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# The effect of eccentric phase duration on maximal strength, muscle hypertrophy and countermovement jump height: A systematic review and meta-analysis

Christian Houmann Amdi  and Andrew King 

Sport Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, Auckland, New Zealand

## ABSTRACT

The duration of the eccentric phase may affect resistance training (RT) adaptations, with narrative reviews yielding equivocal conclusions. Thus, five databases were searched following Cochrane and PRISMA-guidelines, to compare RT outcomes following shorter (SEG) and longer (LEG) eccentric phase durations. A prospectively registered (<https://osf.io/s6uqn/>) random-effects multi-level meta-analysis with robust variance estimation was performed for strength, hypertrophy and countermovement jump height (CMJ), with results interpreted relative to a region of practical equivalence. Evidence quality was assessed using the Cochrane RoB 2 and GRADE criteria. Nine studies involving 166 participants (46% trained, 77% male) were included. SEG enhanced CMJ by a practically worthwhile degree with moderate certainty (Hedge's  $g = -0.73$  [90% CI =  $-1.34, -0.12$ ; 90% PI =  $-1.34, -0.12$ ]), while uncertain estimates were observed for maximal strength ( $g = 0.25$  [90% CI =  $-0.17, 0.67$ ; 90% PI =  $-0.86, 1.36$ ]) and muscle hypertrophy ( $g = 0.05$  [90% CI =  $-0.22, 0.33$ ; 90% PI =  $-0.54, 0.64$ ]). LEG led to practically equivalent or enhanced strength gains, compared to SEG, in trained participants ( $g = 0.33$  [90% CI =  $0.07, 0.60$ ; 90% PI =  $0.07, 0.60$ ]) and volume-load matched trials ( $g = 0.25$  [90% CI =  $0.04, 0.45$ ; 90% PI =  $0.04, 0.45$ ]) with moderate certainty in subgroup analyses. Therefore, SEG enhance CMJ, while LEG may cause similar or higher strength increases in trained participants and volume-load matched conditions. However, more research is needed.

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## KEYWORDS

Tempo; repetition duration; cadence; power; resistance training


## Introduction

Resistance training (RT) induces robust strength, power and hypertrophy adaptations (Currier et al., 2023; Swinton et al., 2024). These adaptations are influenced by numerous variables, including volume (Currier et al., 2023), load (Lopez et al., 2021) and proximity-to-failure (Robinson et al., 2024), among others. However, the impact of tempo (i.e., total and phase-specific repetition speed) has received relatively little attention. Schoenfeld et al. (2015) reported extremely long repetitions ( $> 10$  s per repetition) produced inferior muscle hypertrophy compared to shorter durations (0.5–8 s). Subsequent reviews reported mixed strength and hypertrophy results comparing shorter and longer execution tempos (Davies et al., 2017; Hackett et al., 2018). Notably, these conclusions were based on a limited number of studies, and many manipulated the duration of multiple phases (i.e., concentric, eccentric and/or transition phases) simultaneously. Thus, it remains challenging to determine the distinct effects of altering specific repetition-phase duration versus overall repetition duration.

Emerging evidence suggests individual contraction phase duration may be more relevant for strength and hypertrophy (Hermes & Fry, 2023; Pereira et al., 2016). A recent meta-analysis found greater one-repetition maximum (1RM) strength gains when shorter ( $< 2$  s) concentric phases were performed compared to longer ( $\geq 2$  s) (Cohen's  $d = 0.21$ ,  $p = 0.029$ ) (Hermes & Fry, 2023). Therefore, shorter concentric durations may better enhance strength, potentially because efforts to prolong concentric duration increases difficulty, diminishes neuromuscular performance and possibly lowers motor unit recruitment, irrespective of total repetition duration (Arazi et al., 2014; Lacerda et al., 2017; Wilk et al., 2021).

The impact of extending eccentric actions (i.e., the part of the movement during which lengthening of the muscle under active tension occurs (Prilutsky, 2000)) is less studied. Eccentric-only actions can produce greater or similar magnitudes of hypertrophy than concentric-only contractions and combined eccentric-concentric actions, respectively (Sato et al., 2022; Schoenfeld et al., 2017). By prolonging the eccentric action, the stretch

**CONTACT** Christian Houmann Amdi  [christian.houmann.amdi@autuni.ac.nz](mailto:christian.houmann.amdi@autuni.ac.nz)  Sport Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, AUT Millennium, Lvl. 2 SPRINZ, 17 Antares Place, Rosedale, Auckland 0632, New Zealand

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velocity of the muscle is reduced, which decreases the residual force enhancement of the subsequent concentric action (Prilutsky, 2000) and ultimately decreases RT performance (i.e., absolute load lifted, volume-load completed, concentric lifting velocity, etc.) (Pryor et al., 2011; Wilk et al., 2019; Wilk, Gepfert, et al., 2020; Wilk, Golas, et al., 2020). However, this acute performance decline may not negatively impact long-term adaptations (Pereira et al., 2016). Eccentric actions also require less energy (Prilutsky, 2000) and eccentric strength is higher than concentric strength (Douglas et al., 2017b). However, this strength differential decreases as eccentric action duration increases (Nuzzo et al., 2023) and greater time under tension or impulse (force  $\times$  time) per rep could potentially be achieved by increasing eccentric action duration.

As larger performance decrements seem to occur with longer eccentric action durations (Wilk, Golas, et al., 2020), striking a balance between force output and time under tension may be essential for maximising impulse and adaptation. Consequently, prolonging the eccentric action may lead to greater hypertrophy and strength gains (Kojic et al., 2025; Pereira et al., 2016) due to increased time under tension and possibly impulse (Douglas et al., 2017b; Kojic et al., 2025), despite lower absolute loads lifted and volume-load completed (Pryor et al., 2011; Wilk et al., 2019; Wilk, Gepfert, et al., 2020; Wilk, Golas, et al., 2020). Conversely, shorter eccentric action durations could be hypothesised to enhance hypertrophy and strength gains due to improved RT performance (Pryor et al., 2011; Wilk et al., 2019; Wilk, Gepfert, et al., 2020; Wilk, Golas, et al., 2020), greater eccentric forces (Earp et al., 2016) and the purported preferential stimulation of type II muscle fibres (Douglas et al., 2017a; Prilutsky, 2000). Shorter eccentric actions may also improve stretch-shortening cycle efficiency (i.e., the ratio between countermovement (CMJ) and squat jump height) (Douglas et al., 2017a), potentially by allowing muscles to achieve a higher active state (greater cross-bridge attachment) and force before the concentric phase, resulting in increased early-phase concentric output (Bobbert et al., 1996).

