SCOPING REVIEW

Short-term biochemical, structural, and functional muscle responses to eccentric-based exercise: A scoping review with an evidence gap map

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Abstract

This scoping review aims to map the literature on the acute effects of eccentric, concentric, and isometric training, summarize key outcomes, and identify gaps for future research. Following 2020 PRISMA guidelines, a search was conducted in PubMed, Scopus, and Web of Science on April 1, 2025. Studies were included if they involved healthy or recreationally trained adults undergoing eccentric, concentric, or isometric training, with assessments of biochemical (creatine kinase, myoglobin) or neuromuscular (muscle strength, DOMS) outcomes at baseline and post-exercise (0–72 hours). Studies required comparator groups and multi-arm designs. Risk of bias was assessed using RoB2 and ROBINS-I. Of 4,463 records, 13 studies involving 225 participants (182 men and 43 women) met the inclusion criteria. Most studies involved young, recreationally trained males. Across the included studies, eccentric exercise was generally associated with larger increases in creatine kinase and myoglobin, greater delayed-onset muscle soreness, and larger reductions in muscle strength than concentric or isometric exercise. Some studies also reported transient increases in muscle cross-sectional area following eccentric exercise, consistent with acute post-exercise swelling. Protocols and assessment time points varied considerably, with most outcomes assessed within 24–48 hours after exercise. Four studies were judged to have a high overall risk of bias, while the remaining studies raised some concerns. Overall, the available evidence suggests that eccentric exercise may produce greater acute and short-term perturbations in markers associated with muscle damage and neuromuscular function than concentric or isometric exercise. However, these findings should be interpreted cautiously given the small evidence base, methodological heterogeneity, risk-of-bias concerns, and limited demographic representation.

Keywords: *eccentric training; resistance training; muscle damage; muscle inflammation; fatigue*

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Introduction

Eccentric-based exercise (i.e., muscle actions performed while the muscle–tendon unit lengthens under load) is distinguished by its capacity to generate very high forces and to tolerate supramaximal external loads (often operationalized as >100% 1RM in resistance exercise) while imposing a lower metabolic cost at a given tension than concentric work (Harris-Love et al., 2021). This unique "high-tension/low-cost" profile is one reason eccentric methods are increasingly used across rehabilitation, healthy aging, and performance settings, including sarcopenia management and tendinopathy rehabilitation (Prior et al., 2016), as well as athletic conditioning and injury-risk reduction strategy (de Hoyo et al., 2015). Beyond load tolerance, eccentric actions are associated with distinct neuromuscular control demands, including altered motor unit behavior and heightened cortical involvement relative to other contraction modes, which may contribute to mode-specific strength and power outcomes (Vogt & Hoppeler, 2014).

At the skeletal muscle level, eccentric loading promotes adaptations linked to force production and contractile efficiency, including increases in muscle mass, fascicle length, and sarcomere number, as well as neuromechanical changes that support improved strength and power (Vogt & Hoppeler, 2014). Mechanistically, the giant elastic protein titin is increasingly recognized as central to eccentric force enhancement and energy efficiency, complementing cross-bridge mechanisms and potentially shaping the structural response to loading (Hessel et al., 2017). However, the same high-tension characteristics that make eccentric exercise attractive also increase the likelihood of transient post-exercise impairment: eccentric exercise can induce greater myofibrillar disruption, prolonged weakness, and delayed-onset muscle soreness than concentric work (Clarkson & Sayers, 1999; Proske & Morgan, 2001). In this review, we use acute/immediate to refer to responses occurring during exercise through 6 hours post-exercise, and short-term to refer to responses occurring >6 hours to 7 days post-exercise; we also use residual/post-exercise impairment to denote the persisting functional deficit within that short-term window (e.g., sustained force loss and/or soreness), while early adaptations (weeks) are considered conceptually distinct and outside the primary time horizon (McGlory et al., 2017).

Despite substantial interest and multiple syntheses on longer-term eccentric training effects (e.g., strength development, rehabilitation efficacy, and injury prevention), comparatively less attention has been paid to the acute and short-term sequelae of eccentric-based exercise—particularly muscle damage, functional impairment, and potential transient injury risk immediately following exposure (Douglas et al., 2017; Gérard et al., 2020; Goode et al., 2015). This gap is practically important because programming decisions (load prescription, frequency, recovery duration, and return-to-training criteria) are often made in the days after eccentric exposure, when impairment may be most pronounced. Moreover, evidence spanning broad age ranges (e.g., 20–70 years) and training statuses (sedentary to trained) can obscure inference if not explicitly separated; therefore, our approach is to map and, where data permit, stratify evidence by participant characteristics (age group and training/experience status) and eccentric exposure features (e.g., supramaximal vs submaximal loading) to avoid overly blended conclusions. Accordingly, the purpose of this scoping review was to (i) summarize key findings on skeletal muscle damage occurring acutely and in the short term following eccentric-based exercise versus other contraction modes; (ii) describe the principal biochemical and neuromuscular markers used to quantify these responses; and (iii) provide an evidence-gap map detailing the methodological characteristics of existing studies and priorities for future research.

Methods

This scoping review was reported in accordance with the PRISMA 2020 statement (Page et al., 2021).

Protocol and registration

The protocol for this scoping review was published on March 30, 2025, and is accessible via the Open Science Framework (registration: osf.io/ndgwe) with the following DOI: 10.17605/OSF.IO/W8DYS.

Eligibility criteria

Table 1 specifies the eligibility criteria, derived from the PICOS framework (Participants, Intervention, Comparator, Outcomes, Study Design), which encompassed original research articles from peer-reviewed journals without language or publication year restrictions.

Information sources

Following the pre-registered protocol, a comprehensive literature search was conducted on April 01, 2025, utilizing PubMed, Scopus, and Web of Science (Core Collection) databases. Furthermore, we manually screened the reference lists of selected studies to locate additional relevant sources. To further refine the search, snowball citation tracking via Web of Science was employed. Finally, included studies were checked for errata and retractions. Two internationally recognized experts, specializing in resistance training and located through Expertscape (https://expertscape.com/ex/resistance+training), were consulted to strengthen the review's methodology.

Search strategy

No filters or limitations were applied to publication date, language, or study design, ensuring a broad and thorough search designed to maximize the retrieval of relevant studies. The search strategy incorporated the Boolean operators 'AND' and 'OR' to achieve this objective. This approach was intended to capture the largest possible pool of relevant studies without restricting the scope. The detailed search methodology is outlined below.

[Title/Abstract] "Eccentric*" OR "Lengthening contraction*" OR "Negative Repetition*" OR "Downhill Running" OR Plyometric* OR "Flywheel" OR "Nordic hamstring"

AND

[Title/Abstract] "Post-Exercise" OR "Acute Effect*" OR "Immediate Effect*" OR "Short-Term Effect*" OR "Post-Workout*" OR "Following Exercise*" OR "After Exercise*" OR "Early Response*"

AND

[Title/Abstract] "Muscle Damage" OR "Muscle Injur*" OR "Muscle Soreness" OR "Exercise-Induced Muscle Damage" OR

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Table 1. Inclusion and exclusion criteria according to the PICOS framework.

	Inclusion Criteria	Exclusion Criteria
Population	Human participants of any sex, age, or training status, including injured populations or individuals with specific conditions	Non-human studies
Intervention	The intervention must involve eccentric-based exercises, including but not limited to exercises that emphasize lengthening of the muscle under tension (e.g., Nordics; flywheel). The exercises must be performed under controlled conditions (supervised or self-administered with guidance).	Studies that focus on concentric, isometric, or other exercise modalities that do not involve eccentric muscle actions. Studies were excluded if the intervention consisted primarily of combined concentric–eccentric dynamic repetitions without the ability to isolate eccentric exposure (e.g., traditional resistance training sets), because contraction-mode-specific acute responses could not be attributed to eccentric loading.
Comparator	Another exercise modality or contraction mode (e.g., concentric or isometric exercise).	Studies that use interventions unrelated to exercise (e.g., pharmacological treatments, surgical interventions) or unrelated physical therapies. Studies comparing eccentric exercise to mixed exercise programs where eccentric and non-eccentric exercises are combined but not clearly separated, preventing the assessment of eccentric-specific effects.
Outcomes	Time-course assessments that track changes in biochemical or neuromuscular markers from baseline and at various time points post-exercise (e.g., immediately post-exercise, 24, 48, or 72 hours post-exercise). Biochemical outcomes may include, but are not limited to: changes in biomarkers related to muscle damage (e.g., creatine kinase (CK), lactate dehydrogenase (LDH), myoglobin); inflammatory markers (e.g., C-reactive protein (CRP), interleukins); oxidative stress markers (e.g., malondialdehyde (MDA), glutathione); hormonal responses (e.g., cortisol, testosterone); and muscle protein synthesis and degradation markers. Neuromuscular outcomes may include, but are not limited to: muscle soreness (e.g., delayed onset muscle soreness (DOMS)); muscle strength (e.g., maximal voluntary contraction, isometric strength); electromyographic (EMG) activity following eccentric exercise; neuromuscular fatigue (e.g., rate of force development, fatigue index); and reflexive responses (e.g., Hoffmann (H) reflex, stretch reflex).	Studies where no pre- and post-intervention assessments are made to evaluate the effects of the intervention and comparator. Outcomes that do not focus on acute changes (e.g., chronic adaptations or long-term follow-ups beyond 72 hours post-exercise). Outcomes not directly related to biochemical or neuromuscular responses, such as general fitness measures or psychological outcomes that do not capture acute biochemical or neuromuscular effects. Studies reporting biomarkers that are not specific to muscle damage, inflammation, oxidative stress, or hormonal responses related to exercise (e.g., biomarkers unrelated to muscle tissue like blood glucose levels).
Study design	Two-arm or multi-arm randomized controlled trials.	Non-randomized experimental studies, descriptive studies, systematic reviews, and grey literature.

