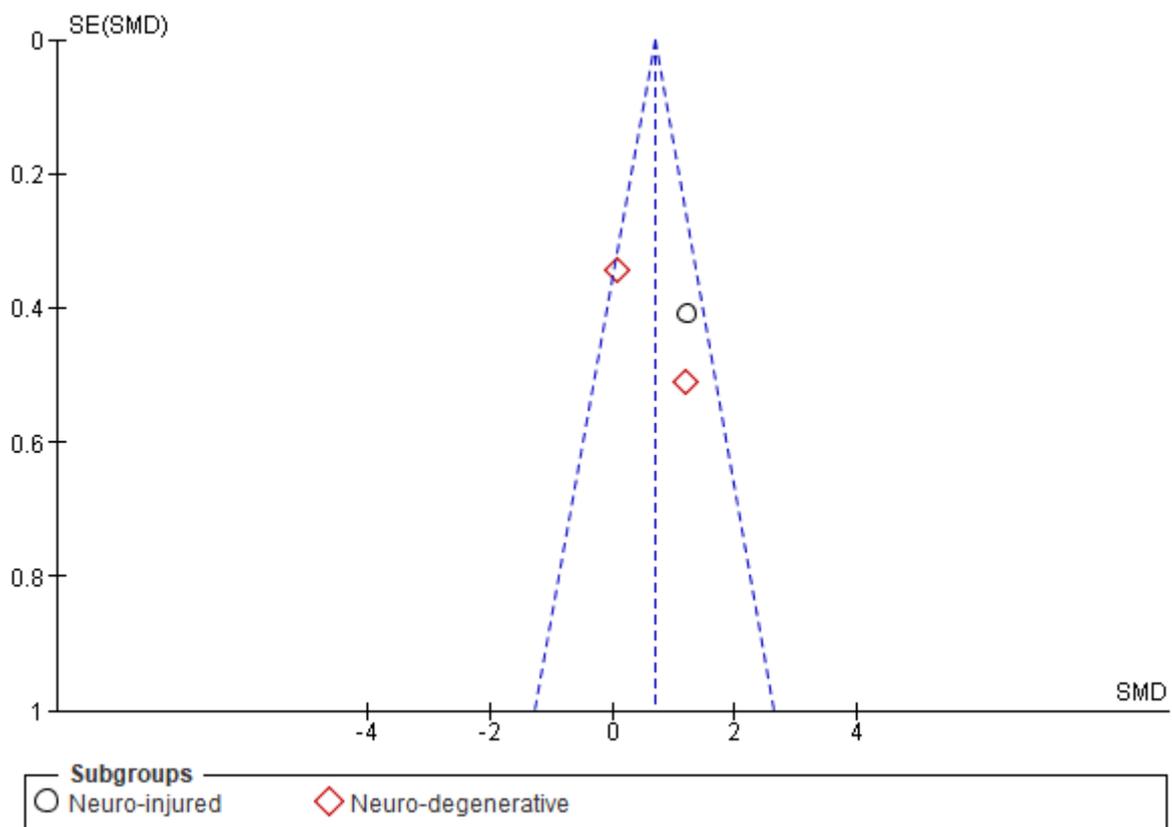


### Eccentric resistance training vs comparator on muscle structure (volume)

The GRADE approach was applied to the pooled analysis of 3 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on muscle structure (volume) (P=0.06; pooled standardised mean difference: 0.79; 95% CI -0.02 to 1.60).

<b>Overall result:</b> Eccentric resistance training may not improve muscle structure in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We did not downgrade the evidence as 2/3 (67%) of studies in the meta-analysis had a RoB 2.0 judgment as 'high'.
<b>Inconsistency of results</b>	We downgraded the evidence by one level as the heterogeneity between trials was substantial ( $I^2=66\%$ ).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had $n=54 < 800$ participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

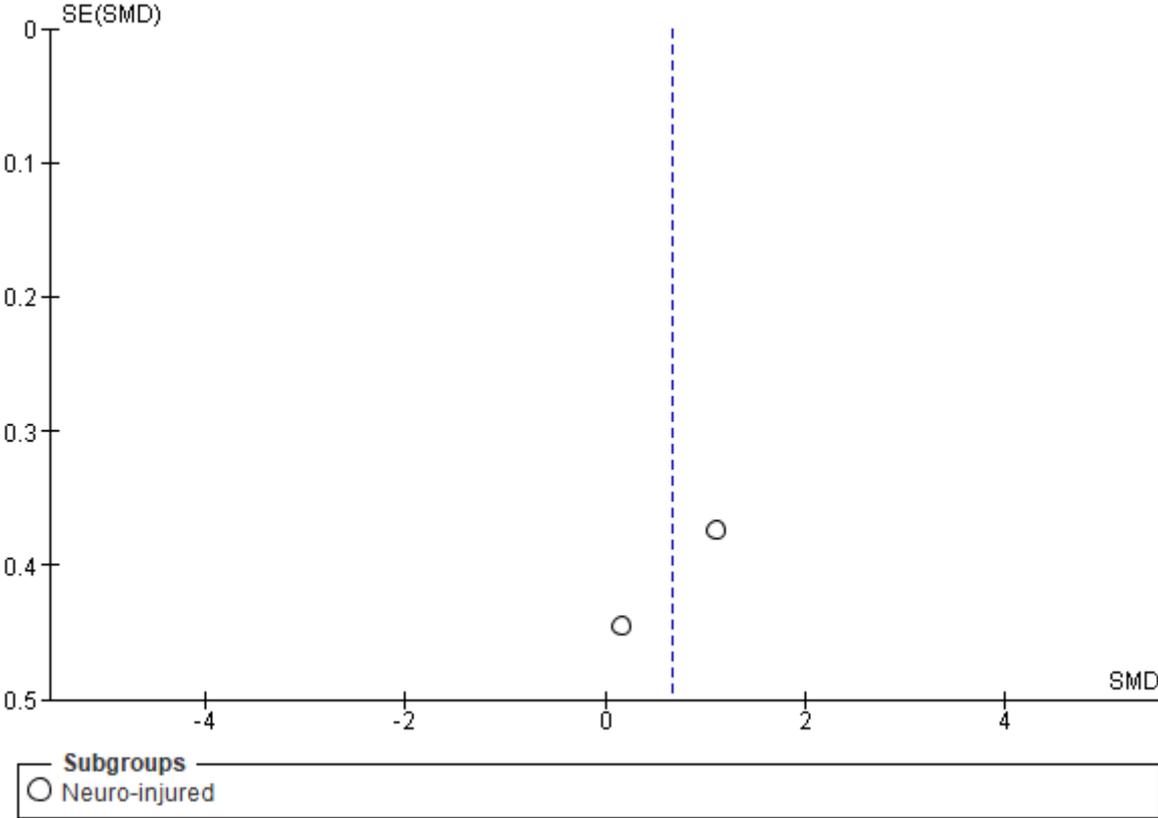


### **Eccentric resistance training vs comparator on muscle activity**

The GRADE approach was applied to the pooled analysis of 8 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on muscle activity (P=0.16; pooled standardised mean difference: 0.67; 95% CI -0.26 to 1.59).

<b>Overall result:</b> eccentric resistance training may not improve muscle activity in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 1/2 (50%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’ or ‘high’.
<b>Inconsistency of results</b>	We did not downgrade the evidence due to heterogeneity of included studies as the heterogeneity between trials was not significant (P=0.10, I <sup>2</sup> =63%).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had n=54<800 participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

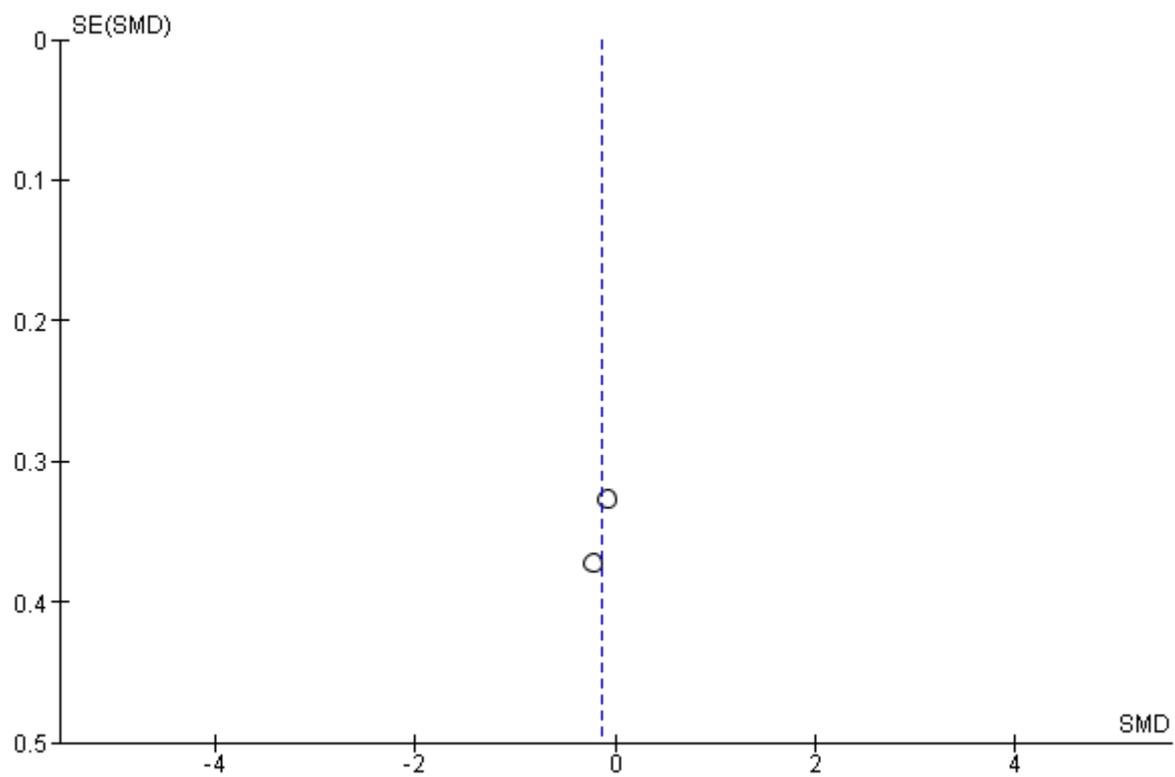


### Eccentric resistance training vs comparator on muscle spasticity

The GRADE approach was applied to the pooled analysis of 8 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on muscle tone (spasticity) (P=0.55; pooled standardised mean difference: -0.15; 95% CI -0.63 to 0.33).

<b>Overall result:</b> eccentric resistance training may not improve muscle spasticity in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 1/2 (50%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’.
<b>Inconsistency of results</b>	We did not downgrade the evidence due to heterogeneity of included studies as the heterogeneity between trials was not significant (P=0.79, I <sup>2</sup> =0%).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had n=66<800 participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

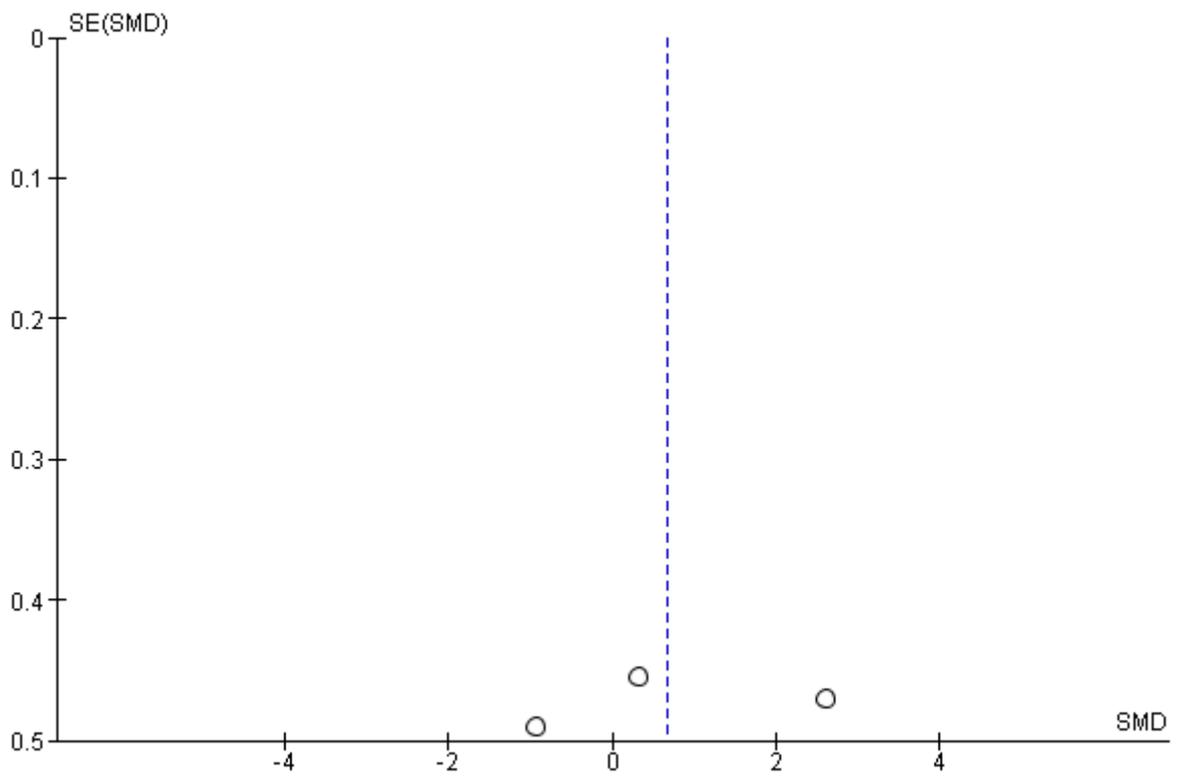


### Eccentric resistance training vs comparator on balance

The GRADE approach was applied to the pooled analysis of 3 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on balance (P=0.51; pooled standardised mean difference: 0.66; 95% CI -1.33 to 2.66).