To date, two reviews have qualitatively addressed the impact of prolonging eccentric actions (Handford et al., 2022; Wilk et al., 2021), yielding differing conclusions and study quality assessments were not performed. Given the inconsistency and gaps in the literature, a meta-analytic approach is more appropriate to assess the impact of different eccentric durations on muscle hypertrophy, 1RM strength and jump height. Thus, we conducted a systematic review with meta-analysis seeking to quantitatively evaluate the impact of varying eccentric durations on muscle hypertrophy, 1RM strength and jump height.

## Methods

### Overview and registration

This systematic review was performed in accordance with the *Cochrane Handbook for Systematic Reviews of Interventions* (version 6.4.0) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page et al., 2021) guidelines. The review was prospectively registered on the Open Science Framework after pilot searches (<https://osf.io/s6uqn/>), but before any formal searches or record screening.

### Search strategy

A comprehensive search strategy using various terms related to resistance exercise and eccentric phase duration was developed in accordance with the PRISMA-S checklist (Rethlefsen et al., 2021), assisted by three specialised tools: the Word Frequency Analyzer (<https://sr-accelerator.com/#/wordfreq>), Research Refiner (<https://sr-accelerator.com/#/searchrefinery>) and Polyglot Search Translator (<https://sr-accelerator.com/#/polyglot>) (Clark, Glasziou, et al., 2020; Clark, Sanders, et al., 2020). The searches were conducted from inception to 10 November 2023 in PubMed/MEDLINE, SCOPUS, SPORTDiscus, CINAHL, ProQuest and Google Scholar. Search results from Google Scholar was mass exported using the *Publish or Perish* software (Harzing, 2007). This comprehensive approach was designed to maximise the chances of locating both peer-reviewed and grey literature. For Google Scholar, the search was limited to the first 1,000 hits (980 results were retrieved due to software error), and for ProQuest, searches were limited to scholarly journals, dissertations and theses. No other predefined limits or filters were applied. The full search strings can be found in Supplementary file 1. Additionally, secondary searches were performed, including: 1) Screening reference lists of all included studies and relevant review papers; 2) Forward citation tracking through Google Scholar for the included studies; and 3) Ongoing search alerts after the initial search date until the week before submission.

### Text screening and selection

After removal of duplicates, titles and abstracts were independently screened for eligibility by the two researchers using the systematic review software Rayyan (<https://rayyan.ai/>). Disagreements were resolved by discussion, and where a consensus could not be reached, an outside reviewer acted as a tie-breaker. For all remaining articles, full-texts were

included if they investigated the impact of eccentric phase duration as the independent variable, classified as either shorter (i.e.,  $\leq 2$  s or 'as fast as possible' [SEG]) or longer (i.e.,  $> 2$  s [LEG]), based on previous literature (Hermes & Fry, 2023), and 1) were published in a peer-reviewed journal, on a pre-print repository, or as a Master's or PhD thesis; 2) written in English; 3) included healthy human participants with no disease or musculoskeletal injury; 4) used parallel groups or contralateral, within-participants designs to assess the effects of altered eccentric phase duration on indices of muscle strength, power, endurance and/or hypertrophy; 5) used traditional combined eccentric/concentric isotonic contractions; 6) matched the duration of all contraction phases except the eccentric (i.e., concentric and possible isometric transition phases); 7) attempted to match frequency, relative-load (% of 1RM or RM relative to tempo), and volume (number of sets or volume-load) between groups; and 8) were at least 4 weeks long to ensure sufficient time for any potential differences to emerge. Studies employing eccentric-only and overloaded eccentrics were excluded.

### Study coding and extraction

The following data were extracted from the included studies: 1) number of participants and their age, sex and training experience; 2) RT protocol including duration, frequency, volume, relative-load, rest periods and exercise selection; 3) study design; 4) duration of each contraction phase; 5) outcome measures; 6) the presence of concurrent training and 7) mean changes and standard deviations of the relevant indices of muscular performance and hypertrophy, as well as within-group correlations of pre-post scores. Where insufficient data were reported, corresponding authors were contacted by email twice over 2 months. If they failed to provide the required data, data were extracted using WebPlotDigitizer and/or calculated in accordance with the Cochrane Handbook (Higgins et al., 2019). All data extraction was completed by the primary researcher and coding files were cross-checked by the senior researcher for accuracy and disagreements were resolved by an outside reviewer.

### Risk of bias assessment

Risk of bias (RoB) was performed using the second version of the Cochrane RoB tool for randomised trials (RoB 2) (Sterne et al., 2019), in accordance with the Cochrane Handbook (Higgins et al., 2023). The effect of adhering, not assignment, to the protocol was the effect of interest. Studies were categorised as: 'Low risk of bias' if all

domains were assessed as low risk; 'Some concerns' if concerns were raised in one domain, but no domain was determined to be high risk; 'High risk of bias' if at least one domain was classified as high risk or if multiple domains raised some concern. The Grading of Recommendations Assessment, Development and Evaluation (GRADE) system was used to evaluate evidence certainty for studies included in the quantitative synthesis, using the GRADEpro GDT software (McMaster University and Evidence Prime, 2024), in accordance with the GRADE (H. Schünemann et al., 2013) and Cochrane (H. J. Schünemann et al., 2019) handbooks, including guidance updates for inconsistency (Guyatt et al., 2023) and imprecision (Zeng et al., 2022). Both RoB and GRADE assessment was performed independently by the two researchers. Disagreements were resolved by an outside reviewer.

### Statistical analysis

#### Multi-level synthesis

Quantitative synthesis was performed for separate outcomes when reported by at least two studies. Sufficient studies were found for maximal strength, hypertrophy and CMJ. Analyses were performed using R Statistical Software (v4.3.0; R Core Team 2021) (R Core Team, 2021). Given that multiple effect sizes were reported in included studies (e.g., more than one longer eccentric phase duration or multiple measures for the same outcome within a study), a three-level (i.e., study, group and outcome) mixed-effect meta-analysis with robust variance estimation were fitted with *metafor* (Viechtbauer, 2010) and *clubSandwich* (Pustejovsky, 2024) packages. Individual studies and effect sizes within studies were treated as random effects. All multi-level meta-analysis models were based on a t-distribution due to the small sample sizes of the included studies (Harrer et al., 2021). Model parameters were estimated using restricted maximum likelihood estimation. Effect sizes were weighted based on their inverse sampling variance. A within-study effect size sampling error correlation coefficient of  $\rho = 0.6$  was assumed for robust variance estimation. Sensitivity analyses with lower ( $\rho = 0.4$ ) and higher ( $\rho = 0.8$ ) values were performed to check robustness. For all multi-level models,  $I^2$  and  $\tau^2$  were calculated to quantify relative and absolute between study heterogeneity, respectively.  $I^2$  and  $\tau^2$  were partitioned across levels 2 (within-study) and 3 (between study) of the multi-level meta-analysis. Publication bias was assessed using the multi-level extension of the Egger's test (Fernández-Castilla et al., 2021) and by funnel plot visual inspection for observed effect sizes and conditional residuals (Nakagawa et al., 2022). To account for between-study heterogeneity, both

confidence (CI) and prediction intervals (PI) were considered for inferences to better understand the precision and reliability of the point estimate from included studies (CI), as well as the possible range of effects when applying the results of this meta-analysis to new studies or practical scenarios (PI).