"Muscle Strain" OR "Myofibrillar Disruption" OR "Sarcomere Disruption" OR "Z-line Streaming" OR "Creatine Kinase" OR "CK" OR "Lactate Dehydrogenase" OR "LDH" OR "Myoglobin" OR "C-Reactive Protein" OR "CRP" OR "Interleukins" OR "Malondialdehyde" OR "MDA" OR "Glutathione" OR "Cortisol" OR "Testosterone" OR "Muscle Proteins" OR "Protein Synthesis" OR "Protein Degradation" OR "DOMS" OR "Muscle Strength" OR "Muscle power" OR "Voluntary Contraction" OR "Electromyography" OR "EMG" OR "Muscle Fatigue" OR "Rate of Force Development" OR "H Reflex" OR "Stretch Reflex" OR "Performance"

Detailed search strategies for all databases are available in the Supplementary Material 1.

Selection process

Initially, two independent authors (RT and DB) conducted a title and abstract screening of the studies, based on pre-defined inclusion criteria. Full-text articles were obtained when necessary. Subsequently, the same reviewers independently assessed the full texts of the selected studies. Discrepancies were resolved through discussion or, if needed, with the assistance of a third reviewer (VAG). EndNoteTM software (version 20.5, Clarivate Analytics, Philadelphia, PA) was used to manage records and remove duplicates, employing both manual and automated methods.

Data collection process

RT performed the data extraction and subsequently rechecked the completed dataset to ensure accuracy and completeness. A custom Microsoft Excel spreadsheet was created to systematically record all relevant data points. If full-text articles lacked necessary information regarding biochemical or neuromuscular markers following eccentric exercise, RT contacted the corresponding authors via email or ResearchGate. Studies failing to respond within a two-week timeframe were excluded. Extracted data from each study included: (i) sample size, (ii) participant characteristics such as physical activity levels (e.g., active, inactive, athlete status), age, sex, and clinical conditions, and (iii) the study design, including randomization methods and blinding procedures. Specifically, for the eccentric training intervention, we collected: (i) training duration and frequency, (ii) total number of sessions, (iii) participant adherence, (iv) specific instruments or tools used for the training; and (v) the specific rehabilitation protocols. Furthermore, we documented the time points for measuring biochemical and neuromuscular markers post-eccentric exercise, to assess acute effects.

Data items

Data concerning the acute effects of eccentric training were extracted solely from studies that presented assessments at both baseline and post-intervention time points. These assessments encompassed various biochemical markers, including creatine kinase (CK), lactate dehydrogenase (LDH), myoglobin, C-reactive protein (CRP), interleukins, malondialdehyde (MDA), glutathione, cortisol, testosterone, and markers of muscle protein synthesis and degradation. Additionally, neuromuscular markers such as delayed onset muscle soreness (DOMS), muscle strength (measured via maximal voluntary contraction and isometric strength), electromyography (EMG) activity following eccentric exercise, rate of force de-

velopment, fatigue index, Hoffmann reflex, and stretch reflex were collected. The specific time points at which these markers were measured post-exercise (e.g., immediately post-exercise, 24, 48, or 72 hours) were also recorded for each study.

Risk of bias assessment

The risk of bias in included randomized controlled trials (RCTs) was assessed using the revised Cochrane risk-of-bias tool for randomized trials (RoB 2) (Sterne et al., 2019). This tool evaluates bias across five domains: (1) bias arising from the randomization process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in 3 the measurement of the outcome, and (5) bias in the selection of the reported result. For each domain, signaling questions were used to judge the risk of bias as 'low,' 'some concerns,' or 'high.' Specifically, for the randomization process, we evaluated the adequacy of sequence generation and allocation concealment. Deviations from intended interventions were assessed by examining whether participants and personnel were aware of assigned interventions and whether there were deviations from the intended intervention that arose because of the experimental context. The risk of bias due to missing outcome data was evaluated by examining whether there were imbalances in missing outcome data across intervention groups, and whether reasons for missing outcome data were adequately described. Bias in the measurement of the outcome was determined by assessing whether outcome assessors were aware of intervention assignments and whether outcome measurement methods were likely to be influenced by knowledge of intervention assignment. Lastly, bias in the selection of the reported result was assessed by evaluating whether the reported outcomes were selected from among multiple measurements of the outcome or multiple analyses of the data. Two independent reviewers (RT and DB) conducted the risk of bias assessment, and any disagreements were resolved through discussion or consultation with a third reviewer (VAG) when necessary. The overall risk of bias for each study was determined based on the assessment of the five domains.

Summary Measures and Evidence Gap Map

For the quantitative synthesis, summary measures were extracted to assess the acute effects of eccentric training on biochemical and neuromuscular markers. Continuous outcomes, such as creatine kinase levels, muscle strength, and rate of force development, were summarized using means, standard deviations, and mean differences. Moreover, the summary of methodological aspects was visually represented in an evidence gap map, which illustrated the distribution of studies across various eccentric training protocols, participant characteristics, and measured outcomes. The evidence gap map highlighted areas of robust evidence as well as gaps in the literature, particularly concerning the time-course effects of eccentric training on biochemical and neuromuscular markers.

Results

Study selection

A database search initially identified 4,463 records. After removing 2,338 duplicate entries, 2,125 studies proceeded to title and abstract screening. Subsequently, 1,987 of these studies were excluded for not meeting the specified criteria, resulting in 129 studies being eligible for full-text review. Following a thorough evaluation of the full-text articles, 116 full-text articles were excluded because they did not meet the predefined eligibility criteria. Consequently, 13 studies were included in the review. Figure 1 shows the PRISMA flowchart.

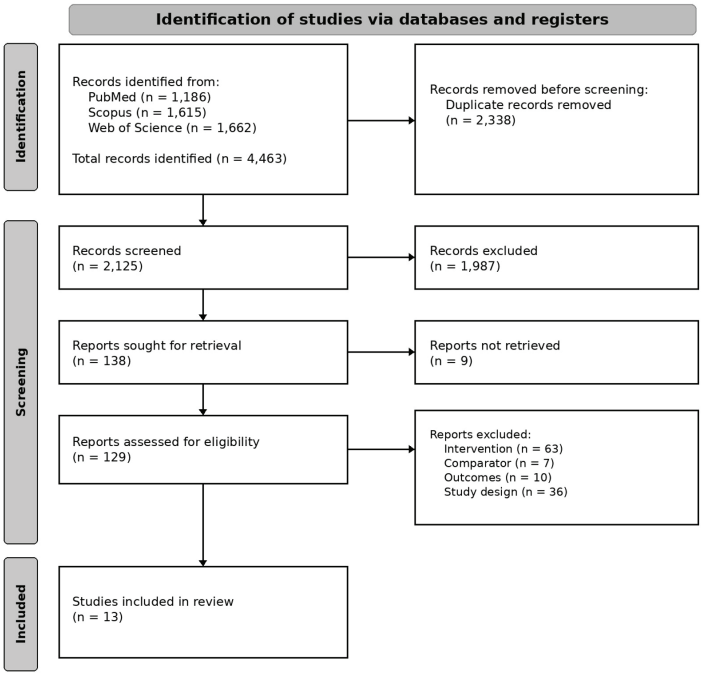

Figure 1. PRISMA 2020 flow diagram

Study characteristics

The 13 included studies comprised 225 participants, including 182 men (80.9%) and 43 women (19.1%). Eight studies included male-only samples, two included female-only samples, and three included both men and women. Participant ages ranged from approximately 21 to 73 years, although most studies involved young adults, with mean ages typically ranging from 20 to 31 years. Training status varied from sedentary or untrained to recreationally strength-trained, and several studies did not fully characterize participants' activity backgrounds (Table 2).