<b>Overall result:</b> eccentric resistance training may not improve balance in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 2/3 (100%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’.
<b>Inconsistency of results</b>	We downgraded the evidence due to heterogeneity of included studies as the heterogeneity between trials was very high ( $p < 0.001$ , $I^2 = 93\%$ ).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had $n = 68 < 800$ participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.

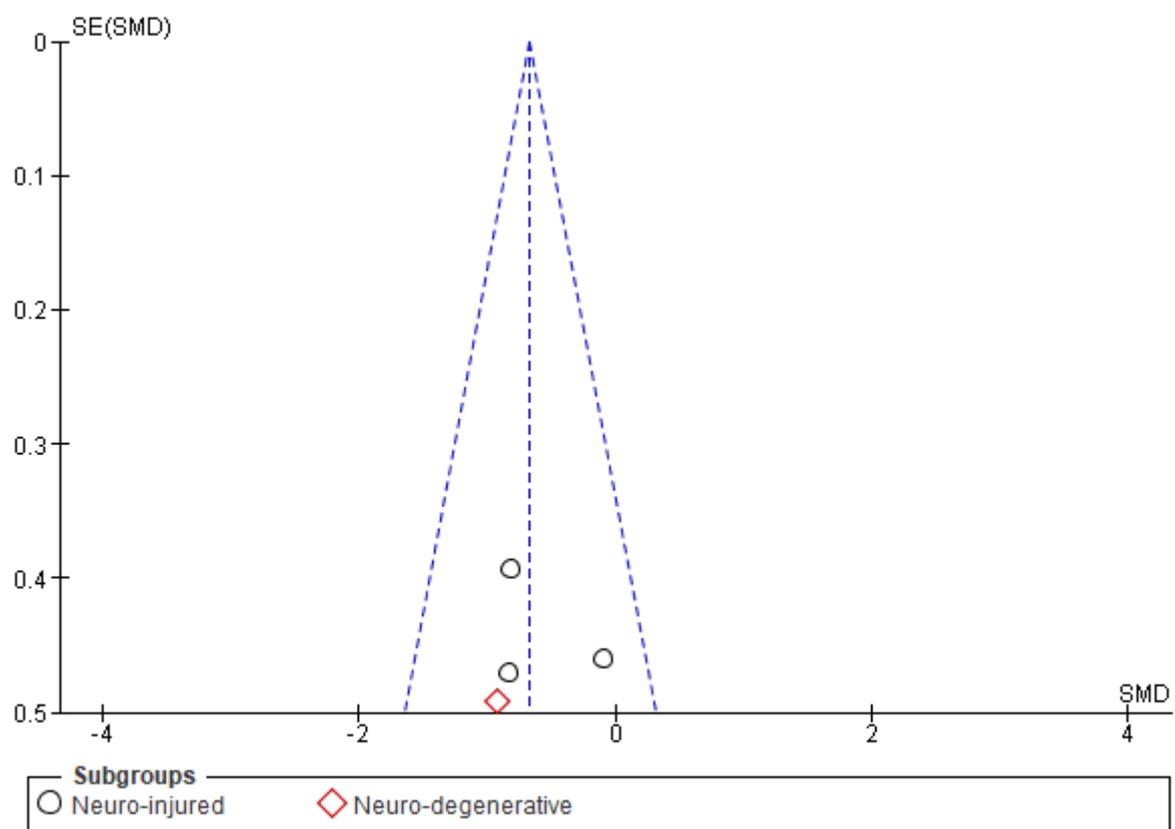


### Eccentric resistance training vs comparator on risk of fall

The GRADE approach was applied to the pooled analysis of 4 trials investigating the effects of eccentric resistance training compared to a control intervention/usual rehabilitation on risk of fall (P=0.003; pooled standardised mean difference: -0.67; 95% CI -1.11 to -0.23).

<b>Overall result:</b> eccentric resistance training may improve gait in neurological populations	
<b>Level of evidence:</b> Very low certainty We have very little confidence in the effect estimate. The true effect is likely to be substantially different from the estimate of effect.	
<b>Risk of Bias</b>	We downgraded the evidence by one level as 3/4 (75%) of studies in the meta-analysis had a RoB 2.0 judgment as ‘some concerns’ or ‘high’.
<b>Inconsistency of results</b>	We did not downgrade the evidence due to heterogeneity of included studies as the heterogeneity between trials was not significant (P=0.22, I <sup>2</sup> =33%).
<b>Indirectness of evidence</b>	Since we only included similar studies in terms of population, intervention, comparator and outcome, we did not downgrade the evidence based on this criterion.
<b>Imprecision</b>	We downgraded the evidence by two levels due to imprecision as the meta-analysis had n=87<800 participants analysed, and a wide CI interval.
<b>Publication bias</b>	We did not downgrade the evidence for publication bias since examination of funnel plot did not suggest serious small study effects.

Shading indicates the items that were downgraded.



**Supplementary File 4.** List of excluded studies and reasons for exclusion.

Title	Author	Year	DOI	Population	Intervention	Comparator	Outcome	Design	Other	Stage
Eccentric rehabilitation induces white matter plasticity and sensorimotor recovery in chronic spinal cord injury.	Faw, TD; Lakhani, B; Schmalbrock, P; Knopp, MV; Lohse, KR; Kramer, JLK; Liu, H; Nguyen, HT; Phillips, EG; Bratasz, A; Fisher, LC; Deibert, RJ; Boyd, LA; McTigue, DM; Basso, DM	2021	10.1016/j.expneurol.2021.113853	X	X		X			FT
Coexistence of neuronal intranuclear inclusion disease and amyotrophic lateral sclerosis: an autopsy case.	Sugiyama, A; Takeda, T; Koide, M; Yokota, H; Mukai, H; Kitayama, Y; Shibuya, K; Araki, N; Ishikawa, A; Isole, S; Ito, K; Honda, K; Yamanaka, Y; Sano, T; Saito, Y; Arai, K; Kuwabara, S	2021	10.1186/s12883-021-02306-5	X	X	X	X	X		T/A
Relationship between bone strength index of the hemiparetic tibial diaphysis and muscle strength in people with chronic stroke: influence of muscle contraction type and speed.	Yang, Z; Miller, T; Pang, MYC	2021	10.1007/s00198-020-05716-2		X	X	X	X		T/A
Magnetization Transfer Ratio and Morphometrics of the Spinal Cord Associates with Surgical Recovery in Patients with Degenerative Cervical Myelopathy.	Paliwal, M; Weber, KA 2nd; Hopkins, BS; Cantrell, DR; Hoggarth, MA; Elliott, JM; Dahdaleh, NS; Mackey, S; Parrish, TD; Dhaher, Y; Smith, ZA	2020	10.1016/j.wneu.2020.09.148		X	X	X			T/A
A New Surgical Approach for the Management of Acute Corneal Hydrops Complicated With Corneal Perforation.	Petrelli, M; Cohen, J; Hashemi, K; Grentzelos, MA; Kymionis, GD	2020	10.1097/ICO.0000000000002377	X	X	X	X	X		T/A
Comparative analysis of power, work and muscle activation during weight-stack and iso-inertial flywheel resistance exercise in young adults with cerebral palsy.	von Walden, F; Hjalmarsson, E; Reimeringer, M; Kvist, O; Raffalt, PC; Pontén, E; Fernandez-Gonzalo, R	2020	10.2340/16501977-2682		X					T/A
Effect of Eccentric Strength Training on Elbow Flexor Spasticity and Muscle Weakness in People With Multiple Sclerosis: Proof-of-Concept Single-System Case Series.	Manca, A; Martinez, G; Aiello, E; Ventura, L; Deriu, F	2020	10.1093/ptj/pzaa055			X		X		T/A
Sensitivity analysis of muscle properties and impact parameters on head injury risk in American football.	Mortensen, JD; Vasavada, AN; Merryweather, AS	2020	10.1016/j.jbiomech.2019.109411	X	X	X	X	X		T/A
Implementation of a Virtual Reality rendered in Portable Devices for Strabismus Treatment based on Conventional Visual Therapy.	Cepeda-Zapata, LK; Romero-Soto, FO; Diaz de Leon, VA; Roa-Huertas, JL; Naal-Ruiz, NE; Ibarra-Zarate, D; Alonso-Valerdi, LM	2019	10.1109/EMBC.2019.8857222	X	X	X	X	X		T/A
Visual search and target detection during simulated driving in Parkinson's disease.	Ranchet, M; Morgan, JC; Akinwuntan, AE; Devos, H	2020	10.1016/j.aap.2019.105328		X		X			FT
Effects of downslope walking on Soleus H-reflexes and walking function in individuals with multiple sclerosis: A preliminary study.	Hoque, M; Borich, M; Sabatier, M; Backus, D; Kesar, T	2019	10.3233/NRE-192701			X	X			T/A
EMG-Based Characterization of Walking Asymmetry in Children with Mild Hemiplegic Cerebral Palsy.	Di Nardo, F; Strazza, A; Mengarelli, A; Cardarelli, S; Tigrini, A; Verdini, F; Nascimbeni, A; Agostini, V; Knaflitz, M; Fioretti, S	2019	10.3390/bios9030082		X	X	X	X		T/A