Pre-planned subgroup analyses were performed for i) study design (categorical: between- and within-participant designs) and ii) training status (categorical: trained and untrained), while exploratory subgroup and moderator analyses were performed when at least two studies were represented in each subgroup, and based on the study characteristics. These subgroups were: i) exercise selection (categorical: multi-joint and single-joint), ii) muscle group (categorical: elbow flexor and anterior thigh), iii) volume matching (categorical: sets to failure and volume-load).

### Effect size calculation

Due to the different tests used to measure maximal strength (Scott curl, back squat, etc.), hypertrophy (e.g., ultrasound and MRI) and CMJ (e.g., force plates, camera-based or vertec), calculating a standardised mean difference (SMD) was deemed more appropriate than using raw mean differences. SMD with a small sample size correction (Hedges'  $g$ ) was calculated, in accordance with Borenstein et al. (2009), such that a positive effect size favoured LEG. To account for the inter-dependencies of effects in within-participant designs, separate effect size calculations were used for between-participant (i.e., parallel group designs [equations 1-3]) and within-participant designs (i.e., contralateral limb designs [equations 4-7]), and then combined in the final analysis (Borenstein et al., 2009).

$$g = \frac{\bar{X}_1 - \bar{X}_2}{SD_{pooled}} J \quad (1)$$

$$SD_{pooled} = \sqrt{\frac{(n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2}{n_1 + n_2 - 2}} \quad (2)$$

$$J = 1 - \frac{3}{4(n_1 + n_2 - 2) - 1} \quad (3)$$

where  $\bar{X}_1$  and  $\bar{X}_2$  are the mean group change scores,  $SD_{pooled}$  is the pooled standard deviation,  $J$  is a small sample size correction, and  $n_1$  and  $n_2$  are the sample sizes of each group.

$$g = \frac{\bar{Y}_1 - \bar{Y}_2}{SD_{pooled}} J \quad (4)$$

$$SD_{pooled} = \frac{S_{diff}}{\sqrt{2(1-r)}} \quad (5)$$

$$SD_{diff} = \sqrt{SD_1^2 + SD_2^2 - 2 * r * SD_1 * SD_2} \quad (6)$$

$$J = 1 - \frac{3}{4(n-1) - 1} \quad (7)$$

where  $\bar{Y}_1$  and  $\bar{Y}_2$  are the mean change scores for each limb,  $SD_{diff}$  is the standard deviation of the within-participant difference between change scores and  $r$  is correlation of the between-limb within-participant change scores (calculated using raw data).

### Model diagnostics

To identify potential outliers and influential observations, Cook's distance and hat values were calculated in *metafor* (Viechtbauer, 2010). Model diagnostics were not performed for jump height due to the small number of included studies ( $k=3$ ). Cook's distance was judged according to the F distribution where  $\alpha=0.50$  and (Aguinis et al., 2013):

$$df = (k + 1, n - k - 1)$$

Hat values ( $h$ ) were deemed noteworthy where exceeding twice the average (Belsley et al., 2005):

$$\bar{h} = \frac{k + 1}{n}$$

Where potential outliers or influential observations were identified, a separate meta-analysis was performed with the corresponding potential outlier/influential study removed and the results were compared to the main meta-analysis to check the interpretation (i.e., direction of effect, CI and PI) (Viechtbauer & Cheung, 2010). This check was conducted as a sensitivity analysis since it is not possible to distinguish between (large) sampling error and true outliers (Schmidt, 2008).

### Statistical inferences

A limitation of traditional meta-analyses with null hypothesis significance testing (NHST) is that they can reject the absence of an effect but cannot support it (Berner & Amrhein, 2022; Lakens, 2017). This often leads to erroneous conclusions of 'no effect' when no statistically significant differences are observed. A non-significant difference may simply indicate substantial uncertainty, due to low statistical power from either low samples sizes and/or high variability, and the need for additional research (Berner & Amrhein, 2022; McShane et al., 2019). Therefore, we adopted equivalence and minimum effects procedures (Lakens, 2017, 2022), within an estimation-

based approach (Gardner & Altman, 1986). As such, the practical implications of all results compatible with the data, including their precision (90% CI and PI), were interpreted, relative to our region of practical equivalence (ROPE) (Lakens, 2022). Evidence of no practically worthwhile effects is supported if the point estimate and its entire 90% CI and PI falls within our ROPE (i.e., effects are practically equivalent to zero) (Lakens, 2017). Conversely, to support a practically worthwhile effect, the point estimate and its entire 90% CI and PI must fall outside of our ROPE. When either the CI or PI partially overlaps with the ROPE (i.e., crosses only one bound), this suggests some uncertainty but indicates that the effect is either practically equivalent or potentially favourable in the direction of the point estimate. Complete overlap with both bounds of the ROPE reflects the greatest degree of uncertainty, where no clear conclusion can be made about the presence or absence of practically meaningful effects. In such cases, additional evidence is needed before firm conclusions can be drawn. Inferences from equivalence and minimum effects procedures are normally interpreted relative to the 90% CI, based on a type one error rate of 5% applied to 2 one-sided tests (Lakens, 2022). Thus, under our estimation-based framework, results which might be non-significant under traditional NHST at the 5% error level are interpreted in terms of precision and practical relevance – whether the estimated effects and their intervals fall entirely within, entirely outside or overlap with the ROPE. This differs from traditional null hypothesis significance testing (NHST), where a non-significant result is considered as failure to reject the null hypothesis (or often misinterpreted as evidence of no effect). 95% CI, 95% PI and *p*-values (two-tailed NHST) were also calculated to allow readers to interpret results through their preferred lens (Supplementary file 2), but they did not influence our inferences, except for GRADE imprecision (Zeng et al., 2022).