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All studies were randomized controlled trials, most using crossover designs (9/13) and the remainder parallel-group designs (4/13), with outcomes commonly assessed at baseline, immediately post-exercise, and follow-up time points spanning 1–2 h and 24–72 h post-exercise. Outcome domains clustered into biochemical markers (6 studies; most often creatine kinase, with limited and inconsistent inclusion of inflammatory, oxidative stress, metabolic, and endocrine markers such as IL-6/TNF-α, MDA/protein carbonyls/GPx, lactate, insulin, and myostatin-related factors), muscle properties (3 studies; MRI/ultrasound morphology and NIRS-derived oxygenation), and—most frequently—muscle function (10 studies; primarily MVC/MVIC via isokinetic dynamometry, complemented by neuromuscular and performance/clinical indicators including torque and voluntary activation, surface EMG measures, soreness ratings, ROM, CMJ, balance/sway assessments, and force control measures).

Table 2. Characteristics of the included studies

Study	N	Sex	Sport	Age	Study Design	Time points analyzed	Biochemical outcomes	Muscle properties outcomes	Muscle functional outcomes	Methods of measurement
Clarkson et al. (Clarkson et al., 1986)	28	F	Not specified (College level)	Not specified	Randomized, parallel design	Pre-exercise; 24h post-exercise	CK	Not reported	Muscle soreness (subjective rating 1–10 scale)	Blood assay for CK; subjective muscle soreness scale
González-Bartholin et al. (González-Bartholin et al., 2019)	10	M/F	Not specified (healthy older adults)	51-73 Years	Randomized crossover design	Pre, immediately post, 24h post, 48h post	CK, IL-6, TNF-α, MDA, protein carbonyl, GPx	Not reported	MVC	Blood samples analyzed in duplicate; MVC assessed via dynamometer; soreness by VAS
Latella et al. (Latella et al., 2019)	14	M/F	Recreational strength training	26.8±2.9 years	Randomized crossover design	Baseline, immediately post-exercise, 1 hour post	Not reported	Not reported	MVIC, ICF, LICI, SICI	Transcranial magnetic stimulation (TMS) for cortical measures; isokinetic dynamometer for torque; EMG for muscle activation
Muthalib et al. (Muthalib et al., 2010)	10	M/F	Not specified (healthy adults)	28.9±6.3 years	Randomized crossover design	Baseline, immediate post-exercise, 24h, 48h and 72h post-exercise	CK	Muscle oxygenation (Tissue Oxygenation Index, TOI), total hemoglobin (tHb)	MVC, muscle soreness (VAS)	Isokinetic dynamometer for MVC, Near-infrared spectroscopy (NIRS) for muscle oxygenation, VAS for soreness
Ochi, Tsuchiya & Nosaka, 2016 (Ochi et al., 2016)	12	M	Untrained	28.1±5.3 years	Randomized crossover design	Baseline, immediately post, 24h and 72h post-exercise	Blood lactate	Cross-sectional area	MVC, torque, ROM, muscle soreness (VAS)	MRI for T2 and CSA, Isokinetic dynamometer for MVC, VAS for soreness, blood lactate assay
Philippe et al. (Philippe et al., 2016)	7	F	Sedentary	20.7±2.9 years	Randomized crossover design	Pre-exercise, 24 hours post	CK, IL-6, TNF-α, insulin	Not reported	Not reported	Blood samples for CK, IL-6, TNF-α, insulin
Philippou et al. (Philippou et al., 2010)	14	M	Untrained	26.4±5.9 years	Randomized, parallel design	Baseline, post-exercise, 24h, 48h, 72h	Not reported	Not reported	Peak force, DOMS, ROM	Isokinetic dynamometer, subjective scales for soreness
Piitulainen et al. (Piitulainen et al., 2011)	24	M	Not specified (physically active)	27.2±4.2 years	Randomized, parallel design	Baseline, immediately post, 2h, 24h, 48h, 72h	Not reported	Muscle thickness	MVIC, muscle soreness, muscle fiber conduction velocity	Surface EMG, isokinetic dynamometer
Rappelt et al. (Rappelt et al., 2021)	25	M	Not specified (healthy adults)	30±6 years	Randomized crossover design	Baseline, immediately post.	Blood lactate	Not reported	Countermovement jump height (CMJ), functional balance (Y-Balance-Test composite score), postural sway (Posturomed total distance)	Force plates (CMJ), Y-Balance-Test, Posturomed platform for postural sway

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Table 2. Characteristics of the included studies

Study	N	Sex	Sport	Age	Study Design	Time points analyzed	Biochemical outcomes	Muscle properties outcomes	Muscle functional outcomes	Methods of measurement
Royer et al. (Royer et al., 2022)	33	M	Not specified (physically active)	18-24 years	Randomized, parallel design	Baseline, immediately post, 24 h, 48 h	Not reported	Not reported	MVC torque, voluntary activation, evoked torque (10 Hz and 100 Hz), 10/100 Hz ratio, M-wave amplitude, muscle soreness	Isokinetic dynamometer (MVC), electromyography (M-wave), muscle soreness scales
Willoughby & Taylor (Willoughby & Taylor, 2004)	8	M	Not specified (healthy adults)	21±1 years	Randomized crossover design	Pre, 24 h, 48 h post-exercise	Serum myostatin, FLRG concentrations	Not reported	Not reported	ELISA (biochemical), strength testing
Ye et al. (Ye et al., 2014)	25	M	Resistance trained	23.6±3.8 years	Randomized crossover design	Pre, immediate post-exercise	Not reported	Not reported	Maximal force	Isokinetic dynamometer, EMG
Ye et al. (Ye et al., 2015)	15	M	Resistance trained	23.7±3.5 years	Randomized crossover design	Pre, immediate post-exercise	Not reported	Not reported	MVIC, force steadiness (coefficient of variation at 40% MVC), surface EMG amplitude and mean frequency	Isokinetic dynamometer, EMG

M: male; F: female; CK: creatine kinase; MVC: maximum voluntary contraction force; MVIC: maximal voluntary isometric contraction; PPT: pressure pain threshold; ROM: range of motion; VAS: pain intensity; LDH: lactate dehydrogenase; ICF: intracortical facilitation; LICI: long-interval intracortical facilitation; SICI: short-interval intracortical inhibition;

Intervention characteristics

Intervention protocols were highly heterogeneous across the included studies, differing in the number of sessions (single exposure to up to three sessions, most commonly one or two), contraction modes (eccentric, concentric, and less frequently isometric), exercise modality, volume prescription (sets/repetitions or continuous bouts), rest structure, pacing, and intensity (see Supplementary Material S1 for protocol-level details). Eccentric exposures were typically delivered as maximal voluntary or tightly controlled lengthening actions using biceps curls, isokinetic elbow flexor work, downhill treadmill walking, eccentric cycling, and knee extension paradigms, with session volume ranging from one continuous bout (e.g., cycling/walking) to as many as 10 sets and ~6–25 repetitions per set when discrete sets were used; rest intervals likewise ranged from none in continuous protocols to ~5 minutes between sets, with inter-repetition recovery either continuous (cadence-driven) or time-regulated (seconds to ~20 s). Where reported, movement velocities/cadences were standardized within modality (e.g., isokinetic work commonly ~30–60°/s; cycling sprints ~80 rpm; treadmill gradients at fixed speeds), and comparator concentric protocols generally mirrored exercise selection and pacing with volume- or intensity-matching approaches. Importantly, eccentric intensity was frequently prescribed as maximal effort and, in overload designs, reached supramaximal levels (up to ~150% of concentric 1-RM), whereas concentric work was typically set between moderate and maximal intensities (e.g., ~50–100% of concentric power output or ~75–100% 1-RM), and isometric protocols—reported in fewer studies—consisted of brief maximal holds (~1.6–10 s) separated by structured rest.