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Spinal subependymoma surgery: do no harm. Little may be more!	Soleiman, HA; Ironside, J; Kealey, S; Demetriades, AK	2020	10.1007/s10143-019-01128-x	X	X	X	X	X		T/A	
Ultrasound-Guided Percutaneous Electrical Nerve Stimulation of the Radial Nerve for a Patient With Lateral Elbow Pain: A Case Report With a 2-Year Follow-up.	Soleiman, HA; Ironside, J; Kealey, S; Demetriades, AK	2019	10.2519/jospt.2019.8570	X	X	X		X		T/A	
Effects of backward-downhill treadmill training versus manual static plantarflexor stretching on muscle-joint pathology and function in children with spastic Cerebral Palsy.	Hösl, M; Böhm, H; Eck, J; Döderlein, L; Arampatzis, A	2018	10.1016/j.gaitpost.2018.07.171					X		T/A	
Strength and Step Activity After Eccentric Resistance Training in Those With Incomplete Spinal Cord Injuries.	Stone, WJ; Stevens, SL; Fuller, DK; Caputo, JL	2018	10.1310/sci17-00052			X				T/A	
Ambulation and physical function after eccentric resistance training in adults with incomplete spinal cord injury: A feasibility study.	Stone, WJ; Stevens, SL; Fuller, DK; Caputo, JL	2019	10.1080/10790268.2017.1417804			X				T/A	
Long-Term Regular Eccentric Exercise Decreases Neuropathic Pain-like Behavior and Improves Motor Functional Recovery in an Axonotmesis Mouse Model: the Role of Insulin-like Growth Factor-1.	Martins, DF; Martins, TC; Batisti, AP; Dos Santos Leonel, L; Bobinski, F; Belmonte, LAO; Mazzardo-Martins, L; Carginin-Ferreira, E; Santos, ARS	2018	10.1007/s12035-017-0829-3	X		X				T/A	
Effects of Classic Progressive Resistance Training Versus Eccentric-Enhanced Resistance Training in People With Multiple Sclerosis.	Patrocinio de Oliveira, CE; Moreira, OC; Carrión-Yagual, ZM; Medina-Pérez, C; de Paz, JA	2018	10.1016/j.apmr.2017.10.021			X				T/A	
The Subclinical Cardiomyopathy of Friedreich's Ataxia in a Pediatric Population.	Plehn, JF; Hasbani, K; Ernst, I; Horton, KD; Drinkard, BE; Di Prospero, NA	2018	10.1016/j.cardfail.2017.09.012		X	X	X	X		FT	
Mechanisms contributing to gait speed and metabolic cost in children with unilateral cerebral palsy.	Pinto, TPS; Fonseca, ST; Gonçalves, RV; Souza, TR; Vaz, DV; Silva, PLP; Mancini, MC	2018	10.1016/j.bjpt.2017.06.015		X	X	X	X		T/A	
Consideration of Dose and Timing When Applying Interventions After Stroke and Spinal Cord Injury.	Basso, DM; Lang, CE	2017	10.1097/NPT.000000000000165		X	X	X	X		T/A	
Effects of Exercise on Type 2 Diabetes Mellitus-Related Cognitive Impairment and Dementia.	Callisaya, M; Nosaka, K	2017	10.3233/JAD-161154	X	X			X		T/A	
Extrarenal rhabdoid tumor presented with an immobile arm in a one-year-old boy.	Chung, C; Liu, YL; Cheng, CJ; Hsieh, KLC; Tsai, ML; Wong, TT	2017	10.1016/j.braindev.2017.04.001		X	X	X	X		T/A	
Medial gastrocnemius and soleus muscle-tendon unit, fascicle, and tendon interaction during walking in children with cerebral palsy.	Barber, L; Carty, C; Modenese, L; Walsh, J; Boyd, R; Lichtwark, G	2017	10.1111/dmcn.13427		X			X		T/A	
Effectiveness and feasibility of eccentric and task-oriented strength training in individuals with stroke.	Folkerts, MA; Hijmans, JM; Elsinghorst, AL; Mulderij, Y; Murgia, A; Dekker, R	2017	10.3233/NRE-171433					X		T/A	
Blink-associated contralateral eccentric saccades as a rare sign of unilateral brain injury.	Zivi, I; Bertelli, E; Bilotti, G; Clemente, IA; Saltuari, L; Frazzitta, G	2017	10.1212/WNL.0000000000003484		X	X	X	X		T/A	
Contractile behavior of the medial gastrocnemius in children with bilateral	Hösl, M; Böhm, H; Arampatzis, A; Keymer, A; Döderlein, L	2016	10.1016/j.clinbiomech.2016.05.008		X	X		X		T/A	

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spastic cerebral palsy during forward, uphill and backward-downhill gait.											
Is better preservation of eccentric strength after stroke due to altered prefrontal function?	Hedlund, M; Lindström, B; Sojka, P; Lundström, R; Boraxbekk, CJ	2016	10.1080/13554794.2015.1130232	X	X			X		T/A	
Increased spinal reflex excitability is associated with enhanced central activation during voluntary lengthening contractions in human spinal cord injury.	Kim, HE; Corcos, DM; Hornby, TG	2015	10.1152/jn.01074.2014		X			X		T/A	
Simulated activity but real trauma: a systematic review on Nintendo Wii injuries based on a case report of an acute anterior cruciate ligament rupture.	Müller, SA; Vavken, P; Pagenstert, G	2015	10.1097/MD.000000000000648	X	X	X	X	X		T/A	
A systematic review and meta-analysis of strength training in individuals with multiple sclerosis or Parkinson disease.	Cruickshank, TM; Reyes, AR; Ziman, MR	2015	10.1097/MD.000000000000041					X		FT	
Energy flow analysis of the lower extremity during gait in persons with chronic stroke.	Novak, AC; Li, Q; Yang, S; Brouwer, B	2015	10.1016/j.gaitpost.2014.12.018		X	X		X		T/A	
Homocysteine-induced attenuation of vascular endothelium-dependent hyperalgesia in the rat.	Joseph, EK; Green, PG; Ferrari, LF; Levine, JD	2015	10.1016/j.neuroscience.2014.10.056	X	X	X	X	X		T/A	
Forward stair descent with hybrid neuroprosthesis after paralysis: Single case study demonstrating feasibility.	Bulea, TC; Kobetic, R; Audu, ML; Schnellenberger, JR; Pinault, G; Triolo, RJ	2014	10.1682/JRRD.2013.12.0257		X	X	X	X		T/A	
Long-term efficacy and complications of black diaphragm intraocular lens implantation in patients with traumatic aniridia.	Qiu, X; Ji, Y; Zheng, T; Lu, Y	2015	10.1136/bjophthalmol-2014-305581	X	X	X	X	X		T/A	
Defining success in infant penetrating keratoplasty for developmental corneal opacities.	Medsing, A; Speedwell, L; Nischal, KK	2014	10.3368/aoj.64.1.81	X	X	X	X	X		T/A	
A biomechanical cause of low power production during FES cycling of subjects with SCI.	Szeesi, J; Straube, A; Fornusek, C	2014	10.1186/1743-0003-11-123		X	X		X		T/A	
Muscle activation varies with contraction mode in human spinal cord injury.	Kim, HE; Thompson, CK; Hornby, TG	2015	10.1002/mus.24285		X	X	X	X		T/A	
Understanding stand-to-sit maneuver: implications for motor system neuroprostheses after paralysis.	Chang, SR; Kobetic, R; Triolo, RJ	2014	10.1682/JRRD.2013.12.0264		X	X		X		T/A	
Evaluation of fixation pattern and reading ability in patients with Leber hereditary optic neuropathy.	Altpeter, EK; Blanke, BR; Leo-Kottler, B; Nguyen, XN; Trauzettel-Klosinski, S	2013	10.1097/WNO.0b013e31829d1f5b		X	X	X	X		T/A	
Machine-based morphologic analysis of glioblastoma using whole-slide pathology images uncovers clinically relevant molecular correlates.	Kong, J; Cooper, LAD; Wang, F; Gao, J; Teodoro, G; Scarpace, L; Mikkelsen, T; Schniederjan, MJ; Moreno, C S; Saltz, JH; Brat, DJ	2013	10.1371/journal.pone.0081049	X	X	X	X	X		T/A	
Visual contrast sensitivity deficits in 'normal' visual field of patients with homonymous visual field defects due to stroke: a pilot study.	Clatworthy, PL; Warburton, EA; Tolhurst, DJ; Baron, JC	2013	10.1159/000354810		X	X	X	X		T/A	
Influence of contraction type, speed, and joint angle on ankle muscle weakness in Parkinson's disease: implications for rehabilitation.	Pang, MY; Mak, MK	2012	10.1016/j.apmr.2012.06.004		X	X		X		T/A	

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Transfer effects of training-induced visual field recovery in patients with chronic stroke.	Bergsma, DP; Elshout, JA; van der Wildt, GJ; van den Berg, AV	2012	10.1310/tsr1903-212		X	X	X	X		FT	
Effects of intensive physical rehabilitation on neuromuscular adaptations in adults with poststroke hemiparesis.	Andersen, LL; Zeeman, P; Jørgensen, JR; Bech-Pedersen, DT; Sørensen, J; Kjær, M; Andersen, JL	2011	10.1519/JSC.0b013e31822a62ef		X	X				T/A	
Increased power generation in impaired lower extremities correlated with changes in walking speeds in sub-acute stroke patients.	Brincks, J; Nielsen, JF	2012	10.1016/j.clinbiomech.2011.08.007		X					T/A	
Oculomotor behavior of hemianopic chronic stroke patients in a driving simulator is modulated by vision training.	Bergsma, DP; Leenders, MJA; Verster, JC; van der Wildt, GJ; van den Berg, AV	2011	10.3233/RNN-2011-604		X	X		X		T/A	
Tremor during movement correlates well with disability in people with essential tremor.	Norman, KE; D'Amboise, SN; Pari, G; Héroux, ME	2011	10.1002/mds.23811	X	X	X	X	X		T/A	
Recovery of visual-field defects after occipital lobe infarction: a perimetric study.	Çelebisoy, M; Çelebisoy, N; Bayam, E; Köse, T	2011	10.1136/jnnp.2010.214387	X	X	X	X	X		T/A	
Visual field expansion after visual restoration therapy.	Marshall, RS; Chmayssani, M; O'Brien, KA; Handy, C; Greenstein, VC	2010	10.1177/0269215510362323	X	X	X	X	X		T/A	
Low resonance frequency vibration affects strength of paretic and non-paretic leg differently in patients with stroke.	Tihanyi, J; Di Giminiani, R; Tihanyi, T; Gyulai, G; Trzaskoma, L; Horváth, M	2010	10.1556/APhysiol.97.2010.2.3		X					FT	
Stroke affects locomotor steering responses to changing optic flow directions.	Lamontagne, A; Fung, J; McFadyen, B; Faubert, J; Paquette, C	2010	10.1177/1545968309355985		X	X	X	X		T/A	
Neuromuscular adaptations to eccentric strength training in children and adolescents with cerebral palsy.	Reid, S; Hamer, P; A, Jacqueline; Lloyd, D	2010	10.1111/j.1469-8749.2009.03409.x					X		T/A	
Muscle torque preservation and physical activity in individuals with stroke.	Eng, JJ; Lomaglio, MJ; Macintyre, DL	2009	10.1249/MSS.0b013e31819aaad1		X	X		X		T/A	
Long-term learning of visual functions in patients after brain damage.	Mueller, I Gall, C; Kasten, E; Sabel, BA	2008	10.1016/j.bbr.2008.03.005		X	X		X		T/A	
Effect of botulinum toxin injection in the rectus femoris on stiff-knee gait in people with stroke: a prospective observational study.	Stoquart, GG; Detrembleur, C; Palumbo, S; Deltombe, T; Lejeune, TM	2008	10.1016/j.apmr.2007.08.131		X	X		X		FT	
Frequency of parafunctional oral habits in patients with cerebral palsy.	Ortega, AOL; Guimarães, AS; Ciamponi, AL; Marie, SKN	2007	10.1111/j.1365-2842.2006.01703.x		X	X	X	X		T/A	
Determinants of walking function after stroke: differences by deficit severity.	Patterson, SL; Forrester, LW; Rodgers, MM; Ryan, AS; Ivey, FM; Sorkin, JD; Macko, RF	2007	10.1016/j.apmr.2006.10.025		X	X		X		FT	
Temporal sensitivity in a hemianopic visual field can be improved by long-term training using flicker stimulation.	Raninen, A; Vanni, S; Hyvärinen, L; Näsänen, R	2007	10.1136/jnnp.2006.099366		X	X		X		T/A	
Activation impairment alters muscle torque-velocity in the knee extensors of persons with post-stroke hemiparesis.	Clark, DJ; Condliffe, Elizabeth G; Patten, C	2006	10.1016/j.clinph.2006.07.131		X	X		X		T/A	
Reliability of concentric and eccentric torque during isokinetic knee extension in post-stroke hemiparesis.	Clark, DJ; Condliffe, Elizabeth G; Patten, C	2006	10.1016/j.clinbiomech.2005.11.004		X	X	X	X		T/A	
[Amblyopia and strabismus in our environment].	Ebana MC; Ellong, A; Owona, D; Luma, H; Bella, LA	2005		X	X	X	X	X		T/A	