We based our ROPEs on meta-analytic data (Currier et al., 2023; Swinton et al., 2022), with effects less than  $\pm 0.25$ ,  $\pm 0.28$ , and  $\pm 0.11$  for maximal strength, hypertrophy and CMJ, respectively, considered practically not worthwhile. These thresholds align with the 25<sup>th</sup> percentile of RT effects on the given outcomes (Swinton et al., 2022). Although no specific recommendations were provided for hypertrophy, the 95% credible interval (0.10 to 0.66) of RT vs. control for hypertrophy from 119 studies by Currier et al. (2023) was used to estimate the 25<sup>th</sup> percentile of effects, assuming a normal distribution. The same data were also used to delineate small (maximal strength: 0.25 to <0.59; hypertrophy: 0.28 to <0.38; CMJ: 0.11 to <0.38), moderate (50<sup>th</sup> percentile [maximal strength: 0.59 to <0.98; hypertrophy: 0.38 to <0.48; CMJ: 0.38 to <0.67]) and large (75<sup>th</sup> percentile [maximal

strength:  $\geq 0.98$ ; hypertrophy:  $\geq 0.48$ ; CMJ:  $\geq 0.67$ ) effect size magnitudes for each outcome.

## Results

### Selection of sources of evidence

Our systematic search yielded 3227 results. After removing duplicates, 2195 articles were eligible for title and abstract screening. Subsequently, 48 articles underwent full-text review, with 38 excluded due to: i) non-accessible full-text, ii) incorrect study design, iii) combined ECC-CON isotonic contractions not performed, iv) no manipulation of eccentric duration, v) lack of matched concentric tempo between groups and vi) comparison of two eccentric durations, both of which considered slow by the inclusion criteria. Consequently, nine and one articles were included from the primary search and search alerts, respectively. Two articles reported data from the same study, resulting in 9 unique studies (Azevedo et al., 2022; Dias et al., 2015; Kojic et al., 2025; Kojić et al., 2021; Mike et al., 2017; Pearson et al., 2022; Pereira et al., 2016; Segers et al., 2022; Shibata et al., 2021) (Figure 1, Table 1). Additional data was requested from all first and/or corresponding authors, of which all but one (Mike et al., 2017) responded. As such, mean changes, change SD, correlations of within-group pre-post scores and within-participant between-limb change scores (for within-participant designs) or sufficient data to estimate them were provided either directly by authors (Dias et al., 2015; Kojic et al., 2025; Shibata et al., 2021), calculated from raw data (Azevedo et al., 2022; Kojić et al., 2021; Pearson et al., 2022; Pereira et al., 2016; Segers et al., 2022) or estimated from extracted full-text data (Mike et al., 2017), in accordance with the Cochrane Handbook (Higgins et al., 2019).

### Study characteristics

An overview of the studies is available in Table 1. The pooled number of participants across all studies was 166, of which 46% ( $n = 77$ ) and 77% ( $n = 128$ ) were resistance-trained and male, respectively. Two studies required a minimum of 3 years of RT experience to classify participants as trained (Mike et al., 2017; Pearson et al., 2022), while one study required at least 1 year (Pereira et al., 2016) and another required 2 years (Segers et al., 2022) of RT experience for participants to be considered trained. The median sample size per comparator group was 10 participants (range: 6–13). Two studies employed a within-participants design (Azevedo et al., 2022; Pearson et al., 2022), while the remaining utilised parallel-groups design. The median intervention period was 7 weeks (range: 4–12 weeks). All

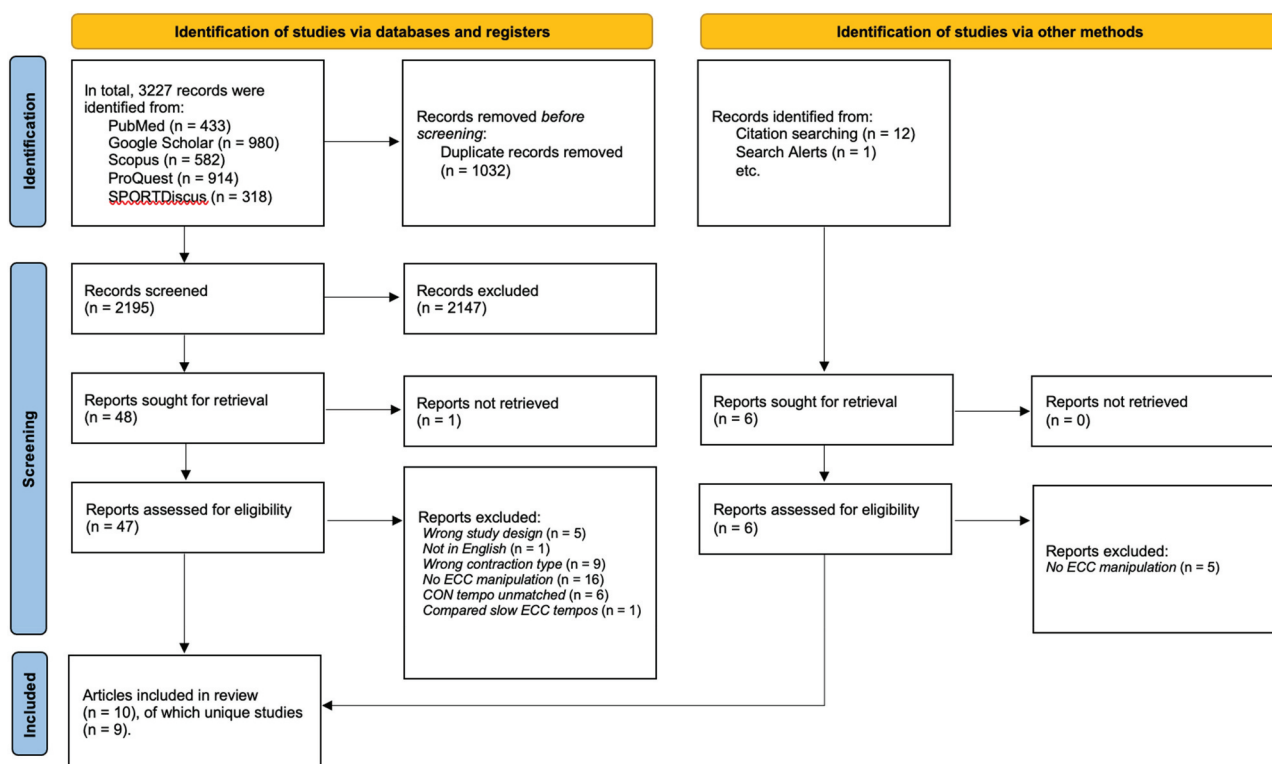


Figure 1. PRISMA-flowchart. ECC eccentric tempo, CON control.