Risk of bias in studies

The risk-of-bias assessments for the crossover and parallel-group studies are summarized in Supplementary Materials S2 and S3. Thirteen studies were evaluated, comprising nine crossover trials and four parallel-group trials. Among the crossover studies, three were judged to have a high overall risk of bias, while the remaining six raised some concerns. None was judged to have a low overall risk of bias. High-risk judgments most commonly arose from Domain 2 (bias due to deviations from intended interventions) and Domain 1 (bias arising from the randomization process). González-Bartholin et al. (2019), Rappelt et al. (2021), and Ye et al. (2014) were judged to have a high overall risk of bias, with concerns in Domain 2 contributing to the overall judgment in all three studies. Domain 5 (bias in selection of the reported result) also raised concerns in most crossover studies. Latella et al. (2019), Ochi et al. (2016), and Willoughby and Taylor (2004) had comparatively fewer risk-of-bias concerns, although issues related to randomization or selective reporting precluded an overall low-risk judgment.

Among the parallel randomized studies, one was rated as high risk of bias, and the remaining three were judged to have some concerns. Clarkson et al. (Clarkson et al., 1986) was identified as high risk, primarily due to problems in Domain 1 (randomization process) and Domain 4 (measurement of the outcome). The remaining studies (Philippou et al., 2010; Piitulainen et al., 2011; Royer et al., 2022) were generally consistent in showing some concerns across Domains 1, 4, and 5 but did not meet the criteria for high risk in any individual domain. The most common limitations related to deviations from in-

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tended interventions, inadequate or unclear randomization procedures, and potential selective reporting of outcomes.

Results of individual studies

Table 3 synthesizes biochemical responses to eccentric, concentric, and isometric interventions, with outcomes most commonly sampled immediately post-exercise and at 24 h and 48 h (fewer data were available at 72 h). Across studies, creatine kinase (CK) and myoglobin showed the clearest mode-dependent pattern, since eccentric protocols generally elicited larger and more sustained elevations (including delayed peaks extending to 72 h in some datasets), whereas concentric conditions produced smaller increases that tended to stabilize or decline earlier, and isometric protocols showed comparatively modest changes when reported. Evidence for inflammatory cytokines was sparse and inconsistent, with only isolated reporting of IL-6 and TNF-α indicating small or variable post-exercise fluctuations and minimal divergence between contraction modes. Blood lactate rose acutely after both eccentric and concentric exercise (consistent with immediate metabolic perturbation) and typically returned toward baseline by 24 h when follow-up data were provided; isometric lactate data were limited. A small subset of studies assessed endocrine/regulatory markers, suggesting transient post-exercise increases in myostatin-related measures after eccentric loading with generally similar but less pronounced responses after concentric work, while isometric evidence remained insufficient for firm inference.

Table 3. Biochemical outcomes following eccentric, concentric, and isometric interventions.

Study	Outcome	Intervention	Baseline (Mean±SD)	Immediately Post (Mean±SD)	24h Post-exercise (Mean±SD)	48h Post-exercise (Mean±SD)	72h Post-exercise (Mean±SD)
Clarkson et al. (Clarkson et al., 1986)	CK (mU/ml)	Eccentric	89.8*	110*	-	-	-
		Concentric	73.2*	88.8*	-	-	-
		Isometric	99.8*	-	120*	-	-
González-Bartholin et al. (González-Bartholin et al., 2019)	CK (mU/ml)	Moderate Eccentric	25.6±14.7	-	38.7±25.6	40.3±23.5	-
		High Eccentric	47.0±28.4	-	93.4±69.0	59.2±40.9	-
		Concentric	-	-	34.8*	38.8±16.2	35.4±22.3
Muthalib et al. (Muthalib et al., 2010)	CK (IU/L)	Eccentric	87.3±11.4	-	213.5±56.4	211.6±37.6	493.2±199.0
		Concentric	89.8±7.2	-	122.7±20.2	114.9±10.9	106.9±8.6
Ochi, Tsuchiya & Nosaka (Ochi et al., 2016)	Lactate (mmol/L)	Eccentric	2.5±0.8	4.9±1.2	-	-	-
		Concentric	2.5±0.8	5.4±1.4	-	-	-
Philippe et al. (Philippe et al., 2016)	CK (U/L)	Eccentric	98.8±61.5	-	197.2±58.5	-	-
		Concentric	-	-	117.8±63.6	97.0±42.0	-
	Insulin (mU/L)	Eccentric	7.2±3.1	-	6.6±2.7	-	-
		Concentric	-	-	9.5±3.9	8.8±5.2	-
	IL-6 (pg/ml)	Eccentric	1.1±0.7	-	0.9±0.3	-	-
		Concentric	-	-	0.8±0.3	0.9±0.2	-
	TNF-α (pg/ml)	Eccentric	1.5±0.2	-	3.4±3.8	-	-
		Concentric	-	-	1.3±0.4	2.2±1.8	-
	Lactate (mmol/L)	Eccentric	1.4±0.8	2.8±2.1	1.1±0.4	-	-
		Concentric	-	-	1.1±0.6	1.7±0.9	-
Piitulainen et al. (Piitulainen et al., 2011)	Myoglobin (mmol/L)	Eccentric	44.7±14.1	75.5±27.6	64.0±19.0	-	-
		Concentric	-	-	42.0±10.8	46.6±7.2	-
	K^+ (mmol/L)	Eccentric	4.2±0.4	4.4±0.3	-	-	-
		Concentric	-	-	4.3±0.4	4.3±0.3	-
	Na^+ (mmol/L)	Eccentric	140±2.3	139±1.7	141±2.2	-	-
		Concentric	-	-	139±2.3	140±2.2	-
Willoughby & Taylor (Willoughby & Taylor, 2004)	Myostatin (ng/ml)	Eccentric	136.8±70.9	-	231.7±69.6	179.9±69.6	-
		Concentric	-	-	145.4±78.9	225.5±80.1	-
	FLRG (ng/ml)	Eccentric	43.7±25.3	-	67.7±25.1	63.7±25.3	-
		Concentric	-	-	41.9±19.9	65.3±19.8	-

*No standard deviation reported; IL-6: interleukin 6; TNF-α: tumor necrosis factor alpha; CK: creatine kinase; FLRG: follistatin-like related gene.

Tables 4 and 5 summarize muscle property outcomes, with Table 4 focusing primarily on eccentric versus concentric interventions and Table 5 reporting the available isometric data. Overall, morphological indices suggested a more prominent acute swelling/edema response after eccentric loading than after concentric work, most clearly demonstrated by MRI-derived increases in elbow flexor cross-sectional area (CSA) that rose immediately post-exercise and, in some

muscles, peaked within 24–48 h before trending back toward baseline; in contrast, concentric conditions showed smaller and more variable CSA fluctuations within the same observation window. Ultrasound-derived muscle thickness outcomes were comparatively stable across modes, showing only minor, clinically modest post-exercise changes. Electrophysiological markers (M-wave properties) indicated a transient neuromuscular perturbation after eccentric exercise (reductions in maximal M-wave amplitude and duration immediately post-exercise with recovery toward or above baseline by 24–48 h), whereas concentric exercise produced smaller immediate changes and faster normalization. Isometric interventions exhibited the least disruption overall, with M-wave amplitude and duration remaining largely stable across time points and only slight, short-lived deviations immediately after exercise.

Table 4. Muscle property outcomes following eccentric, concentric, and isometric interventions.

Study	Outcome	Intervention	Baseline (Mean±SD)	Immediately Post-exercise (Mean±SD)	24h Post-exercise (Mean±SD)	48h Post-exercise (Mean±SD)	72h Post-exercise (Mean±SD)
Ochi, Tsuchiya & Nosaka (Ochi et al., 2016)	Brachialis CSA (cm^2)	Eccentric	7.1±1.6	7.7±2.6	8.2±2.8	-	7.7±2.5
		Concentric	5.9±2.3	6.1±2.8	8.2±2.5	-	6.1±2.7
	Brachioradialis CSA (cm^2)	Eccentric	3.5±1.3	4.7±2.6	5.3±2.4	-	6.6±3.3
		Concentric	4.4±1.5	4.0±3.0	6.4±2.6	-	4.4±2.5
Royer et al. (Royer et al., 2022)	Vastus Lateralis Mmax (mV)	Eccentric	6.0±1.8	5.5±1.9	6.4±2.8	6.8±3.2	-
		Concentric	6.1±3.0	5.7±2.6	6.0±2.4	6.8±3.3	-
		Isometric	6.9±2.6	6.1±2.3	6.7±2.2	6.9±3.0	-
	Vastus Medialis Mmax (mV)	Eccentric	12.1±3.0	10.2±3.0	11.4±3.1	11.4±3.2	-
		Concentric	13.3±3.1	12.7±2.8	13.0±2.8	12.6±3.3	-
		Isometric	12.9±3.2	12.7±3.3	12.7±3.2	12.7±2.7	-
	Vastus Lateralis Mdur (m/s)	Eccentric	8.5±1.7	7.4±1.6	8.0±1.9	8.3±2.0	-
		Concentric	8.3±2.7	7.4±2.3	8.6±2.0	8.9±2.5	-
		Isometric	7.7±7.3	7.3±2.2	7.5±1.9	7.3±1.6	-
	Vastus Medialis Mdur (m/s)	Eccentric	7.3±1.0	6.5±0.5	7.5±2.0	7.1±1.7	-
		Concentric	9.0±2.7	8.2±2.7	8.8±2.4	8.6±2.3	-
		Isometric	7.0±1.0	6.9±1.1	7.1±1.2	6.6±1.1	-

CSA: cross-sectional area; Mmax: M-wave first phase amplitude; Mdur: M-wave duration.