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What change in isokinetic knee muscle strength can be detected in men and women with hemiparesis after stroke?	Flansbjerg, UB; Holmbäck, AM; Downham, D; Lexell, J	2005	10.1191/0269215505cr854oa		X	X	X	X		T/A
Break-technique handheld dynamometry: relation between angular velocity and strength measurements.	Burns, S P; Spanier, DE	2005	10.1016/j.apmr.2004.12.041		X	X	X	X		T/A
Postural control in otolith disorders.	Basta, D; Todt, I; Scherer, H; Clarke, A; Ernst, A	2005	10.1016/j.humo.v.2005.04.002	X	X	X		X		FT
[Eccentric isokinetic strengthening in hamstrings of patients with multiple sclerosis].	Robineau, S; Nicolas, B; Gallien, P; Petrilli, S; Durufle, A; Edan, G; Rochcongar, P	2005	10.1016/j.anrmp.2004.04.005			X		X		T/A
Application of graph theory: prediction of glycogen synthase kinase-3 beta inhibitory activity of thiazolidinones as potential drugs for the treatment of Alzheimer's disease.	Kumar, V; Madan, AK	2005	10.1016/j.ejps.2004.10.013		X	X	X	X		T/A
Adults with cerebral palsy: walking ability after progressive strength training.	Andersson, C; Grooten, W; Hellsten, M; Kaping, K; Mattsson, E	2003	10.1017/s0012162203000446		X					T/A
Kinetic analysis of planned gait termination in healthy subjects and patients with balance disorders.	O'Kane, FW; McGibbon, CA; Krebs, DE	2003	10.1016/s0966-6362(02)00104-2		X	X	X	X		T/A
Predicting anticonvulsant activity of benzamides/benzylamines: computational approach using topological descriptors.	Sardana, S; Madan, A K	2002	10.1023/a:1021904803057	X	X	X	X	X		T/A
Effects of osteopathic manipulative treatment and concentric and eccentric maximal-effort exercise on women with multiple sclerosis: a pilot study.	Yates, HA; Vardy, Terence C; Kuchera, Michael L; Ripley, DD; Johnson, JC	2002			X	X				T/A
Contrast dependence of perceptual grouping in brain-damaged patients with visual extinction.	Pavlovskaya, M; Sagi, D; Soroker, N	2000	10.1163/156856800741289		X	X	X	X		T/A
Effects of thoraco-lumbar electric sensory stimulation on knee extensor spasticity of persons who survived cerebrovascular accident (CVA).	Wang, RY; Chan, RC; Tsai, MW	2000			X	X		X		FT
Development of fatigue during repeated eccentric-concentric muscle contractions of plantar flexors in patients with stroke.	Svantesson, UM; Sunnerhagen, KS; Carlsson, US; Grimby, G	1999	10.1016/s0003-9993(99)90024-2		X	X		X		T/A
"Task-oriented" exercise improves hamstring strength and spastic reflexes in chronic stroke patients.	Smith, GV; Silver, KH; Goldberg, AP; Macko, RF	1999	10.1161/01.str.30.10.2112		X	X		X		T/A
Isokinetic assessment of spasticity in subjects with traumatic spinal cord injury (ASIA A).	Franzoi, AC; Castro, C; Cardone, C	1999	10.1038/sj.sc.3100849		X	X		X		T/A
Limbal transplantation after chemical injuries of the eye.	Cardoen, L; Foets, B	1999			X	X	X	X		T/A
Eccentric exercise and neuroleptic malignant syndrome.	Gralton, E; Wildgoose, J; Donovan, W M; Wilkie, J	1998	10.1016/s0140-6736(98)08029-5	X						T/A
The spatial distribution of visual attention in hemineglect and extinction patients.	Smania, N; Martini, M C; Gambina, G; Tomelleri, G; Palamara, A; Natale, E; Marzi, CA	1998	10.1093/brain/121.9.1759		X	X	X	X		T/A
The standing heel-rise test in patients with upper motor neuron lesion due to stroke.	Svantesson, U; Osterberg, U; Grimby, G; Sunnerhagen, KS	1998			X	X	X	X		T/A

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Stretch-shortening contraction in Parkinson patients: evidence of normal muscle contraction execution with low efficiency.	Pedersen, SW; Oberg, B	1997			X	X	X	X		T/A	
Gait analysis, isokinetic muscle strength measurement in patients with Parkinson's disease.	Pedersen, SW; Oberg, B; Larsson, LE; Lindval, B	1997			X	X		X		T/A	
Isokinetic muscle strength and its association with neuropsychological capacity in cirrhotic alcoholics.	Tarter, RE; Panzak, G; Switala, J; Lu, S; Simkevitz, H; Van Thiel, D	1997		X	X	X	X	X		T/A	
Stretch-shortening cycle in patients with upper motor neuron lesions due to stroke.	Svantesson, U; Sunnerhagen, KS	1997	10.1007/s004210050166		X	X		X		T/A	
Community photoscreening of six to nine month old infants for amblyopiogenic risk factors.	Hope, C; Roulston, J; Hoey, C; Wong, A; Clover, G	1994	10.1111/j.1442-9071.1994.tb01716.x	X	X	X	X	X		T/A	
Neurovisual rehabilitation in cerebral blindness.	Kerkhoff, G; Münsinger, U; Meier, EK	1994	10.1001/archneur.1994.00540170050016		X	X	X	X		T/A	
Eccentric and concentric muscle performance in patients with spastic paresis secondary to motor neuron disease. A preliminary report.	Griffin, JW; Tooms, RE; Vander Zwaag, R; O'Toole, ML; Bertorini, TE	1994	10.1016/0960-8966(94)90004-3		X	X		X		T/A	
Rising and sitting down in stroke patients. Auditory feedback and dynamic strength training to enhance symmetrical body weight distribution.	Engardt, M	1994			X	X	X	X		T/A	
The problem of macular sparing after unilateral occipital lesions.	Sugishita, M; Hemmi, I; Sakuma, I; Beppu, H; Shiokawa, Y	1993	10.1007/BF00870664	X	X	X	X	X		T/A	
Adaptive control of functional neuromuscular stimulation-induced knee extension exercise.	Ezenwa, BN; Glaser, RM; Couch, W; Figoni, SF; Rodgers, MM	1991	10.1682/jrtd.1991.10.0001		X	X		X		FT	
Group training in parkinsonism: quantitative measurements of treatment.	Pedersen, W; Oberg, B; Insulander, A; Vretman, M	1990			X	X	X	X		T/A	
[Central dysregulations as a cause of movement disorders in performance sports? An analysis of movement in sports with reference to functional anatomic and neurophysiologic viewpoints].	Sommer, HM; von Rohrscheidt, C	1988	10.1055/s-2007-993660	X	X	X	X	X		T/A	
Visual field rehabilitation in the cortically blind?	Balliet, R; Blood, KM; Bach-y-Rita, P	1985	10.1136/jnnp.48.11.1113		X	X	X	X		T/A	
Visual field recovery from scotoma in patients with postgeniculate damage. A review of 55 cases.	Zihl, J; von Cramon, D	1985	10.1093/brain/108.2.335		X	X	X	X		T/A	
Restitution of visual field in patients with damage to the geniculostriate visual pathway.	Zihl, J; von Cramon, D	1982			X	X	X	X	X	T/A	
Are the dominant eyes of amblyopes normal?	Kandel, GL; Grattan, PE; Bedell, HE	1980	10.1097/00006324-198001000-00001	X	X	X	X	X		T/A	
[Better prognosis for amblyopics by means of full prismatic correction after monocular treatment (author's trans)].	Pestalozzi, D; Schwarzenbach, A	1979		X	X	X	X	X		T/A	
A displaced Stiles-Crawford effect associated with an eccentric pupil.	Bonds, AB; MacLeod, DI	1978		X	X	X	X	X		T/A	
[On the occlusive treatment of amblyopia with eccentric fixation].	Priegnitz, F; Zimmer, R	1965		X	X	X	X	X		T/A	

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Finishing stationary cycling too early after anterior cruciate ligament reconstruction is likely to lead to higher failure	Sonkodi, B; Varga, E; Hangody, L; Poór, G; Berkes, I		10.1186/s13102-021-00377-y	X	X	X	X	X		T/A	
X-ray diffraction analysis to explore molecular traces of eccentric contraction on rat skeletal muscle parallelly evaluated with signal protein phosphorylation levels	Hirano, K; Yamauchi, H; Nakahara, N; Kinoshita, K; Yamaguchi, M; Takemori, S		10.3390/ijms22312644	X	X	X	X	X		T/A	
Eccentric exercise causes delayed sensory nerve conduction velocity but no repeated bout effect in the flexor pollicis brevis muscles	Ochi, E; Ueda, H; Tsuchiya, Y; Nakazato, K		10.1007/s00421-021-04773-7		X	X	X	X		T/A	
Delayed onset muscle soreness (Doms): The repeated bout effect and chemotherapy-induced axonopathy may help explain the dying-back mechanism in amyotrophic lateral sclerosis and other neurodegenerative diseases	Sonkodi, B		10.3390/brainsci11010108	X	X	X	X	X		T/A	
"going Backward": Effects of age and fatigue on posterior-directed falls in Parkinson disease	Papa, EV; Patterson, RM; Bugnariu, N		10.3233/NRE-210040		X	X	X	X		T/A	
Spider as a rehabilitation tool for patients with neurological disabilities: The preliminary research	Glowinski, S; Blazejewski, A		10.3390/jpm10020033		X	X		X		T/A	
Measuring Motor Fatigability in the Upper Limbs in Individuals With Neurologic Disorders: A Systematic Review	Brauers, L; Rameckers, E; Severijns, D; Feys, P; Smeets, R; Klingels, K		10.1016/j.apmr.2019.11.015		X	X		X		T/A	
Reliability of isokinetic knee strength measurements in children: A systematic review and meta-analysis	Muñoz-Bermejo, L; Pérez-Gómez, J; Manzano, F; Collado-Mateo, D; Villafaina, S; Adsuar, JC		10.1371/journal.pone.0226274		X	X		X		T/A	
Mechanomyography-based muscle fatigue detection during electrically elicited cycling in patients with spinal cord injury	Naeem, J; Hamzaid, NA; Islam, MA; Azman, AW; Bijak, M		10.1007/s11517-019-01949-4		X	X	X	X		T/A	
Measuring motor fatigability in the upper limb in subjects with neurological disorders: A systematic review	Brauers, L; Rameckers, E; Severijns, D; Feys, P; Smeets, R; Klingels, K		10.1111/dmcn.14244		X	X		X		T/A	
The mystery behind the exercise-induced muscle damage	Qamar, MM; Javed, MS; Dogar, MZUH; Basharat, A; Rasul, A				X	X	X	X		FT	
Adaptation to poststroke visual field loss: A systematic review	Howard, C; Rowe, FJ		10.1002/brb3.1041		X	X	X	X		T/A	
Eicosahexanoic acid (EPA) and docosahexanoic acid (DHA) in muscle damage and function	Ochi, E; Tsuchiya, Y		10.3390/nu10050552	X	X	X	X	X		T/A	
Effect of insoles with arch support on gait pattern in patients with multiple sclerosis	Güner, S; Haghari, S; Alsancak, S; Uluğ, N; İnanıcı, F		10.5606/tftrd.2018.2246		X					T/A	
Muscle strength and power in persons with multiple sclerosis – A systematic review and meta-analysis	Jørgensen, MLK; Dalgas, U; Wens, I; Hvid, LG		10.1016/j.jns.2017.03.022		X	X		X		T/A	
Medial gastrocnemius fascicle function during walking in children with cerebral palsy following gastrocnemius lengthening surgery	Barber, LA; Carty, C; Walsh, J; Boyd, RN; Lichtwark, GA		10.1111/dmcn.13455		X	X				T/A	
How to restore shoulder external rotation in erb's palsy	Afzal, F; Manzoor, S; Afzal, A			X	X	X	X	X		T/A	