studies required participants to train twice weekly, with a median 3.5 sets per exercise (range: 2–5 sets). Two studies incorporated 5–7 exercises per session (Dias et al., 2015; Segers et al., 2022), while the rest included one. The SEG maintained a median tempo of 1.25 s (range: 1–2 s) and 1 s (range: 1–2 s) in the eccentric and concentric parts of the movement, respectively. The LEG took a median 4 s (range: 3–6 s) and 1 s (range: 1–2 s) to lower and raise the weight, respectively. Four studies matched volume-load (sets  $\times$  repetitions  $\times$  load) between groups (Dias et al., 2015; Mike et al., 2017; Pearson et al., 2022; Segers et al., 2022), allowing for variations in proximity-to-failure. The remaining five had groups perform an equal number of sets to failure (Azevedo et al., 2022; Kojic et al., 2025; Kojić et al., 2021; Pereira et al., 2016; Shibata et al., 2021), allowing differences in performed repetitions or absolute load. All studies evaluated 1RM strength, on either the free-weight (Kojic et al., 2025; Segers et al., 2022; Shibata et al., 2021) or smith-machine (Mike et al., 2017) back squat, leg press (Dias et al., 2015), leg extension (Azevedo et al., 2022; Dias et al., 2015; Pearson et al., 2022) or Scott curl (Kojić et al., 2021; Pereira et al., 2016). Five studies measured hypertrophy of the elbow flexors (Kojić et al., 2021; Pereira et al., 2016) or anterior thigh (Azevedo et al., 2022; Kojic et al., 2025; Pearson et al., 2022; Shibata et al., 2021) using ultrasound (Azevedo et al., 2022; Kojic et al., 2025; Kojić et al., 2021; Pearson et al., 2022; Pereira et al., 2016) or MRI

(Shibata et al., 2021). Three studies assessed CMJ (Mike et al., 2017; Segers et al., 2022; Shibata et al., 2021). Tensiomyography (Kojic et al., 2025; Kojić et al., 2021), squat jump (Shibata et al., 2021), loaded CMJ (Mike et al., 2017), functional capacity tests (6 m walk, timed up-and-go, stair-climbing and stair-rising) (Dias et al., 2015), 20 m sprint (Segers et al., 2022), 505 agility (Segers et al., 2022), T-test (Shibata et al., 2021) and Yo-Yo intermittent recovery test level 2 (Shibata et al., 2021) were also assessed. However, these results were not extracted for meta-analysis due to an insufficient number of studies.

### Study quality and certainty of evidence

One study (Pearson et al., 2022) had a low risk of bias regarding the randomisation process, while the remaining eight studies (Azevedo et al., 2022; Dias et al., 2015; Kojic et al., 2025; Kojić et al., 2021; Mike et al., 2017; Pereira et al., 2016; Segers et al., 2022; Shibata et al., 2021) were rated as 'some concerns' due to insufficient information about randomisation procedures and allocation sequence concealment. For deviations from intended interventions, eight studies had a low risk of bias. One study (Pereira et al., 2016) had some concerns due to a lack of blinding and insufficient information about external training influences. All studies had a low risk of bias concerning missing outcome data, as either no dropouts or equally distributed

**Table 1.** Study overview.

Study	Participants	Training protocol	Tempo (s) [ECC/ISO/CON]	Primary outcome(s)
Dias et al. (2015)	SEG: 68 ± 7 y, 68 ± 14 kg, 1.59 ± 0.07 m n = 10F	Exercise/s: Leg press, leg extension, among others*.	SEG: 1.5/0/1.5	Strength: 1RM leg press and leg extension.
	LEG: 66 ± 6 y, 70 ± 10 kg, 1.57 ± 0.05 m n = 9F	Prescription: 12 weeks, 2 sessions/week. 2–3 sets of 8–12 repetitions at 45–70% of 1RM, 2–3 mins inter-set rest.	LEG: 4.5/0/1.5	
Pereira et al. (2016)	SEG: 28 ± 8 y, 72 ± 9 kg, 1.72 ± 0.05 m n = 6 M	Exercise/s: Scott curl.	SEG: 1/0/1	Strength: 1RM Scott curl;  Hypertrophy: Biceps brachii MT via US.
	LEG: 30 ± 6 y, 74 ± 5 kg, 1.73 ± 0.05 m n = 6 M	Prescription: 12 weeks, 2 sessions/week. 3 sets of 8 repetitions to failure, 2 mins inter-set rest.	LEG: 4/0/1	
Mike et al. (2017)	SEG: 22 ± 2 y, 79 ± 5 kg, 1.80 ± 0.07 m n = 10 M	Exercise/s: Smith machine squat.	SEG: 2/1/2	Strength: 1RM Smith machine squat;  Power: CMJ (Vertec).
	LEG1: 22 ± 2 y, 82 ± 12 kg, 1.76 ± 0.05 m n = 9 M	Prescription: 4 weeks, 2 sessions/week. 4 sets of 6 repetitions at 80–85% of 1RM, 3 mins inter- set rest.	LEG1: 4/1/2	
	LEG2: 23 ± 4 y, 85 ± 17 kg, 1.78 ± 0.08 m n = 11 M	RT experience: Trained (≥3 y of at least 3 RT sessions/ week)	LEG2: 6/1/2	
Kojić et al. (2021)	SEG: 28 ± 8 y, 72 ± 14 kg, 1.78 ± 0.07 m n = 6 M, 4F	Exercise/s: Scott curl.	SEG: 1/0/1	Strength: 1RM Scott curl;  Hypertrophy: Biceps brachii MT via US.
	LEG: 30 ± 6 y, 69 ± 12 kg, 1.72 ± 0.08 m n = 5 M, 5F	Prescription: 7 weeks, 2 sessions/week. 3–4 sets at 60–70% of 1RM to failure, 2 mins inter-set rest.	LEG: 4/0/1	
Shibata et al. (2021)	SEG: 20 ± 1 y, 66 ± 5 kg, 1.71 ± 0.03 m n = 11 M	Exercise/s: Back squat.	SEG: 2/0/2	Strength: 1RM back squat;  Hypertrophy: Quadriceps CSA at 30%, 50%, and 70% of femur length via MRI;  Power: CMJ (high-speed camera).
	LEG: 20 ± 1 y, 67 ± 8 kg, 1.74 ± 0.04 m n = 11 M	Prescription: 6 weeks, 2 sessions/week. 3 sets at 75% of 1RM to failure, 3 mins inter-set rest.	LEG: 4/0/2	
Pearson et al. (2022)	SEG: 23 ± 10 y, 78 ± 10 kg n = 13 M	Exercise/s: Unilateral leg extension.	SEG: 1/0/1	Strength: 1RM unilateral leg extension;  Hypertrophy: Anterior thigh MT at 40% and 60% of femur length via US.
	LEG: 23 ± 10 y, 78 ± 10 kg n = 13 M	Prescription: 8 weeks, 2 sessions/week. 3–4 sets of 8–10 repetitions at 8–10RM, 2 mins inter-set rest. Within-participants design.	LEG: 3/0/1	
Azevedo et al. (2022)	SEG: 25 ± 5 y, 70 ± 11 kg, 1.73 ± 0.10 m n = 8 M, 2F	Exercise/s: Unilateral leg extension.	SEG: 2/0/1	Strength: 1RM unilateral leg extension;  Hypertrophy: Rectus femoris, vastus medialis and vastus lateralis MT via US.
	LEG: 25 ± 5 y, 70 ± 11 kg, 1.73 ± 0.10 m n = 8 M, 2F	Prescription: 8 weeks, 2 sessions/week. 5 sets at 70% of 1RM to failure, 3 mins inter-set rest. Within-participants design.	LEG: 4/0/1	