Table 5 summarizes muscle function outcomes across eccentric, concentric, and isometric interventions, centering on maximal voluntary force/torque (MVC/MVIC), soreness (DOMS), range of motion (ROM), and selected indices of neuromuscular/cortical excitability. Overall, eccentric protocols produced the most consistent and largest acute decrements in voluntary force/torque immediately post-exercise, accompanied by substantial DOMS and, where assessed, transient ROM reductions, with recovery generally progressing over 24–72 h and being slower after higher-load eccentric exposures. Several studies also reported concurrent short-lived neurophysiological changes after eccentric work (e.g., altered intracortical inhibition/facilitation), consistent with a temporary disturbance in activation and/or neuromuscular function during early recovery. In contrast, concentric interventions typically resulted in smaller and more variable force changes (sometimes minimal impairment or even slight immediate increases), lower DOMS, and less pronounced ROM restriction, with faster normalization across follow-up time points. Isometric interventions exhibited the least post-exercise impact overall, characterized by comparatively modest and transient force reductions (when present), minimal soreness, and largely preserved neuromuscular function relative to eccentric loading.

Evidence gap map

Figures 2–4 present the evidence gap maps for biochemical, muscle property, and functional outcomes, organized by sampling time point (immediate, 24 h, 48 h, 72 h) and by the most frequent contraction-mode comparisons (predominantly eccentric vs concentric, with fewer eccentric vs isometric contrasts). Across biochemical outcomes, creatine kinase (CK) was the most frequently assessed biochemical marker most consistently tracked across the full post-exercise window (immediate through 72 h), reflecting its widespread use as an index of muscle damage; by comparison, lactate and myoglobin are measured less often and largely confined to immediate and early follow-up (typically immediate and/or 24 h), while cytokines (e.g., IL-6, TNF-α) and endocrine/metabolic markers (e.g., insulin, myostatin-related proteins) appear sporadically and are rarely sampled at later recovery time points. For muscle properties, the map indicates that structural metrics (CSA and thickness) and electrophysiological indices (M-wave amplitude/duration) are most commonly assessed at baseline and immediately post-exercise, with follow-up concentrated within 24–48 h and limited extension to 72 h; isometric conditions contribute relatively little property-level evidence and are usually assessed at fewer time points, often without direct dynamic-mode comparisons. For functionality, the densest evidence clusters around MVC/MVIC and DOMS, typically measured at baseline, immediately post-exercise, and at 24–48 h (with fewer studies extending to 72 h), whereas measures such as ROM, jump performance, postural control, and cortical excitability indices (SICI/ICF/LICI) are comparatively sparse and generally restricted to immediate or early follow-up. Collectively, the gap maps underscore both a strong comparative emphasis on eccentric vs concentric responses across early

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Table 5. Muscle function outcomes following eccentric, concentric, and isometric interventions.

Study	Outcome	Intervention	Baseline (Mean±SD)	Immediately Post-exercise (Mean±SD)	24h Post-exercise (Mean±SD)	48h Post-exercise (Mean±SD)	72h Post-exercise (Mean±SD)
Clarkson et al. (Clarkson te al., 1986)	Forearm Flexors DOMS (AU)	Eccentric	1.5*	-	5.3*	-	-
		Concentric	1.0*	-	0.8*	-	-
		Isometric	1.0*	-	3.5*	-	-
	Forearm Extensors DOMS (AU)	Eccentric	1.0*	-	2.8*	-	-
		Concentric	1.0*	-	1.1*	-	-
		Isometric	1.0*	-	1.7*	-	-
	Wrist Flexors DOMS (AU)	Eccentric	1.0*	-	3.3*	-	-
		Concentric	1.0*	-	1.3*	-	-
		Isometric	1.0*	-	1.9*	-	-
	Wrist Extensors DOMS (AU)	Eccentric	1.0*	-	2.1*	-	-
		Concentric	1.0*	-	1.1*	-	-
		Isometric	1.0*	-	1.5*	-	-
González-Bartholin et al. (González-Bartholin et al., 2019)	MVC Moderate (N)	Eccentric	747.4±157.6	688.5±157.6	721.4±112.1	762.3±160.8	-
	MVC High (N)	Eccentric	732.7±162.3	571.0±162.3	672.0±162.3	659.4±146.1	-
	DOMS Moderate (AU)	Eccentric	0±1	-	9.7±7.9	7.9±10.5	-
	DOMS High (AU)	Eccentric	0±0.5	-	20.3±19.0	18.2±21.3	-
	MVC Moderate (N)	Concentric	-	-	663.5±191.2	709.9±204.6	689.0±198.9
	DOMS Moderate (AU)	Concentric	-	-	1.8±3.7	1.1±3.0	2.4±3.0
Latella et al. (Latella et al., 2019)	MVIC Torque (Nm)	Eccentric	49.2±4.6	34.1±6.5	-	-	-
		Concentric	49.1±5.0	37.7±4.9	-	-	-
	SICI (%)	Eccentric	58.7±22.1	86.3±10.5	-	-	-
		Concentric	50.8±14.9	75.4±23.0	-	-	-
	ICF (%)	Eccentric	129.0±20.3	194.4±18.8	-	-	-
		Concentric	129.0±20.3	162.1±16.6	-	-	-
	LICI (%)	Eccentric	77.0±20.8	112.9±21.6	-	-	-
		Concentric	77.7±16.9	82.4±14.3	-	-	-
Muthalib et al. (Muthalib et al., 2010)	MVC (Nm)	Eccentric	55.1±5.4	24.6±3.0	30.6±4.3	32.9±5.0	35.6±4.3
		Concentric	56.4±5.7	45.2±5.3	53.2±6.3	53.6±6.2	55.2±6.4
	DOMS VAS (mm)	Eccentric	0.0±0.0	-	31.9±2.8	47.2±4.4	42.9±6.4
		Concentric	0.0±0.0	-	2.3±1.0	2.7±1.2	1.0±1.0
Ochi, Tsuchiya & Nosaka (Ochi et al., 2016)	MVC Torque (Nm)	Eccentric	64.6±12.5	44.6±14.4	42.9±11.5	-	53.3±11.9
		Concentric	68.8±15.0	52.7±12.5	60.6±11.0	-	67.5±15.4
	Brachialis DOMS VAS (mm)	Eccentric	7.9±12.6	20.7±21.7	45.6±21.7	-	39.9±21.2
		Concentric	8.6±11.6	16.0±21.5	18.2±14.3	-	13.3±17.8
	Brachioradialis DOMS VAS (mm)	Eccentric	6.4±8.6	16.4±12.1	35.0±19.8	-	37.8±25.2
		Concentric	5.9±5.7	15.3±14.3	11.4±8.4	-	8.3±7.4
	ROM (°)	Eccentric	113.6±9.3	76.0±19.6	83.3±21.4	-	85.9±24.7
		Concentric	113.6±10.8	99.5±12.6	117.3±6.3	-	117.3±10.1
Philippou et al. (Philippou et al., 2010)	DOMS VAS (mm)	Eccentric	0±0	-	39.2±8.6	53.2±9.6	49.3±8.0
		Concentric	-	-	-	-	-
		Isometric	0±0	-	20.9±5.1	27.8±6.6	-
	ROM (rad)	Eccentric	2.12±0.0	-	1.8±0.1	1.8±0.1	1.8±0.1
		Concentric	-	-	-	-	-
		Isometric	2.1±0.0	-	1.8±0.0	1.9±0.0	-
	Peak Force (N)	Eccentric	283.7±17.3	-	135.6±13.1	157.0±13.1	166.4±21.3
		Concentric	-	-	-	-	-
		Isometric	252.0±9.4	-	184.7±9.3	209.1±12.9	-

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Table 5. Muscle function outcomes following eccentric, concentric, and isometric interventions.