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The effect of maximal strength training on strength, walking, and balance in people with multiple sclerosis: A pilot study	Karpatkin, HI; Cohen, ET; Klein, S; Park, D; Wright, C; Zervas, M		10.1155/2016/5235971		X			X		FT	
Promoting Physical Activity Through a Manual Wheelchair Propulsion Intervention in Persons with Multiple Sclerosis	Rice, IM; Rice, LA; Motl, RW		10.1016/j.apmr.2015.06.011		X	X	X	X		T/A	
Pronounced decrease in concentric strength following stroke due to pre-frontally mediated motor inhibition	Hedlund, M; Lindström, B; Sojka, P; Lundström, R; Olsson, C-J		10.1016/j.physio.2015.03.3368		X	X	X	X		T/A	
Chronic stroke patients show early and robust improvements in muscle and functional performance in response to eccentric-overload flywheel resistance training: A pilot study	Fernandez-Gonzalo, R; Nissemark, C; Åslund, B; Tesch, PA; Sojka, P		10.1186/1743-0003-11-150			X		X		T/A	
Beware the kettlebell	Calzetta, MA; Barnes, MB			X	X	X	X	X		T/A	
Treatment of muscle haematomas in haemophiliacs with special emphasis on percutaneous drainage	De La Corte-Rodriguez, H; Rodriguez-Merchan, EC		10.1097/MBC.000000000000159	X	X	X	X	X		T/A	
Effects of 8 weeks of water-based exercise on the lower limb muscles strength in parkinson's patients	Azizi, S; Kargarfard, M; Azizi, R				X			X		T/A	
An overview of animal models of pain: Disease models and outcome measures	Gregory, NS; Harris, AL; Robinson, CR; Dougherty, PM; Fuchs, PN; Sluka, KA		10.1016/j.jpain.2013.06.008	X	X	X	X	X		T/A	
Positive and negative work during walking in children with cerebral palsy	Van De Walle, P; Hallemans, A; Molenaers, G; De Beeck, NO; Desloovere, K		10.1016/j.gaitpost.2013.07.155		X	X		X		T/A	
Mirror training to augment cross-education during resistance training: A hypothesis	Howatson, G; Zult, T; Farthing, JP; Zijdwind, I; Hortobágyi, T		10.3389/fnhum.2013.00396	X	X	X	X	X		T/A	
160th ENMC International Workshop (First ENMC practical care workshop) Exercise training in patients with muscle diseases. 20-22 June 2008, Naarden, The Netherlands.	Vissing, J; van Engelen, BGM		10.1016/j.nmd.2012.08.005	X	X	X	X	X		T/A	
Isokinetic assessment of muscle function: Our experience with patients afflicted with selected diseases of the nervous system	Lexell, J; Flansbjerg, U-B; Brogårdh, C		10.3233/IES-2012-0478		X	X		X		T/A	
Isokinetic knee extension and flexion strength in individuals with hemiparesis after stroke	Flansbjerg, UB; Lexell, J		10.3233/IES-2012-0446		X	X		X		T/A	
Torque-angle relationship are better preserved during eccentric compared to concentric contractions in patients with stroke	Hedlund, M; Sojka, P; Lundström, R; Lindström, B		10.3233/IES-2012-0455		X	X		X		T/A	
Strength and aerobic requirements during stair ambulation in persons with chronic stroke and healthy adults	Novak, AC; Brouwer, B		10.1016/j.apmr.2011.10.009		X	X		X		T/A	
Insufficient loading in stroke subjects during conventional resistance training	Hedlund, M; Sojka, P; Lundström, R; Lindström, B		10.3109/14038196.2012.658861		X	X	X	X		T/A	
Ankle muscle weakness in individuals with parkinson's disease: The influence of contraction type, speed, and joint angle	Pang, MYC; Mak, MKY		10.1016/j.hkjp.2011.08.026		X	X		X		T/A	
Atrophy and intramuscular fat in specific muscles of the thigh: Associated weakness and hyperinsulinemia in stroke survivors	Ryan, AS; Buscemi, A; Forrester, L; Hafer-Macko, CE; Ivey, FM		10.1177/1545968311408920		X	X		X		T/A	

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The positive effect of mirror visual feedback on arm control in children with Spastic Hemiparetic Cerebral Palsy is dependent on which arm is viewed	Smorenburg, ARP; Ledebt, A; Feltham, MG; Deconinck, FJA; Savelsbergh, GJP		10.1007/s00221-011-2789-6		X	X		X		T/A	
Chemodervation of the antagonist muscle	Gaber, TA; Azer, A; Basu, B; Mannemela, S		10.1007/s00415-011-6026-9		X	X		X		T/A	
Analgesics and Anti-inflammatory Medications in Sports: Use and Abuse	Feucht, CL; Patel, DR		10.1016/j.pcl.2010.02.004	X	X	X	X	X		T/A	
Upper limb targeted complex rehabilitation with mechanotherapy in acute stroke patients	Samsygina, OM; Ivanova, GE; Kovrazhkina, EA		10.1159/000321266		X					T/A	
Elbow Tendinopathy and Tendon Ruptures: Epicondylitis, Biceps and Triceps Ruptures	Rineer, CA; Ruch, DS		10.1016/j.jhsa.2009.01.022	X	X	X	X	X		FT	
Disorders of the Achilles tendon	Duerden, JD; Keeling, JJ		10.1097/BCO.0b013e3282f379ad	X	X	X	X	X		T/A	
One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke	Tihanyi, TK; Horváth, M; Fazekas, G; Hortobágyi, T; Tihanyi, J		10.1177/0269215507077814		X					T/A	
Functional output improvement in FES cycling by means of forced smooth pedaling	Szelesi, J; Krause, P; Krafczyk, S; Brandt, T; Straube, A		10.1249/mss.0b013e3180334966		X			X		T/A	
The Safety and Feasibility of High-Force Eccentric Resistance Exercise in Persons With Parkinson's Disease	Dibble, LE; Hale, T; Marcus, RL; Gerber, JP; LaStayo, PC		10.1016/j.apmr.2006.05.016					X		T/A	
Reproducibility analysis of isokinetic strength measurements of shoulder and elbow muscles in subjects with spinal cord injury	Kakebeeke, TH; Lechner, HE; Handschin, C		10.3233/ies-2005-0215		X	X	X	X		T/A	
Eccentric exercise in patients with chronic health conditions: a systematic review	Roig M; Shadgan B; Reid WD	2008		X				X		FT	
Uphill and downhill walking in multiple sclerosis: a randomized controlled trial [with consumer summary]	Samaei A; Bakhtiary AH; Hajihassani A; Fatemi E; Motaharinezhad F	2016			X					T/A	
One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke [with consumer summary]	Tihanyi TK; Horvath M; Fazekas G; Hortobagy T; Tihanyi J	2007			X					T/A	
Effects of concentric and eccentric control exercise on gross motor function and balance ability of paretic leg in children with spastic hemiplegia	Park SI; Kim M-S; Choi JD	2016			X					T/A	
Effects of backward-downhill treadmill training versus manual static plantarflexor stretching on muscle-joint pathology and function in children with spastic cerebral palsy [with consumer summary]	Hosl M; Bohm H; Eck J; Doderlein L; Arampatzis A	2018			X					T/A	
Effects of high resistance training in patients with myotonic dystrophy	Tollback A; Eriksson S; Wredenberg A; Jenner G; Vargas R; Borg K; Ansved T	1999			X	X		X		T/A	
The effect of a high resistance exercise program in slowly progressive neuromuscular disease	Kilmer DD; McCrory MA; Wright NC; Aitkens SG; Bernauer EM	1994			X					T/A	
Physical activity and exercise for chronic pain in adults: an overview of Cochrane	Geneen LJ; Moore RA; Clarke C; Martin D; Colvin LA; Smith BH	2017		X	X			X		FT	

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reviews (Cochrane review) [with consumer summary]											
Effectiveness of surgical and non-surgical management of crouch gait in cerebral palsy: a systematic review [with consumer summary]	Galey SA; Lerner ZF; Bulea TC; Zimble S; Damiano DL	2017			X	X		X		FT	
Efficacy of gait training using a treadmill with and without visual biofeedback in patients after stroke: a randomized study	Druzicki M; Guzik A; Przysada G; Kwolek A; Brzozowska-Magon A	2015			X					T/A	
Combined effects of Botulinum toxin and casting treatments on lower limb spasticity after stroke	Farina S; Migliorini C; Gandolfi M; Bertolasi L; Casarotto M; Manganotti P; Fiaschi A; Smania N	2008			X	X				T/A	
The effect of exercise training in improving motor performance and corticomotor excitability in people with early Parkinson's disease	Fisher BE; Wu AD; Salem GJ; Song J; Lin C-HJ; Yip J; Cen S; Gordon J; Jakowec M; Petzinger G	2008			X	X				FT	
A randomized controlled trial of early surgery in Duchenne muscular dystrophy	Manzur AY; Hyde SA; Rodillo E; Heckmatt JZ; Bentley G; Dubowitz V	1992			X					FT	
Reduction of spasticity in cerebral palsy using feedback of the tonic stretch reflex: a controlled study	O'Dwyer N; Neilson P; Nash J	1994			X	X		X		T/A	
Blood Flow Restriction Exercise for Those With SCI	McDaniel, J	2021		X	X					T/A	
Effects of Flywheel Exercise on Muscle and Walking Function in Teenagers and Young Adults With Cerebral Palsy	Fernandez Gonzalo, R	2017						X		T/A	
Investigation of the Effects of Selective Exercise Training in Multiple Sclerosis	Firat, T	2021							X	FT	no data available
Intensive cycle ergometer training improves gait speed and endurance in patients with Parkinson's disease: a comparison with treadmill training	Arcolin, I; Pisano, F; Delconte, C; Godi, M; Schieppati, M; Mezzani, A; Picco, D; Grasso, M; Nardone, A	2016	10.3233/RNN-150506		X					T/A	
Training and Parkinson's	Signorile, J	2018			X					T/A	
Botulinum Toxin Type A and Kinesitherapy of Post-stroke Patients	Melo, A	2009			X			X		T/A	
Comparison of Concentric or Eccentric Virtual Reality Training Program in Subacute-stroke Patients With Hemispatial Neglect	Deog Young, K	2020			X					T/A	
Eccentric Contraction-based Resistance Exercise for Chronic Stroke Patients	Lim, JY	2020							X	FT	no data available
Improving Stretching Interventions for Children With Cerebral Palsy	O'Brien TD	2016			X					FT	
Stretching in Children and Adolescents With Spastic Cerebral Palsy	Kruse, A	2020			X					FT	
Progressive Functional Strength Training in Unilateral Spastic Cerebral Palsy	Kara, OK	2015			X					T/A	
Amblyopia and Stereoptic Games for Vision	Steffen, H	2021		X	X	X		X		T/A	
Treadmill in the Rehabilitation of Parkinsonian Gait	Tassorelli, C	2019			X			X		T/A	
Radial Extracorporeal Shock Wave Therapy for Spastic Plantar Flexor Muscles in Young Children With Cerebral Palsy	Jia, F	2016			X			X		T/A	

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Tendon Vibrations Effect on Upper Limb Motor Recovery After Recent Stroke	Yelnik, A	2021			X					T/A	
Intervention Assessing the Role of Exercise Program and Nutrition Supplement for Sarcopenia	Chan, R	2017			X					T/A	
Effects of Sleep Deprivation on Blood Hormones and Inflammatory Status After Exercise Induced-muscle Damage	Mello, MT	2013			X		X	X		T/A	
The Effects of Functional Power Training on Frail and Pre-frail Community - Dwelling Older Adults in Singapore	Wee, SL	2020		X						FT	
Study of Epicutaneously Applied Ketoprofen Transfersome® Gel With or Without Combination With Oral Celecoxib for the Treatment of Muscle Pain Induced by Eccentric Exercise	Xpert Med GmbH				X				X	T/A	
Different Proprioceptive Neuromuscular Facilitation (PNF) Technique in Patients With Knee Osteoarthritis	Can, F	2021		X	X					FT	
Effect of Open Kinetic Chain Shoulder Exercises on Scapulothoracic Muscle Activity on Stable and Unstable Ground	Canli, K	2022			X					T/A	
Exercises With Elastic Bands and Stability in Proprioception and Strength in Female Athletes of Taekwondo	Investigación en Hemofilia y, Fisioterapia	2020		X	X					T/A	
Somatosensory Dysfunction as the Underlying Mechanism of Upper Limbs Motor Blocks in People With Parkinson's Disease	Nieuwboer, A	2016			X			X		T/A	
Vibrational-proprioceptive Resistance Exercise Training Versus Neuromuscular Electrical Stimulation Training in Elderly People With Muscle Weakness	Kern, H	2014		X						T/A	
Pilates Method in People With HAM/TSP	Pedreira, E	2018			X					T/A	
Effect of Body Suspension and Tilting Exercises in Parkinson's Disease	De Oliveira, CB	2016			X					T/A	
Whole-body Electromyostimulation in Inpatient Rehabilitation	Mooren, F	2020			X					T/A	
Functional Vision in TBI	Schuchard, R	2013			X			X		T/A	
Detection and Treatment of Sarcopenia and Myosteatosis in Older African Americans	Harris-Love, M	2021			X					T/A	
Kabat Technique and Neuromuscular Effect in Patients With Bell's Palsy	Saeed, A	2020		X	X					T/A	
Contralateral Strength-training After Anterior Cruciate Ligament (ACL) Reconstruction	Maffioletti, NA	2015		X						T/A	
Effects of Eccentric Training Intervention in Older Adults	Lim, JY	2019		X						T/A	
Somatic Yoga and Meditation for Cancer Survivors With Pain From Neuropathy	Galantino, ML	2019		X	X					FT	
Two Resistance Training Protocols to Reduce the Risk of Falls in Parkinson's Disease	Intzandt, B	2016			X				X	T/A	