(Continued)

Table 1. (Continued).

Study	Participants	Training protocol	Tempo (s) [ECC/ISO/CON]	Primary outcome(s)
Segers et al. (2022)	SEG: 22 ± 3 y, 77 ± 6 kg, 1.82 ± 0.06 m n = 11 M	Exercise/s: Back squat, hex bar deadlift, among others.	SEG: 1/0/X	Strength: 1RM back squat; Power: CMJ (force plates).
	LEG: 22 ± 3 y, 77 ± 6 kg, 1.82 ± 0.06 m n = 11 M	Prescription: 4 weeks, 2 sessions/week.	LEG: 4/0/X	
	RT experience: Trained (≥2 y)	3–4 sets of 3–4 repetitions at 70–80% of 1RM.	X = maximal intent	
Kojic et al. (2025)	SEG: 24 ± 2 y, 70 ± 10 kg, 1.75 ± 0.07 m n = 5 M, 4F	Exercise/s: Back squat.	SEG: 1/0/1	Strength: 1RM back squat; Hypertrophy: Rectus femoris, vastus medialis, vastus intermedius, and vastus lateralis CSA via US.
	LEG: 24 ± 2 y, 70 ± 10 kg, 1.75 ± 0.07 m n = 5 M, 4F	Prescription: 7 weeks, 2 sessions/week.	LEG: 4/0/1	
	RT experience: Untrained	3–4 sets at 60–70% of 1RM to failure, 2 mins inter-set rest.		

\*Among others' indicate that other exercises were also performed, typically as part of a whole-body routine, but were either irrelevant for the measured outcomes or not subject to tempo manipulation. SEG shorter eccentric group, LEG longer eccentric group, RT resistance training, ECC eccentric, ISO isometric, CON concentric, M males, F female, RM repetition maximum, CMJ countermovement jump, MT muscle thickness, US ultrasound, y year.

dropouts were reported. Regarding the measurement of outcomes, two study (Kojic et al., 2025; Pereira et al., 2016) had a high risk of bias for strength measurements, while seven had some concerns. For hypertrophy outcomes, one study had high risk (Kojic et al., 2025), three studies (Azevedo et al., 2022; Kojić et al., 2021; Pereira et al., 2016) had some concerns, while two had a low risk of bias (Pearson et al., 2022; Shibata et al., 2021). Regarding power measurements, one study was low risk (Shibata et al., 2021), while the remaining two had some concerns (Mike et al., 2017; Segers et al., 2022). The primary sources of bias in these domains arose when a lack of assessor blinding was combined with methods susceptible to human influence (e.g., load selection and encouragement during strength tests, or researcher-controlled probe tilting and pressure during ultrasound), particularly when conclusions aligned with *a priori* hypotheses. All studies had some concerns related to the selection of reported results because most were not pre-registered, and the one that was (Kojic et al., 2025), did not report planned methods or statistical approaches, making it impossible to assess deviations from a specified plan. No studies were excluded based on risk of bias, as i) this was not specified in our

inclusion criteria, and ii) risk of bias is addressed in our GRADE assessment of the certainty of evidence. In summary, two studies (Kojic et al., 2025; Pereira et al., 2016) had a high overall risk of bias, while the remaining seven studies had some concerns overall (Figure 2, Supplementary files 3 and 4). Funnel plot visual inspection did not suggest publication bias (Supplementary file 4), which was corroborated by the Egger's test for maximal strength ( $p = 0.58$ ), hypertrophy ( $p = 0.14$ ) and CMJ ( $p = 0.39$ ). The certainty of evidence for pooled and subgroup analyses can found in Table 2 and Supplementary file 5.

### Quantitative analysis

#### Maximal strength

The pooled analysis for maximal strength revealed that the average effect most compatible with our data, given our statistical model, was a small effect favouring LEG with poor precision (Figure 3, Table 2). The effect size ranged from a not practically worthwhile effect favouring SEG to a moderate effect favouring LEG ( $g = 0.25$  [90% CI =  $-0.17, 0.67$ ; 90% PI =  $-0.86, 1.36$ ],  $I^2_{\text{within}} = 0\%$ ,  $I^2_{\text{between}} = 65.3\%$ ,

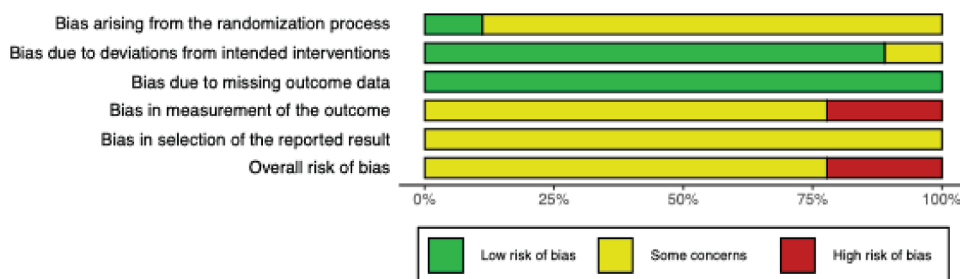


Figure 2. Risk of bias assessment.