Study	Outcome	Intervention	Baseline (Mean±SD)	Immediately Post-exercise (Mean±SD)	24h Post-exercise (Mean±SD)	48h Post-exercise (Mean±SD)	72h Post-exercise (Mean±SD)
Piitulainen et al. (Piitulainen et al., 2011)	MVC (N)	Eccentric	318±82	208±88	-	-	-
		Concentric	259±79	171±88	-	-	-
		Isometric	334±108	234±94	-	-	-
	MVIC CV (m/s)	Eccentric	4.2±0.3	4.2±0.4	-	-	-
		Concentric	4.2±0.5	4.6±0.5	-	-	-
	MNF (Hz)	Eccentric	105.9±27.4	104.7±22.7	-	-	-
		Concentric	105.4±25.3	114.9±32.6	-	-	-
Rappelt et al. (Rappelt et al., 2021)	CMJ (m)	Eccentric	0.3±0.1	0.3±0.1	-	-	-
		Concentric	0.3±0.1	0.3±0.1	-	-	-
	YBTcs (%)	Eccentric	96.4±6.8	96.0±6.3	-	-	-
		Concentric	96.0±7.0	94.2±6.3	-	-	-
	Posturomedtd	Eccentric	3.4±0.7	3.3±0.1	-	-	-
		Concentric	3.4±0.8	3.6±0.6	-	-	-
Royer et al. (Royer et al., 2022)	Voluntary Torque (Nm)	Eccentric	187.0±27.2	46.3±16.9	85.5±29.6	109.1±31.6	-
		Concentric	185.6±32.5	76.6±24.9	191.0±40.5	212.8±42.7	-
		Isometric	189.2±32.9	105.1±24.9	140.7±26.7	163.8±32.5	-
	Evoked Torque (Nm)	Eccentric	83.4±3.3	37.2±8.4	57.4±9.9	70.0±10.6	-
		Concentric	79.1±4.1	45.5±6.8	86.8±8.9	85.4±8.2	-
		Isometric	71.9±3.9	46.6±6.0	62.8±6.2	68.0±2.4	-
	DOMS VAS (mm)	Eccentric	3.4±1.4	23.8±3.6	60.6±8.9	58.0±13.7	-
		Concentric	12.3±4.5	28.9±9.2	19.0±6.2	8.4±3.8	-
		Isometric	7.5±2.6	14.7±5.3	38.2±10.6	40.4±14.6	-
Ye et al. (Ye et al., 2014)	Forearm Flexors Maximal Force (N)	Eccentric	444.3±90.4	372.2±80.9	-	-	-
		Concentric	442.6±86.1	379.1±79.1	-	-	-
Ye et al. (Ye et al., 2014)	%CV of Force Output	Eccentric	2.7±0.9	3.2±0.8	-	-	-
		Concentric	2.1±0.5	2.2±0.5	-	-	-

*No standard deviation reported in any form; DOMS: delayed onset muscle soreness; MVC: maximal voluntary contraction; MVIC: maximal voluntary isometric contraction; SICI: short-interval intracortical inhibition; ICF: intracortical facilitation; LICI: long-interval intracortical inhibition; VAS: visual analog scale; ROM: range of motion; CMJ: countermovement jump; YBTcs: Y balance test composite score; Posturomedtd: Posturomed test duration; MNF: mean frequency; CV: coefficient of variation.

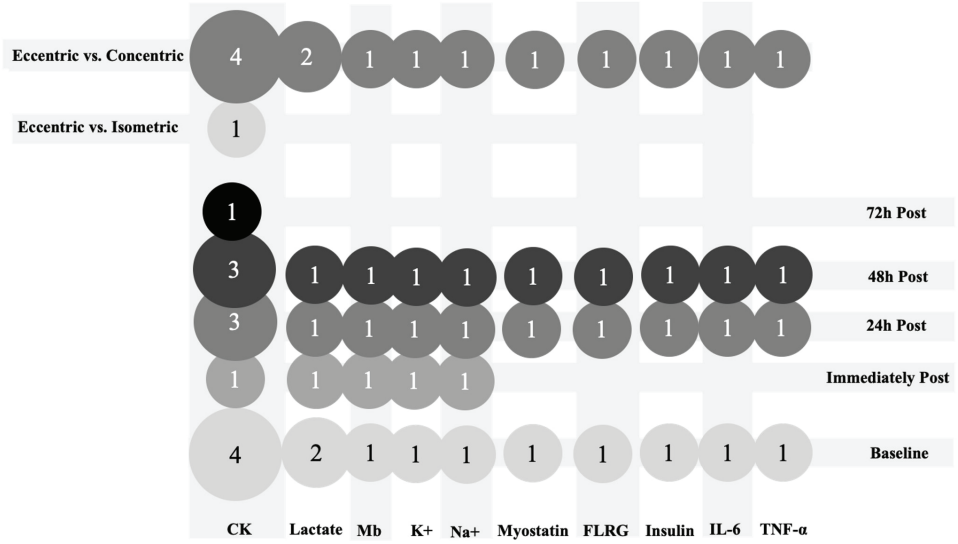

Figure 2. Evidence gap map showing the number of studies by contraction-mode comparison and assessment time point for biochemical outcomes. CK, creatine kinase; Mb, myoglobin; K^+, potassium; Na^+, sodium; FLRG, follistatin-like related gene; IL-6, interleukin-6; TNF-α, tumor necrosis factor-alpha

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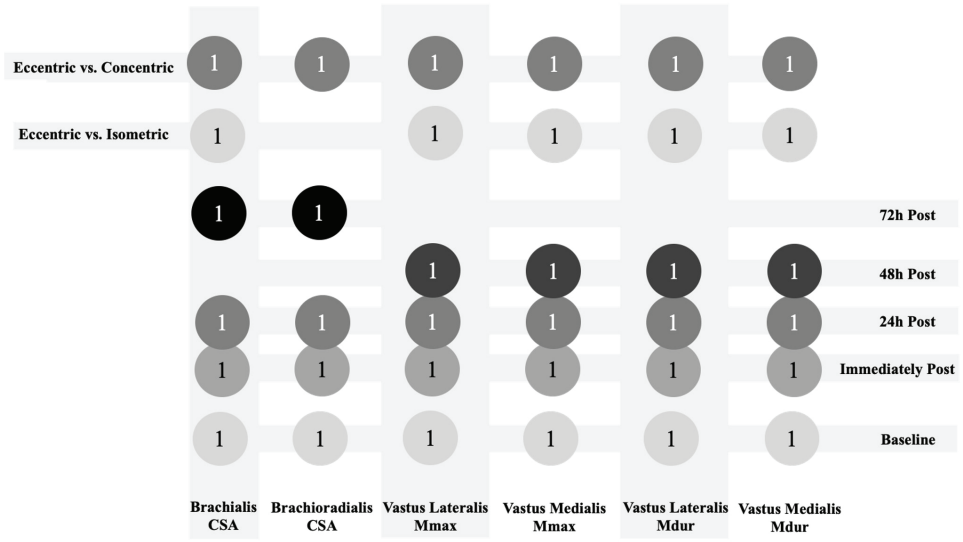

Figure 3. Evidence gap map showing the number of studies by contraction-mode comparison and assessment time point for muscle property outcomes. CSA, cross-sectional area; Mmax, M-wave first-phase amplitude; Mdur, M-wave duration