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The Effect of Isokinetic Strengthening Training	Cheng, YY	2022				X				T/A	
Mobility Training Using a Bionic Knee Orthosis in Patients Chronic Post-Stroke: A Case Series	Byl, NN	2011			X			X		T/A	
The Effect of the Reverse Nordic Curl Exercise on Quadriceps Femoris Muscles Injury Rate Among Soccer Players	Al Attar, WSA	2021		X			X			T/A	
Resistance Exercise Modify Cardiovascular Responses of Professors During Teaching and Sleep	Teixeira-Araujo, AA	2014		X	X		X			T/A	
High Intensity Interval Training in Chronic Stroke Patients	Smania, N	2016			X					T/A	
Low-Volume Interval Training and Resistance Exercise in Individual With Stroke	Abd Manaf, MH	2021						X	FT		no data available
Effects of Variable Load Exercise on Aging Atrophy	Pisot, R	2020		X						T/A	
Physical Exercises for Temporomandibular Disorders	Bernhardt, O	2022		X						FT	
Efficacy of Exercise on Post Needling Soreness	Fernández-de-las-Peñas, C	2019		X						FT	
Exercise and Neuroprotection in Older Persons With Multiple Sclerosis	Jørgensen, MLK	2024						X	T/A		no data available
Metabolic Health in Individuals With Spinal Cord Injury (SCI)	Yarar-Fisher, C	2022			X					T/A	
Maximizing Mechanisms of Muscle Hypertrophy to Combat Sarcopenia in Older Adults	Stec, MJ	2012		X				X		T/A	
Muscle Damage and Disuse Atrophy	University of Exeter	2019		X	X					FT	
Muscle Weakness and Post-traumatic Knee OA	Chmielewski, T	2013		X						T/A	
Daily Undulating Periodization Methods With Parkinson's Disease	Signorile, JF	2019		X						T/A	
Structural and Metabolic Determinants of Sarcopenia and the Efficacy of Concentric vs. Eccentric Exercise Training	Narici, MV	2017		X						T/A	
Effects of Parmigiano Reggiano on Muscle and Inflammatory Response to Eccentric Resistance Training in Older Adults	Moro, T	2022		X						T/A	
Effects of High-velocity Resistance Training and Creatine Supplementation in Healthy Aging Males	Candow, DG	2018		X	X		X			T/A	
Reducing Falls With RENEW in Older Adults Who Have Fallen	Lastayo, PC	2014		X						T/A	
Eccentric Resistance Training in Adults with and without Spinal Cord Injuries	Stone, W J; Stevens, SL; Fuller, DK; Caputo, JL					X				T/A	
Michigan Initiative for Anterior Cruciate Ligament Rehabilitation (MiACLRL): A Protocol for a Randomized Clinical Trial	Rodriguez, K; Garcia, SA; Spino, C; Lepley, LK; Pang, Y; Wojtys, E; Bedi, A; Angelini, M; Ruffino, B; Bolley, T; Block, C; Kellum, J; Swartout, A; Palmieri-Smith, RM	2020	10.1093/ptj/pzaa169	X						T/A	

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The mechanisms of adaptation for muscle fascicle length changes with exercise: Implications for spastic muscle	Davis, JF; Khir, AW; Barber, L; Reeves, ND; Khan, T; DeLuca, M; Mohagheghi, AA	2020	10.1016/j.mehy.2020.110199					X		T/A	
Neuromuscular effects of dorsiflexor training with and without blood flow restriction	Kjeldsen, SS; Næss-Schmidt, ET; Hansen, GM; Nielsen, JF; Stubbs, PW	2019	10.1016/j.heliyo.n.2019.e02341	X		X		X		FT	
Whole-body vibration on parallel bar device for gait and balance rehabilitation in stroke patients	de Morais, AV; Tomaz, G, Jr; Lazzareschi, L; de Almeida, DV; dos Santos, MF; da Silva Boschi, SRM; Martini, SC; Scardovelli, TA; da Silva, AP	2019	10.1007/s42600-019-00014-1		X			X		FT	
Isometric training and long-term adaptations: Effects of muscle length, intensity, and intent: A systematic review	Oranchuk, DJ; Storey, AG; Nelson, AR; Cronin, JB	2019	10.1111/sms.13375					X		T/A	
Effects of lengthening velocity during eccentric training on vastus lateralis muscle hypertrophy	Marzilger, R; Bohm, S; Mersmann, F; Arampatzis, A	2019	10.3389/fphys.2019.00957	X	X			X		T/A	
Rehabilitation for Geriatric Patients	LoGiudice, RJ; Starr, L	2018	10.1002/9781119380627	X						T/A	
Physiological responses to different neuromuscular movement task during eccentric bench press	Wilk, M; Stastny, P; Golas, A; Nawrocka, M; Jelen, K; Zajac, A; Tufano, JJ	2018		X	X					FT	
Effects of wearing a compression garment during night sleep on recovery from high-intensity eccentric-concentric quadriceps muscle fatigue	Shimokochi, Y; Kuwano, S; Yamaguchi, T; Abutani, H; Shima, N	2017	10.1519/JSC.000000000002116	X	X					T/A	
Gelatinases and physical exercise: A systematic review of evidence from human studies	Lo Presti, R; Hopps, E; Caimi, G	2017	10.1097/MD.0000000000008072	X	X		X	X		T/A	
Similar movements are associated with drastically different muscle contraction velocities	Hagen, DA; Valero-Cuevas, FJ	2017	10.1016/j.jbiomech.2017.05.019	X	X			X		T/A	
Clinical applications of iso-inertial, eccentric-overload (YoYo™) resistance exercise	Tesch, PA; Fernandez-Gonzalo, R; Lundberg, TR	2017	10.3389/fphys.2017.00241					X		T/A	
Moderate load eccentric exercise; A distinct novel training modality	Hoppeler, H	2016	10.3389/fphys.2016.00483					X		T/A	
New approaches to visual rehabilitation training for patients with visual field defects	Li, M; Zhu, W; Sun, X	2015	10.3760/cma.j.issn.0412-4081.2015.07.020		X					T/A	
Development of a portable gait rehabilitation system for home-visit rehabilitation	Yano, H; Tanaka, N; Kamibayashi, K; Saitou, H; Iwata, H	2015	10.1155/2015/849831		X	X		X		T/A	
Computations underlying the visuomotor transformation for smooth pursuit eye movements	Scott Murdison, T; Leclercq, G; Lefèvre, P; Blohm, G	2015	10.1152/jn.00273.2014		X	X		X		T/A	
C-tactile fibers contribute to cutaneous allodynia after eccentric exercise	Nagi, SS; Mahns, DA	2013	10.1016/j.jpain.2013.01.009	X	X			X		T/A	
Peroneus quartus and functional ankle instability	Lotito, G; Pruvost, J; Collado, H; Coudreuse, J-M; Bensoussan, L; Curvale, G; Viton, J-M; Delarque, A	2011	10.1016/j.rehab.2011.05.004	X	X	X		X		T/A	
Cystic transverse limb of the articular branch: A pathognomonic sign for peroneal intraneural ganglia at the superior tibiofibular joint	Spinner, RJ; Desy, NM; Amrami, KK	2006	10.1227/01.NEU.0000219820.31012.22	X	X	X	X	X		T/A	

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Enhanced temporal summation of pressure pain in the trapezius muscle after delayed onset muscle soreness	Nie, H; Arendt-Nielsen, L; Madeleine, P; Graven-Nielsen, T	2006	10.1007/s00221-005-0196-6	X	X	X		X		T/A	
Upper extremity movement pattern of a common drinking task in well elderly women: A pilot study	Maitra, KK; Junkins, MD	2004	10.1002/oti.198	X		X		X		T/A	
The influence of eccentric contractions and stretch on alpha motoneuron excitability in normal subjects and subjects with spasticity.	Rochester, L; Vujnovich, A; Newstead, D; Williams, M	2001				X				T/A	
Aging muscle: Functional consequences, assessment, rehabilitation program	Dehail, P; Bourdel-Marchasson, I	2001						X		T/A	
Home program of physical therapy: Effect on disabilities of patients with total hip arthroplasty	Sashika, H; Matsuba, Y; Watanabe, Y	1996	10.1016/S0003-9993(96)90111-2	X	X					T/A	
Muscle function after exercise-induced muscle damage and rapid adaptation	Clarkson, PM; Nosaka, K; Braun, B	1992	10.1249/00005768-199205000-00004			X		X		T/A	
Formulation and Simulation of the Neuron Response to Temperature Stimulation	Yamaura, I; Matsumoto, G	1973	10.11239/jsmbe1963.11.395	X					X	T/A	
Eccentric Exercise Training: Modalities, Applications and Perspectives	Isner-Horobeti, ME; Dufour, SP; Vautravers, P; Geny, B; Coudeyre, E; Richard, R		10.1007/s40279-013-0052-y					X		T/A	
MUSCLE PROTEIN-CHANGES FOLLOWING ECCENTRIC EXERCISE IN HUMANS	Reischman, F; Scordilis, SP; Clarkson, PM; Evans, WJ	1991	10.1007/BF00571547					X		T/A	
Eccentric exercise induces chronic alterations in musculoskeletal nociception in the rat	Alvarez, P; Levine, JD; Green, PG	2010	10.1111/j.1460-9568.2010.07359.x	X	X			X		T/A	
Eccentric training for motor rehabilitation of Parkinsonian patients	Dini, M; Corbianco, S; Ciappetta, C; Bongioanni, P; Rossi, B	2009							X	T/A	
TRANSCRIPTIONAL DEFICITS IN OXIDATIVE PHOSPHORYLATION WITH STATIN MYOPATHY	Hubal, MJ; Reich, KA; De Biase, A; Bilbie, C; Clarkson, PM; Hoffman, EP; Thompson, PD	2011	10.1002/mus.22081			X		X		T/A	
Adenosine A(3) receptor stimulation induces protection of skeletal muscle from eccentric exercise-mediated injury	Wang, RB; Urso, ML; Zambraski, EJ; Rader, EP; Campbell, KP; Liang, BT	2010	10.1152/ajpregu.00060.2010	X	X			X		T/A	
Enhanced Corticospinal Excitability and Volitional Drive in Response to Shortening and Lengthening Strength Training and Changes Following Detraining	Tallent, J; Goodall, S; Gibbon, KC; Hortobagyi, T; Howatson, G	2017	10.3389/fphys.2017.00057	X						T/A	
Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions	Fang, Y; Siemionow, V; Sahgal, V; Xiong, FQ; Yue, GH	2004	10.1016/j.brainres.2004.07.035	X	X	X		X		T/A	
Update of Nutritional Antioxidants and Antinociceptives on Improving Exercise-Induced Muscle Soreness	Leelayuwat, N		10.1016/B978-0-12-805094-1.00019-8					X		T/A	
FURTHER IMPAIRMENT OF MUSCLE PHOSPHATE KINETICS BY LENGTHENING EXERCISE IN DMD BMD CARRIERS - AN IN-VIVO P-31-NMR SPECTROSCOPY STUDY	Barbiroli, B; McCully, KK; Iotti, S; Lodi, R; Zaniol, P; Chance, B	1993	10.1016/0022-510X(93)90192-2			X	X	X		T/A	
Greater movement-related cortical potential during human eccentric versus concentric muscle contractions	Fang, Y; Siemionow, V; Sahgal, V; Xiong, FQ; Yue, GH	2001	10.1152/jn.2001.86.4.1764	X	X			X		T/A	