**Table 2.** Summary of findings.

Outcome (n, k)	Hedge's g (90% CI) [90% PI]	$I^2_{within}$ , $I^2_{between}$ [ $\tau^2_{within}$ , $\tau^2_{between}$ ]	Certainty of evidence (GRADE)
<b>Strength</b>			
Pooled (n = 166, k = 9)	0.25 (-0.17, 0.67)	0.0%, 65.3%	⊕ ⊕ ⊕ ⊕
Follow-up: 4–12 weeks	[-0.86, 1.36]	[0.00, 0.30]	<b>Low</b> <sup>a,b,e,h</sup>
Trained (n = 77, k = 4)	0.33 (0.07, 0.60)	0.0%, 0.0%	⊕ ⊕ ⊕ ⊕
Follow-up: 4–12 weeks	[0.07, 0.60]	[0.00, 0.00]	<b>Moderate</b> <sup>e</sup>
Untrained (n = 89, k = 5)	0.15 (-0.80, 1.10)	0.0%, 82.5%	⊕ ⊕ ⊕ ⊕
Follow-up: 6–12 weeks	[-2.00, 2.31]	[0.00, 0.82]	<b>Very low</b> <sup>c,g</sup>
Multi-joint (n = 111, k = 5)	0.08 (-0.73, 0.90)	0.0%, 73.8%	⊕ ⊕ ⊕ ⊕
Follow-up: 4–12 weeks	[-1.69, 1.86]	[0.00, 0.55]	<b>Very low</b> <sup>c,g</sup>
Single-joint (n = 74, k = 4)	0.40 (-0.22, 1.03)	24.9%, 24.9%	⊕ ⊕ ⊕ ⊕
Follow-up: 7–12 weeks	[-0.68, 1.48]	[0.06, 0.06]	<b>Low</b> <sup>c,e</sup>
Sets-to-failure (n = 82, k = 5)	0.26 (-0.73, 1.25)	41.2%, 41.2%	⊕ ⊕ ⊕ ⊕
Follow-up: 7–12 weeks	[-1.96, 2.49]	[0.44, 0.44]	<b>Very low</b> <sup>a,d,g</sup>
Volume-load (n = 84, k = 4)	0.25 (0.04, 0.45)	0.0%, 0.0%	⊕ ⊕ ⊕ ⊕
Follow-up: 4–12 weeks	[0.04, 0.45]	[0.00, 0.00]	<b>Moderate</b> <sup>e</sup>
Between-participants (n = 143, k = 7)	0.31 (-0.31, 0.93)	0.0%, 71.2%	⊕ ⊕ ⊕ ⊕
Follow-up: 4–12 weeks	[-1.21, 1.83]	[0.00, 0.51]	<b>Very low</b> <sup>a,c,f</sup>
Within-participants (n = 23, k = 2)	0.11 (-0.52, 0.75)	0.0%, 0.0%	⊕ ⊕ ⊕ ⊕
Follow-up: 8 weeks	[-0.52, 0.75]	[0.00, 0.00]	<b>Very low</b> <sup>g</sup>
<b>Hypertrophy</b>			
Pooled (n = 95, k = 6)	0.05 (-0.22, 0.33)	31.3%, 0.0%	⊕ ⊕ ⊕ ⊕
Follow-up: 6–12 weeks	[-0.54, 0.65]	[0.06, 0.00]	<b>Low</b> <sup>c,e</sup>
Trained (n = 25, k = 2)	0.46 (-3.84, 4.77)	0.0%, 87.5%	⊕ ⊕ ⊕ ⊕
Follow-up: 8–12 weeks	[-6.49, 7.42]	[0.00, 0.75]	<b>Very low</b> <sup>a,c,g</sup>
Untrained (n = 70, k = 4)	0.02 [-0.36, 0.40]	34.1%, 0%	⊕ ⊕ ⊕ ⊕
Follow-up: 6–8 weeks	[-0.77, 0.81]	[0.07, 0.00]	<b>Very low</b> <sup>a,c,f</sup>
Arm (n = 32, k = 2)	0.29 (-0.82, 1.40)	0.0%, 66.4%	⊕ ⊕ ⊕ ⊕
Follow-up: 7–12 weeks	[-1.57, 2.16]	[0.00, 0.23]	<b>Very low</b> <sup>a,c,g</sup>
Thigh (n = 63, k = 4)	-0.01 (-0.56, 0.55)	37.7%, 0%	⊕ ⊕ ⊕ ⊕
Follow-up: 6–8 weeks	[-1.07, 1.06]	[0.09, 0.00]	<b>Very low</b> <sup>a,c,g</sup>
Between-participants (n = 72, k = 4)	0.15 (-0.59, 0.89)	35.5%, 20.2%	⊕ ⊕ ⊕ ⊕
Follow-up: 6–12 weeks	[-1.30, 1.60]	[0.16, 0.09]	<b>Very low</b> <sup>a,d,g</sup>
Within-participants (n = 23, k = 2)	0.00 (-0.82, 0.83)	5.0%, 0.0%	⊕ ⊕ ⊕ ⊕
Follow-up: 8 weeks	[-0.91, 0.92]	[0.00, 0.00]	<b>Very low</b> <sup>g</sup>
<b>CMJ</b>	-0.73 (-1.35, -0.12)	0.0%, 0.0%	⊕ ⊕ ⊕ ⊕
Pooled (n = 74, k = 3)	[-1.35, -0.12]	[0.00, 0.00]	<b>High</b> <sup>e,i</sup>
Follow-up: 4–6 weeks			

**Explanations.**

- <sup>a</sup>Serious risk of bias due to allocation concealment and lack of blinding.
- <sup>b</sup>Serious inconsistency (moderate heterogeneity  $I^2 > 50\%$  and point estimates vary considerably), that may be explained by training status.
- <sup>c</sup>Serious unexplained inconsistency (point estimates vary considerably).
- <sup>d</sup>Very serious unexplained inconsistency (large point estimates in each direction).
- <sup>e</sup>Serious imprecision (95% CI crosses one equivalence bound).
- <sup>f</sup>Very serious imprecision (95% CI crosses both equivalence bounds).
- <sup>g</sup>Extremely serious imprecision (95% CI crosses both equivalence bounds with large effects in both directions).
- <sup>h</sup>Plausible residual confounder of training status.
- <sup>i</sup>Presence of large effects.