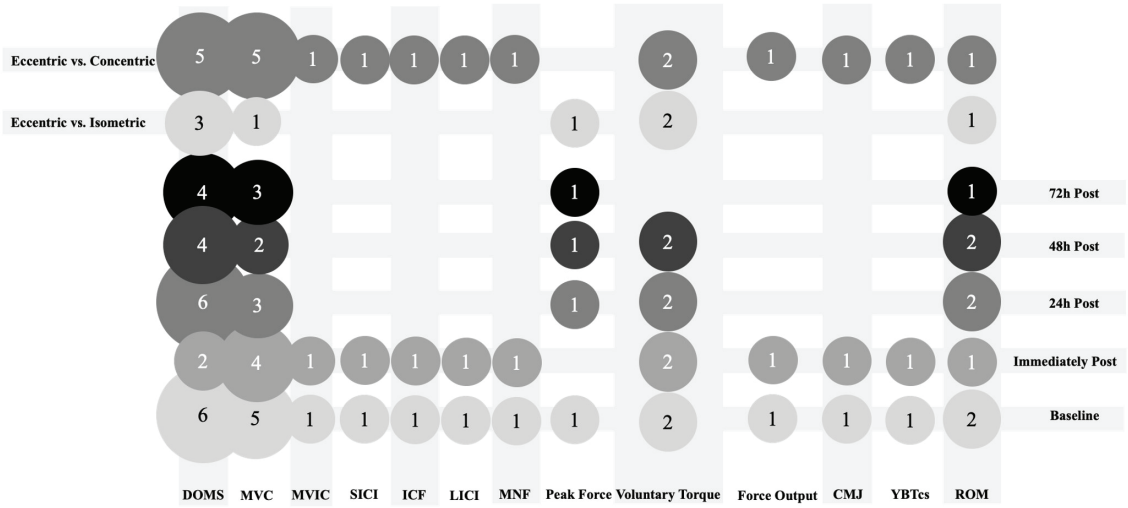

Figure 4. Evidence gap map showing the number of studies by contraction-mode comparison and assessment time point for muscle function outcomes. DOMS, delayed-onset muscle soreness; MVC, maximal voluntary contraction; MVIC, maximal voluntary isometric contraction; SICI, short-interval intracortical inhibition; ICF, intracortical facilitation; LICI, long-interval intracortical inhibition; MNF, mean frequency; CMJ, countermovement jump; YBTcs, Y-Balance Test composite score; ROM, range of motion

recovery and a relative paucity of (i) isometric comparisons, (ii) later-phase biochemical profiling beyond CK, and (iii) broader functional and neuromechanical outcomes tracked consistently across multiple post-exercise time points.

Discussion

This scoping review and evidence gap map synthesized the available evidence on acute and short-term responses to eccentric-based exercise across biochemical, structural, electrophysiological, and functional domains. Overall, eccentric exercise was associated with greater perturbations than concentric and isometric exercise, particularly elevations in creatine kinase (CK), transient changes in muscle morphology, and reductions in maximal voluntary force accompanied by delayed-onset muscle soreness (DOMS) and reduced range of motion (ROM). However, the magnitude and time course of these responses varied considerably across studies and appeared to depend on the characteristics of the exercise protocol, participant population, outcome assessed, and timing of measurement.

Study characteristics, intervention heterogeneity, and methodological considerations

Only 13 studies met the eligibility criteria, and most used relatively small samples. Participant characteristics also varied substantially, although the evidence was concentrated predominantly in healthy young adults, with fewer women and limited representation of older adults. Training backgrounds ranged from sedentary or untrained individuals to recreationally trained participants, which is relevant because age and previous training exposure may influence muscle-damage and recovery responses (González-Bartholin et al., 2019; Latella et al., 2019; Ochi et al., 2016; Philippe et al., 2016; Li et al., 2024; Lacio et al., 2021).

Considerable variability was also evident in the experimental protocols. Studies differed in contraction mode, exercise modality, intensity, volume, movement velocity, rest structure, and follow-up schedule, with eccentric loading ranging from controlled submaximal exercise to supramaximal conditions approaching approximately 150% of concentric 1-RM (Clarkson et al., 1986; Philippou et al., 2010; Piitulainen et al., 2011; Willoughby & Taylor, 2004; Rappelt et al., 2021; Royer et al., 2022). Outcome selection was similarly heterogeneous. CK and maximal voluntary force or torque were investigated relatively frequently, whereas inflammatory and endocrine markers, muscle morphology, electrophysiology, and cortical excitability were assessed less consistently (Muthalib et al., 2010; Philippe et al., 2016; Willoughby & Taylor, 2004; Royer et al., 2022). Risk-of-bias assessment further identified concerns relating mainly to randomization, deviations from intended interventions, outcome measurement, and selective reporting. These characteristics should be considered when interpreting differences between contraction modes.

Principal findings

The clearest biochemical pattern concerned markers associated with muscle damage. Eccentric exercise generally produced larger and more sustained increases in CK than concentric or isometric exercise. Muthalib et al. (2010), for example, reported CK concentrations of 213.5±56.4 IU/L at 24 hours and 493.2±199.0 IU/L at 72 hours after eccentric exercise, whereas increases following concentric exercise were generally smaller. Inflammatory and endocrine markers were investigated much less frequently. Available studies reporting IL-6, TNF-α, or myostatin-related measures suggested post-exercise changes following eccentric loading, but the limited number of observations prevents strong conclusions regarding contraction-mode-specific responses (Philippe et al., 2016; Willoughby & Taylor, 2004).

Structural outcomes showed a similar tendency toward greater perturbation following eccentric exercise. Ochi et al. (2016) reported increases in brachioradialis and brachialis cross-sectional area after eccentric exercise, compatible with transient post-exercise swelling or edema associated with exercise-induced muscle damage (Proske & Morgan, 2001). These changes were more evident during the first 24–48 hours and were generally less pronounced following concentric exercise. Electrophysiological observations also indicated transient alterations after eccentric exercise. Royer et al. (2022), for example, identified reductions in M-wave characteristics immediately after exercise, followed by recovery during subsequent assessments. Such changes may reflect transient alterations in sarcolemmal excitability or neuromuscular function during early recovery (Rodriguez-Falces & Place, 2021).

Functional impairment was one of the most consistent findings. Reductions in MVC or MVIC were generally more pronounced following eccentric exercise, particularly when relatively high mechanical loads were applied (Latella et al., 2019; González-Bartholin et al., 2019). These reductions are compatible with mechanisms involving myofibrillar disruption, excitation-contraction coupling impairment, and changes in neural drive following eccentric loading (Hyldahl & Hubal, 2014). DOMS also tended to be greater following eccentric exercise and was sometimes accompanied by reductions in ROM (Ochi et al., 2016). From a practical perspective, the coexistence of force loss, soreness, and restricted ROM indicates that the consequences of an eccentric exercise bout extend beyond changes in circulating biomarkers and may temporarily affect physical function during the subsequent recovery period.

The available evidence therefore suggests a general tendency toward greater acute and short-term perturbation after eccentric than concentric or isometric exercise, although this pattern should not be interpreted as a uniform hierarchy across every outcome or protocol. Mechanical loading characteristics, participant training status, age, and the timing of outcome assessment may modify the magnitude of the observed response. Furthermore, different markers describe different aspects of the post-exercise response and do not necessarily follow identical temporal trajectories. This distinction is particularly relevant when translating findings into training or rehabilitation settings, where transient biochemical changes do not necessarily correspond directly to the magnitude or duration of functional impairment.

Limitations and future research

Several limitations of the available evidence restrict the strength and generalizability of these conclusions. The evidence base remains small, with predominantly modest sample sizes and limited representation of women and older adults. Experimental protocols differed substantially in exercise modality, intensity, volume, pacing, and follow-up timing, while outcome measurement and instrumentation were also inconsistent. These differences prevented meaningful quantitative pooling and limit direct comparison of contraction-specific dose-response relationships. In addition, incomplete reporting of randomization and blinding, scarce preregistration, the absence of appropriate non-exercise controls in several studies, and concerns regarding selective reporting reduce confidence in some estimates. Future research would benefit from adequately powered and demographically diverse samples, transparent preregistration, clearly defined eccentric loading and progression, appropriate comparator conditions, and more consistent assessment windows such as immediately post-exercise and at 24, 48, and 72 hours. Broader outcome batteries incorporating biochemical, structural, neuromuscular, and functional measures would also help clarify whether these responses occur concurrently or follow distinct recovery trajectories.

Conclusions

The available evidence suggests that eccentric-based exercise may be associated with greater acute and short-term perturbations than concentric or isometric exercise, particularly in markers commonly related to muscle damage, transient muscle swelling, and reductions in muscle function. However, this pattern was not uniform across all outcomes or protocols and should be interpreted cautiously. The evidence base comprised only 13 studies, most with modest sample sizes, substantial methodological heterogeneity, and either some concerns or a high overall risk of bias. The limited representation of women and older adults further constrains generalizability. Future studies should use adequately powered and more diverse samples, clearly defined loading protocols, appropriate comparator conditions, standardized assessment windows, and broader combinations of biochemical, structural, neuromuscular, and functional outcomes to establish the magnitude and time course of contraction-mode-specific responses with greater confidence.

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Declarations

Availability of data and materials

The data supporting the findings of this review are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

RT conceived the study, designed the protocol, conducted the literature searches and study screening, extracted the data, performed the analyses, and drafted the manuscript. D.B. and V.A.G. conducted the literature searches and study screening, extracted the data, performed the analyses, and drafted the manuscript. C.D., P.R.P. and V.P.A. contributed to the interpretation of the findings and drafted the manuscript. All authors critically reviewed the manuscript, read and approved the final version, and agreed to be accountable for their contributions to the work.