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Implications of Impaired Endurance Performance following Single Bouts of Resistance Training: An Alternate Concurrent Training Perspective	Doma, K; Deakin, GB; Bentley, DJ	2017	10.1007/s40279-017-0758-3	X					X		T/A
Regional increases in brain signal variability are associated with pain intensity reductions following repeated eccentric exercise bouts	Boissoneault, J; Sevel, L; Stennett, B; Alappattu, M; Bishop, M; Robinson, M	2020	10.1002/ejp.1532	X					X		T/A
Acute effects from the half-squat performed using a repetition versus differential approach in youth soccer players	Coutinho, D; Abade, E; Goncalves, B; Santos, S; Schollhorn, W; Sampaio, J	2022	10.1186/s13102-022-00413-5	X					X		T/A
Does exercise-induced muscle damage impair subsequent motor skill learning?	Leite, CMF; Profeta, VLD; Chaves, SFN; Benine, RPC; Bottaro, M; Ferreira, JB	2019	10.1016/j.humo v.2019.102504	X	X						T/A
Neuromuscular disturbance outlasts other symptoms of exercise-induced muscle damage	Deschenes, MR; Brewer, RE; Bush, JA; McCoy, RW; Volek, JS; Kraemer, WJ	2000	10.1016/S0022-510X(00)00258-6	X	X						T/A
ECCENTRIC CONTRACTIONS INDUCE RAPID ISOMETRIC TORQUE DROP IN DYSTROPHIN-DEFICIENT DOGS	Tegeler, CJ; Grange, RW; Bogan, DJ; Markert, CD; Case, D; Kornegay, JN; Childers, MK	2010	10.1002/mus.21699	X	X				X		T/A
Fiber-type susceptibility to eccentric contraction-induced damage of hindlimb-unloaded rat AL muscles	Vijayan, K; Thompson, JL; Norenberg, KM; Fitts, RH; Riley, DA	2001	10.1152/jappl.2001.90.3.770	X	X				X		T/A
Characterization of recovered walking patterns and motor control after contusive spinal cord injury in rats	Hansen, CN; Linklater, W; Santiago, R; Fisher, LC; Moran, S; Buford, JA; Basso, DM	2012	10.1002/brb3.71	X	X				X		T/A
ACTN3 genotype is associated with increases in muscle strength in response to resistance training in women	Clarkson, PM; Devaney, JM; Gordish-Dressman, H; Thompson, PD; Hubal, MJ; Urso, M; Price, TB; Angelopoulos, TJ; Gordon, PM; Moyna, NM; Pescatello, LS; Visich, PS; Zoeller, RF; Seip, RL; Hoffman, EP	2005	10.1152/japplphysiol.01139.2004	X			X				T/A
Psychological Influences Predict Recovery Following Exercise Induced Shoulder Pain	Parr, J; Borsa, P; Fillingim, R; Kaiser, K; Tillman, MD; Manini, TM; Gregory, C; George, S	2014	10.1055/s-0033-1345179	X	X				X		T/A
Response of rat muscle to acute resistance exercise defined by transcriptional and translational profiling	Chen, YW; Nader, GA; Baar, KR; Fedele, MJ; Hoffman, EP; Esser, KA	2002	10.1113/jphysiol.2002.021220	X	X		X		X		T/A
Electrically stimulated hind limb muscle contractions increase adult hippocampal astroglialgenesis but not neurogenesis or behavioral performance in male C57BL/6J mice	Gardner, JC; Dvoretzkiy, SV; Yang, YY; Venkataraman, S; Lange, DA; Li, SP; Boppart, AL; Kim, N; Rendeiro, C; Boppart, MD; Rhodes, JS	2020	10.1038/s41598-020-76356-z	X	X		X		X		T/A
Sense of Effort Determines Lower Limb Force Production During Dynamic Movement in Individuals With Poststroke Hemiparesis	Simon, AM; Kelly, BM; Ferris, DP	2009	10.1177/1545968308331163		X	X					T/A
Neural adaptations with chronic physical activity	Enoka, RM	1997	10.1016/S0021-9290(96)00170-4	X					X		T/A
Effect of Load, Angle, and Contraction Type on Clinically Assessed Knee Joint Position Sense	Haggerty, AL; Simon, JE; Grooms, DR; Russell, JA	2021	10.1123/jsr.2020-0552	X	X				X		T/A
Muscle force redistributes segmental power for body progression during walking	Neptune, RR; Zajac, FE; Kautz, SA	2004	10.1016/S0966-6362(03)00062-6	X	X				X		T/A

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Knee strength measurement: Can we switch between isokinetic dynamometers?	Paulus, J; Pauls, J; Radizzi, L; Krecke, L; Bury, T; Le Goff, C; Laly, A; Schwartz, C; Forthomme, B; Kaux, JF; Croisier, JL		10.3233/IES-193193	X	X			X		T/A	
Alterations in Osteopontin Modify Muscle Size in Females in Both Humans and Mice	Hoffman, EP; Gordish-Dressman, H; Mclane, VD; Devaney, JM; Thompson, PD; Visich, P; Gordon, PM; Pescatello, LS; Zoeller, RF; Moyna, NM; Angelopoulos, TJ; Pegoraro, E; Cox, GA; Clarkson, PM	2013	10.1249/MSS.0b013e31828093c1		X		X	X	X	T/A	
SENSITIVITY OF MUSCLE PROTON SPIN-SPIN RELAXATION-TIME AS AN INDEX OF MUSCLE ACTIVATION	Yue, G; Alexander, AL; Laidlaw, DH; Gmitro, AF; Unger, EC; Enoka, RM	1994	10.1152/jappl.1994.77.1.84	X	X			X		T/A	
Damaged muscle fibers might masquerade as hybrid fibers - a cautionary note on immunophenotyping mouse muscle with mouse monoclonal antibodies	Begam, M; Roche, JA		10.4081/ejh.2018.2896	X	X		X	X	X	T/A	
CONTRALESIONAL SPATIAL BIAS IN CHRONIC HEMIANOPIA: THE ROLE OF (EC)CENTRIC FIXATION, SPATIAL CUEING AND VISUAL SEARCH	Kuhn, C; Bublak, P; Jobst, U; Rosenthal, A; Reinhart, S; Kerkhoff, G	2012	10.1016/j.neuroscience.2012.03.020		X			X		T/A	
Variable rescue of microtubule and physiological phenotypes in mdx muscle expressing different miniaturized dystrophins	Nelson, DM; Lindsay, A; Judge, LM; Duan, D; Chamberlain, JS; Lowe, DA; Ervasti, JM	2018	10.1093/hmg/ddy113	X	X		X	X	X	T/A	
A review of current literature on physiological tests and soft tissue biomarkers applicable to work-related upper limb disorders	Saxton, JM	2000	10.1093/occmed/50.2.121	X	X			X		T/A	
The mechanisms of massage and effects on performance, muscle recovery and injury prevention	Weerapong, P; Hume, PA; Koht, GS		10.2165/00007256-200535030-00004	X	X			X		T/A	
Decomposition of surface EMG signals from cyclic dynamic contractions	De Luca, CJ; Chang, SS; Roy, SH; Kline, JC; Nawab, SH	2015	10.1152/jn.00555.2014	X	X	X		X		T/A	
Thigh muscle segmentation of chemical shift encoding-based water-fat magnetic resonance images: The reference database MyoSegmenTUM	Schlaeger, S; Freitag, F; Klupp, E; Dieckmeyer, M; Weidlich, D; Inhuber, S; Deschauer, M; Schoser, B; Bublitz, S; Montagnese, F; Zimmer, C; Rummeny, EJ; Karampinos, DC; Kirschke, JS; Baum, T	2018	10.1371/journal.pone.0198200	X	X	X		X		T/A	
Sarcomere lesion damage occurs mainly in slow fibers of reloaded rat adductor longus muscles	Vijayan, K; Thompson, JL; Riley, DA	1998	10.1152/jappl.1998.85.3.1017	X	X		X	X		T/A	
Five myofibrillar lesion types in eccentrically challenged, unloaded rat adductor longus muscle - A test model	Thompson, JL; Balog, EM; Fitts, RH; Riley, DA	1999	10.1002/(SICI)1097-0185(19990101)254:1<39::AID-AR6>3.0.CO;2-K	X	X		X	X		T/A	
Non-invasive assessment of muscle injury in healthy and dystrophic animals with electrical impedance myography	Sanchez, B; Iyer, SR; Li, J; Kapur, K; Xu, S; Rutkove, SB; Lovering, RM	2017	10.1002/mus.25559	X	X		X	X		T/A	
Correlation of personality assessments with standard selection criteria for neurosurgical residency applicants	Lubelski, D; Healy, AT; Friedman, A; Ferraris, D; Benzel, EC; Schlenk, R	2016	10.3171/2015.7.JNS15880	X	X	X	X	X		T/A	

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Endpoint measures in the mdx mouse relevant for muscular dystrophy pre-clinical studies	Kobayashi, YM; Rader, EP; Crawford, RW; Campbell, KP	2012	10.1016/j.nmd.2011.08.001	X	X		X	X		T/A	
CORTICAL VOLUNTARY ACTIVATION OF THE HUMAN KNEE EXTENSORS CAN BE RELIABLY ESTIMATED USING TRANSCRANIAL MAGNETIC STIMULATION	Sidhu, SK; Bentley, DJ; Carroll, TJ	2009	10.1002/mus.21064	X	X			X		T/A	
An in vivo rodent model of contraction-induced injury in the quadriceps muscle	Pratt, SJP; Lawlor, MW; Shah, SB; Lovering, RM	2012	10.1016/j.injury.2011.09.015	X	X		X	X		T/A	
Chronic administration of a leupeptin-derived calpain inhibitor fails to ameliorate severe muscle pathology in a canine model of Duchenne muscular dystrophy	Childers, MK; Bogan, JR; Bogan, DJ; Greiner, H; Holder, M; Grange, RW; Kornegay, JN		10.3389/fphar.2011.00089	X	X		X	X		T/A	
Visual perceptions of head-fixed and trunk-fixed anterior posterior axes	Darling, WG; Butler, AJ; Williams, TE	1996		X	X	X		X		T/A	
Muscular torque generation during imposed joint rotation: torque-angle relationships when subjects' only goal is to make a constant effort	Burgess, PR; Jones, LF; Buhler, CF; Dewald, JPA; Zhang, LQ; Rymer, WZ		10.1080/0899022021000037791	X	X	X		X		T/A	
SERCA1 overexpression minimizes skeletal muscle damage in dystrophic mouse models	Mazala, DAG; Pratt, SJP; Chen, DP; Molkentin, JD; Lovering, RM; Chin, ER	2015	10.1152/ajpcell.00341.2014	X	X		X	X		T/A	
Lower limb force production and bilateral force asymmetries are based on sense of effort	Simon, AM; Ferris, DP	2008	10.1007/s00221-008-1288-x	X	X	X		X		T/A	
Dysferlin stabilizes stress-induced Ca2+ signaling in the transverse tubule membrane	Kerr, JP; Ziman, AP; Mueller, AL; Muriel, JM; Kleinhans-Welte, E; Gumerson, JD; Vogel, SS; Ward, CW; Roche, JA; Bloch, RJ	2013	10.1073/pnas.1307960110	X	X		X	X		T/A	
The Proton Pump Inhibitor Lansoprazole Improves the Skeletal Phenotype in Dystrophin Deficient mdx Mice	Sali, A; Many, GM; Gordish-Dressman, H; van der Meulen, JH; Phadke, A; Spurney, CF; Cnaan, A; Hoffman, EP; Nagaraju, K	2013	10.1371/journal.pone.0066617	X	X		X	X		T/A	
Understanding muscle coordination of the human leg with dynamical simulations	Zajac, FE	2002	10.1016/S0021-9290(02)00046-5	X	X	X		X		T/A	
beta-Sarcoglycan gene transfer decreases fibrosis and restores force in LGMD2E mice	Pozsgai, ER; Griffin, DA; Heller, KN; Mendell, JR; Rodino-Klapac, LR	2016	10.1038/gt.2015.80	X	X		X	X		T/A	
Effects of Reinnervation of the Biarticular Shoulder-Elbow Muscles on Joint Kinematics and Electromyographic Patterns of the Feline Forelimb during Downslope Walking	Livingston, BP; Nichols, TR		10.1159/000371542		X	X		X		T/A	
Contributions of the individual ankle plantar flexors to support, forward progression and swing initiation during walking	Neptune, RR; Kautz, SA; Zajac, FE	2001	10.1016/S0021-9290(01)00105-1	X	X	X		X		T/A	
Losartan Restores Skeletal Muscle Remodeling and Protects Against Disuse Atrophy in Sarcopenia	Burks, TN; Andres-Mateos, E; Marx, R; Mejias, R; Van Erp, C; Simmers, JL; Walston, JD; Ward, CW; Cohn, RD	2011	10.1126/scitranslmed.3002227	X	X	X	X	X		T/A	
DYSTROPHIN-DEFICIENT MDX MUSCLE-FIBERS ARE PREFERENTIALLY VULNERABLE TO NECROSIS INDUCED BY	Weller, B; Karpati, G; Carpentier, S	1990	10.1016/0022-510X(90)90005-8	X	X	X	X	X		T/A	

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EXPERIMENTAL LENGTHENING CONTRACTIONS											
Early response of heat shock proteins to functional overload of the soleus and plantaris in rats and mice	Huey, KA; Burdette, S; Zhong, H; Roy, RR	2010	10.1113/expphysiol.2010.054692	X	X	X	X	X		T/A	
Immunohistochemical myofiber typing and high-resolution myofibrillar lesion detection in LR White embedded muscle	Thompson, JL; Vijayan, K; Riley, DA	2000	10.1002/1097-0029(20000615)49:6<589::AID-JEMT9>3.0.CO;2-8	X	X	X	X	X		T/A	
Mechanisms Mediating Vibration-Induced Chronic Musculoskeletal Pain Analyzed in the Rat	Dina, OA; Joseph, EK; Levine, JD; Green, PG	2010	10.1016/j.jpain.2009.08.007	X	X	X	X	X		T/A	
Genetic deletion of trkB.T1 increases neuromuscular function	Dorsey, SG; Lovering, RM; Renn, CL; Leitch, CC; Liu, XY; Tallon, LJ; Sadzewicz, LD; Pratap, A; Ott, S; Sengamalay, N; Jones, KM; Barrick, C; Fulgenzi, G; Becker, J; Voelker, K; Talmadge, R; Harvey, BK; Wyatt, RM; Vernon-Pitts, E; Zhang, C; Shokat, K; Fraser-Liggett, C; Balice-Gordon, RJ; Tessarollo, L; Ward, CW	2012	10.1152/ajpcell.00469.2010	X	X	X	X	X		T/A	

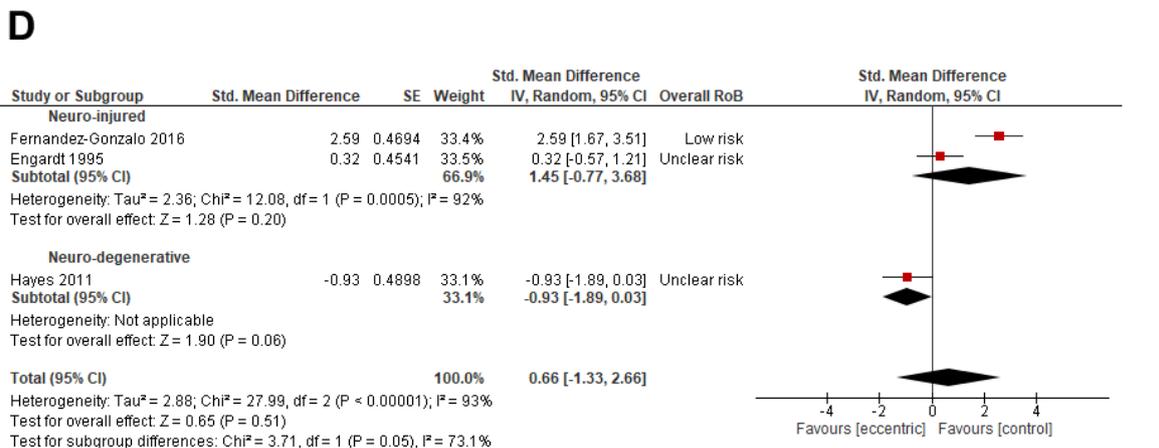
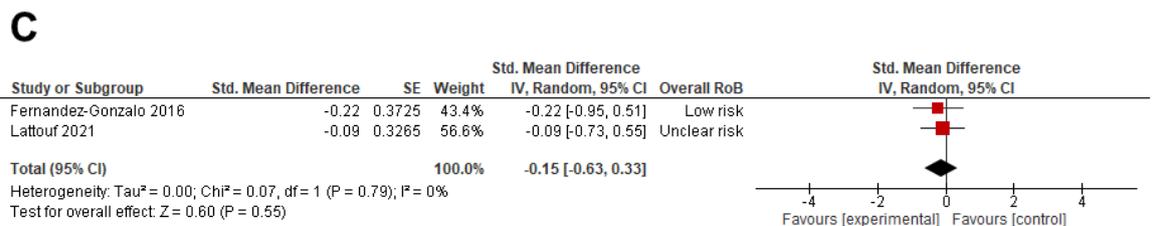
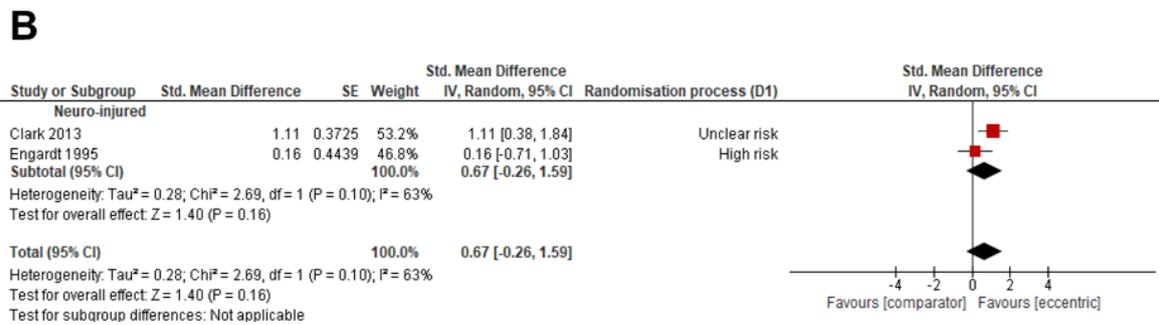
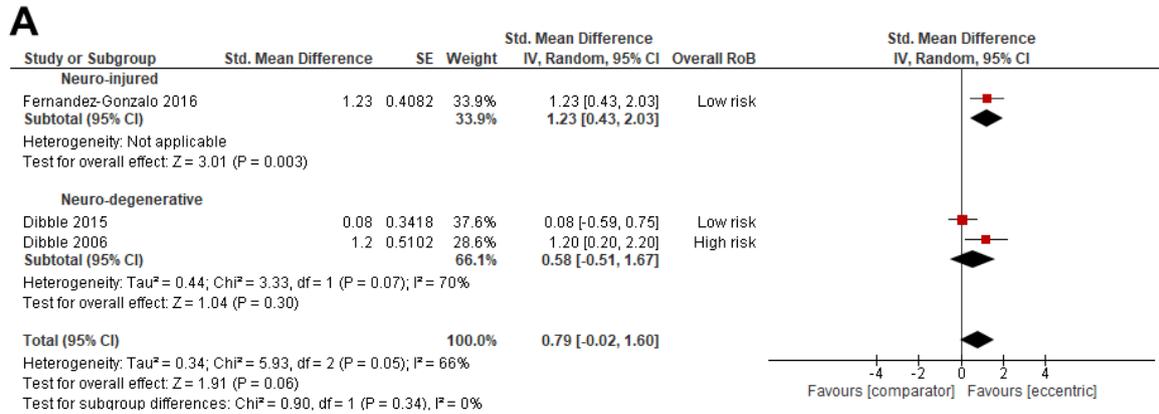
T/A: title/abstract; FT: full text

**Supplementary File 5.** Adherence scoring for the ACSM guideline recommendations for resistance training, from Hendrey et al (2018).

	Frequency	Intensity	Type of exercise	Specificity	Repetitions	Sets	Patterns	Progressivity	TOTAL
<b>Rating</b>	0 : < 2d/wk 1 : ≥ 2d/wk	0 : RM/ max force : not determined 0 : not based on ACSM guidelines 1 : adapted and adjusted to participant	0 : not all major muscle groups 1 : all major muscle groups	0 : no 0,5 : partially, RoM or contraction type 1 : RoM and contraction type	0 : not adapted/precised 1 : precised	0 : not detailed 1 : adapted to objective	0 : <1-2 minutes (between sets), or <48h (between sessions) 0.5 : partially, between sets or sessions 1: between sets and between sessions	0 : no progression or reported 1 : progression	
<b>Study</b>									
Lattouf 2021	1	1	0	0.5	1	1	0.5	0	5
Kadkhodaie 2020	1	1	0	1	0	1	1	1	6
Dibble 2015	1	1	0	0.5	0	0	0.5	1	4
Clarke 2012	1	1	1	1	1	1	1	1	8
Hayes 2011	1	0	1	0.5	0	0	1	1	4.5
Dibble 2009	1	1	0	0.5	0	0	0.5	1	4
Engardt 1995	1	1	0	0.5	0	0	1	1	4.5
Fernandez-Gonzalo 2016	1	0	0	0.5	1	1	0.5	0	3.5
Lee 2013	1	0	0	0.5	1	1	0.5	0	4
Dibble 2006	1	1	0	0.5	0	0	0.5	1	4

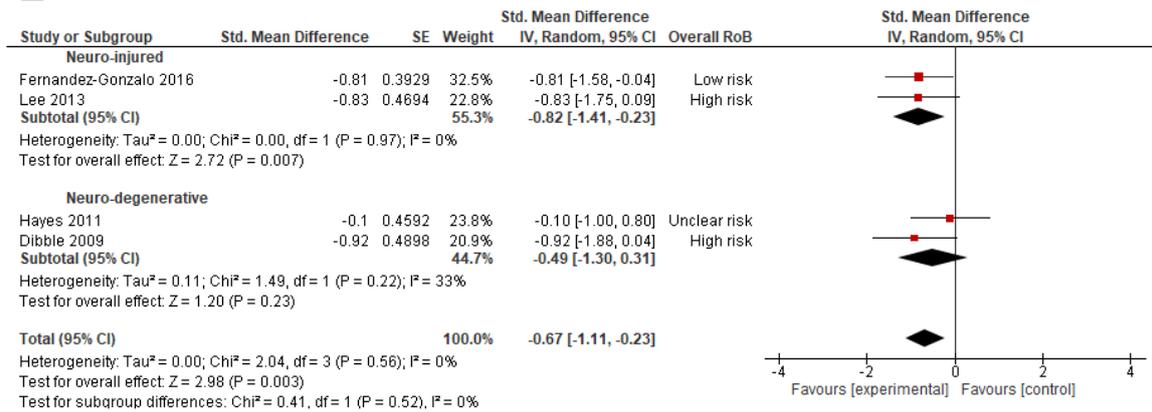
Hendrey G, Holland AE, Mentiplay BF, Clark RA, Williams G. Do Trials of Resistance Training to Improve Mobility After Stroke Adhere to the American College of Sports Medicine Guidelines? A Systematic Review. Archives of physical medicine and rehabilitation. 2018;99(3): 584-597 e51

**Supplementary File 6.** Standardised mean difference (95% CI) of effect of eccentric resistance training versus comparator (usual rehabilitation, or control) on muscle structure (A, n=83), muscle activity (B, n=54), spasticity (C, n=68), balance (D, n=66), and risk of fall (E, n=77) immediately after the intervention.



# Eccentric training in neurological patients

**E**



## Additional analyses on overall effect

### Large effect studies

All studies – not Fernandez-Gonzalo (2016): **-0.60 [-1.13, -0.07]**

All studies – not Lee (2013): **-0.62 [-1.12, -0.12]**

All studies – not Dibble (2009): **-0.60 [-1.10, -0.11]**

### Initial severity of motor impairment

All studies – not 'severe' motor impairment: **-0.60 [-1.13, -0.07]**

All studies – not 'good' motor impairment: **-0.82 [-1.41, -0.23]**

All studies – not 'severe' and 'moderate' motor impairment: **-0.49 [-1.30, 0.31]**