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References

Clarkson, P. M., Byrnes, W. C., Mccormick, K. M., Turcotte, L. P., & White, J. S. (1986). *Muscle Soreness and Serum Creatine Kinase Activity Following Isometric, Eccentric, and Concentric Exercise*.

Clarkson, P. M., & Hubal, M. J. (2002). Exercise-Induced Muscle Damage in Humans. *American Journal of Physical Medicine & Rehabilitation*, *81*(Supplement), S52–S69. https://doi.org/10.1097/00002060-200211001-00007

Clarkson, P. M., & Sayers, S. P. (1999). Etiology of Exercise-Induced Muscle Damage. *Canadian Journal of Applied Physiology*, *24*(3), 234–248. https://doi.org/10.1139/h99-020

de Hoyo, M., Pozzo, M., Sañudo, B., Carrasco, L., Gonzalo-Skok, O., Domínguez-Cobo, S., & Morán-Camacho, E. (2015). Effects of a 10-Week In-Season Eccentric-Overload Training Program on Muscle-Injury Prevention and Performance in Junior Elite Soccer Players. *International Journal of Sports Physiology and Performance*, *10*(1), 46–52. https://doi.org/10.1123/ijspp.2013-0547

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2017). Chronic Adaptations to Eccentric Training: A Systematic Review. *Sports Medicine*, *47*(5), 917–941. https://doi.org/10.1007/s40279-016-0628-4

Gérard, R., Gojon, L., Decleve, P., & Van Cant, J. (2020). The Effects of Eccentric Training on Biceps Femoris Architecture and Strength: A Systematic Review With Meta-Analysis. *Journal of Athletic Training*, *55*(5), 501–514. https://doi.org/10.4085/1062-6050-194-19

González-Bartholin, R., Mackay, K., Valladares, D., Zbinden-Foncea, H., Nosaka, K., & Peñailillo, L. (2019). Changes in oxidative stress, inflammation and muscle damage markers following eccentric versus concentric cycling in older adults. *European Journal of Applied Physiology*, *119*(10), 2301–2312. https://doi.org/10.1007/s00421-019-04213-7

Goode, A. P., Reiman, M. P., Harris, L., DeLisa, L., Kauffman, A., Beltramo, D., Poole, C., Ledbetter, L., & Taylor, A. B. (2015). Eccentric training for prevention of hamstring injuries may depend on intervention compliance: a systematic review and meta-analysis. *British Journal of Sports Medicine*, *49*(6), 349–356. https://doi.org/10.1136/bjsports-2014-093466

Harris-Love, M. O., Gollie, J. M., & Keogh, J. W. L. (2021). Eccentric Exercise: Adaptations and Applications for Health and Performance. *Journal of Functional Morphology and Kinesiology*, *6*(4), 96. https://doi.org/10.3390/jfmk6040096

Hessel, A. L., Lindstedt, S. L., & Nishikawa, K. C. (2017). Physiological Mechanisms of Eccentric Contraction and Its Applications: A Role for the Giant Titin Protein. *Frontiers in Physiology*, *8*. https://doi.org/10.3389/fphys.2017.00070

Hyldahl, R. D., & Hubal, M. J. (2014). Lengthening our perspective: Morphological, cellular, and molecular responses to eccentric exercise. *Muscle & Nerve*, *49*(2), 155–170. https://doi.org/10.1002/mus.24077

Konrad, A., Kasahara, K., Yoshida, R., Yahata, K., Sato, S., Murakami, Y., Aizawa, K., & Nakamura, M. (2022). Relationship between Eccentric-Exercise-Induced Loss in Muscle Function to Muscle Soreness and Tissue Hardness. *Healthcare*, *10*(1), 96. https://doi.org/10.3390/healthcare10010096

Latella, C., Goodwill, A. M., Muthalib, M., Hendy, A. M., Major, B., Nosaka, K., & Teo, W. P. (2019). Effects of eccentric versus concentric contractions of the biceps brachii on intracortical inhibition and facilitation. *Scandinavian Journal of Medicine and Science in Sports*, *29*(3), 369–379. https://doi.org/10.1111/sms.13334

Lavender, A. P., & Nosaka, K. (2006). Changes in fluctuation of isometric force following eccentric and concentric exercise of the elbow flexors. *European Journal of Applied Physiology*, *96*(3), 235–240. https://doi.org/10.1007/s00421-005-0069-5

McGlory, C., Devries, M. C., & Phillips, S. M. (2017). Skeletal muscle and resistance exercise training; the role of protein synthesis in recovery and remodeling. *Journal of Applied Physiology*, *122*(3), 541–548. https://doi.org/10.1152/japplphysiol.00613.2016

Muthalib, M., Lee, H., Millet, G. Y., Ferrari, M., & Nosaka, K. (2010). Comparison between maximal lengthening and shortening contractions for biceps brachii muscle oxygenation and hemodynamics. *Journal of Applied Physiology*, *109*(3), 710–720. https://doi.org/10.1152/japplphysiol.01297.2009

Ochi, E., Tsuchiya, Y., & Nosaka, K. (2016). Differences in post-exercise T2 relaxation time changes between eccentric and concentric contractions of the elbow flexors. *European Journal of Applied Physiology*, *116*(11–12), 2145–2154. https://doi.org/10.1007/s00421-016-3462-3

Philippe, M., Junker, G., Gatterer, H., Melmer, A., & Burtscher, M. (2016). Acute effects of concentric and eccentric exercise matched for energy expenditure on glucose metabolism in healthy females: a randomized crossover trial. *SpringerPlus*, *5*(1). https://doi.org/10.1186/s40064-016-3062-z

Philippou, A., Bogdanis, G. C., & Maridaki, M. (2010). Neuromuscular dysfunction with the experimental arm acting as its own reference following eccentric and

isometric exercise. *Somatosensory and Motor Research*, *27*(2), 45–54. https://doi.org/10.3109/08990220.2010.483204

Piitulainen, H., Botter, A., Merletti, R., & Avela, J. (2011). Muscle fiber conduction velocity is more affected after eccentric than concentric exercise. *European Journal of Applied Physiology*, *111*(2), 261–273. https://doi.org/10.1007/s00421-010-1652-y

Prior, S. J., Ryan, A. S., Blumenthal, J. B., Watson, J. M., Katzel, L. I., & Goldberg, A. P. (2016). Sarcopenia Is Associated With Lower Skeletal Muscle Capillarization and Exercise Capacity in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *71*(8), 1096–1101. https://doi.org/10.1093/gerona/glw017

Proske, U., & Morgan, D. L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology*, *537*(2), 333–345. https://doi.org/10.1111/j.1469-7793.2001.00333.x

Rappelt, L., Held, S., & Donath, L. (2021). Concentric not eccentric cycling sprint intervals acutely impair balance and jump performance in healthy active young adults: A randomized controlled cross-over study. *Gait and Posture*, *90*, 55–60. https://doi.org/10.1016/j.gaitpost.2021.08.006

Rodriguez-Falces, J., & Place, N. (2021). Sarcolemmal Excitability, M-Wave Changes, and Conduction Velocity During a Sustained Low-Force Contraction. *Frontiers in Physiology*, *12*. https://doi.org/10.3389/fphys.2021.732624

Royer, N., Nosaka, K., Doguet, V., & Jubeau, M. (2022). Neuromuscular responses to isometric, concentric and eccentric contractions of the knee extensors at the same torque-time integral. *European Journal of Applied Physiology*, *122*(1), 127–139. https://doi.org/10.1007/s00421-021-04817-y

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M. S., Eldridge, S. M., Emberson, J. R., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., … Higgins, J. P. T. (2019). RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*, l4898. https://doi.org/10.1136/bmj.l4898

Vogt, M., & Hoppeler, H. H. (2014). Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. *Journal of Applied Physiology*, *116*(11), 1446–1454. https://doi.org/10.1152/japplphysiol.00146.2013

Willoughby, D. S., & Taylor, L. (2004). Effects of Concentric and Eccentric Muscle Actions on Serum Myostatin and Follistatin-Like Related Gene Levels. ©*Journal of Sports Science and Medicine*, *3*, 226–233. http://www.jssm.org

Ye, X., Beck, T. W., Defreitas, J. M., & Wages, N. P. (2014). *An examination of the strength and electromyographic responses after concentric vs. eccentric exercise of the forearm flexors*. www.nsca.com

Ye, X., Beck, T. W., & Wages, N. P. (2015). *Acute effects of concentric vs. eccentric exercise on force steadiness and electromyographic responses of the forearm flexors*. *3*(29), 604–611. www.nsca.com

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