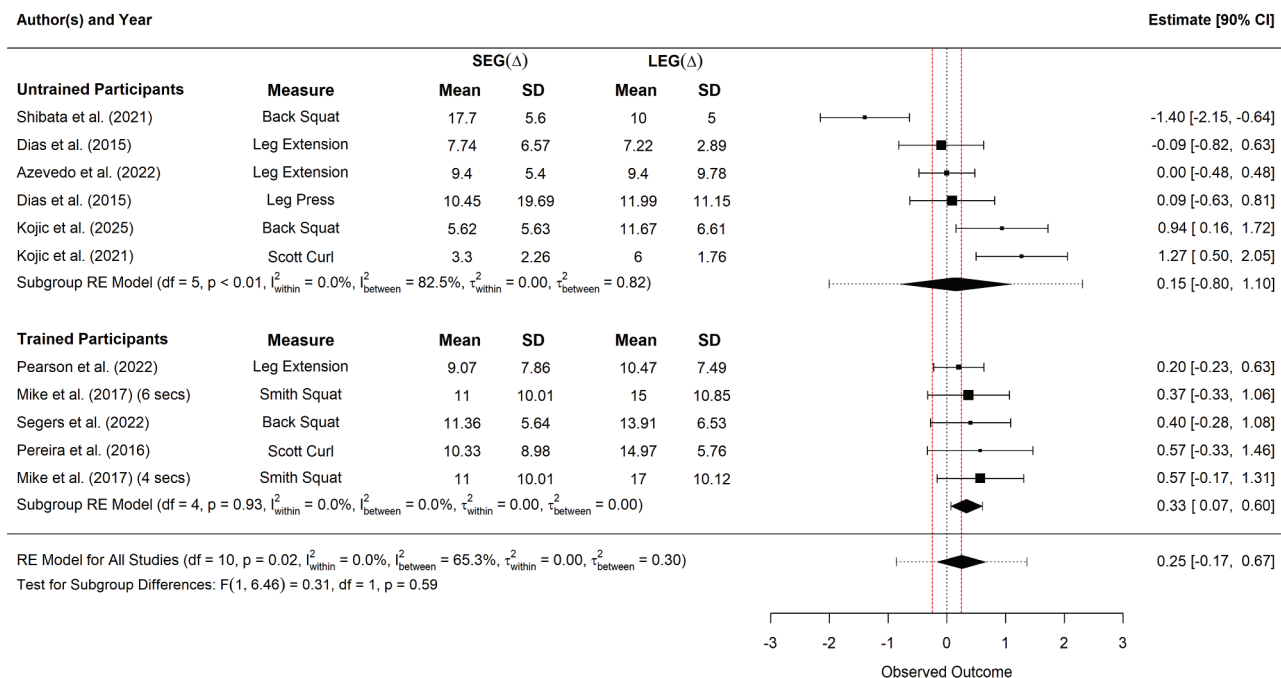
CI confidence interval, PI prediction interval, SD standard deviation, CMJ countermovement jump, k number of studies, n number of participants.

$\tau^2_{within} = 0.00$ ,  $\tau^2_{between} = 0.30$ ). Considering our ROPE ( $\pm 0.25$ ), the 90% CI overlapped with both the ROPE and values outside the ROPE, indicating that we cannot confidently conclude whether LEG produces practically meaningful differences in maximal strength gains compared to SEG. While the CI suggests that LEG is unlikely to harm maximal strength gains, the wide PI indicates substantial heterogeneity in potential outcomes across different contexts, suggesting that results may vary considerably in future studies.

Subgroup analyses revealed small effects with poor precision, ranging from practically not worthwhile to small or moderate effects favouring LEG (Table 2). This

was observed when i) participants were trained ( $g = 0.33$  [90% CI = 0.07, 0.60; 90% PI = 0.07, 0.60]), and ii) volume-load was matched ( $g = 0.25$  [90% CI = 0.05, 0.44; 90% PI = 0.05, 0.44]). Considering our ROPE ( $\pm 0.25$ ), the 90% CI, and 90% PI, LEG does not practically harm maximal strength gains in these subgroups, but whether it enhances maximal strength gains by a practically worthwhile degree cannot be inferred with certainty.

The remaining subgroup analyses and moderator analyses found practically not worthwhile to small average effects, with very poor precision, ranging from small to large in both directions (Tables 2 and 3), indicating



**Figure 3.** Forest plot for pooled maximal strength analysis, including subgroup and moderator analysis for training status. Estimates are Hedge's  $g$ . The red lines represent the lower and upper bounds of our region of practical equivalence ( $\pm 0.25$ ). *SEG* shorter eccentric group, *LEG* longer eccentric group, *CI* confidence interval, *SD* standard deviation.

**Table 3.** Results from moderator analyses.

	Hedge's $g$ [90% CI]	$p$ -value	95% CI
<b>Strength</b>			
Training status	-0.24 [-1.08, 0.59]	0.59	-1.29, 0.80
Exercise type	0.36 [-0.53, 1.25]	0.46	-0.75, 1.47
Volume matching	0.01 [-0.88, 0.90]	0.98	-1.10, 1.12
Study design	-0.21 [-1.25, 0.83]	0.60	-1.78, 1.37
<b>Hypertrophy</b>			
Training status	-0.16 [-1.89, 1.56]	0.81	-2.71, 2.39
Muscle group	-0.19 [-1.05, 0.67]	0.65	-1.34, 0.96
Study design	-0.09 [-0.82, 0.64]	0.80	-1.07, 0.89

*CI* confidence interval.

highly uncertain results warranting further research. These results were robust to sensitivity analyses (Supplementary file 6).

### Muscle hypertrophy

The pooled analysis for hypertrophy revealed that the average effect most compatible with our data, given our statistical model, was a practically not worthwhile effect favouring LEG with poor precision (Figure 4, Table 2). The effect size ranged from a practically not worthwhile effect favouring SEG to a small effect favouring LEG ( $g = 0.05$  [90% CI = -0.22, 0.33]; 90% PI = -0.54, 0.64;  $I^2_{within} = 31.4\%$ ,  $I^2_{between} = 0\%$ ,  $\tau^2_{within} = 0.06$ ,  $\tau^2_{between} = 0.00$ ). Considering our ROPE ( $\pm 0.28$ ), the 90% CI overlapped with both the ROPE and values outside the ROPE, indicating that we cannot confidently conclude whether LEG produces practically meaningful differences in muscle hypertrophy compared to SEG. While the CI suggests

that LEG is unlikely to harm maximal strength gains, the wide PI indicates substantial heterogeneity in potential outcomes across different contexts, suggesting that results may vary considerably in future studies.

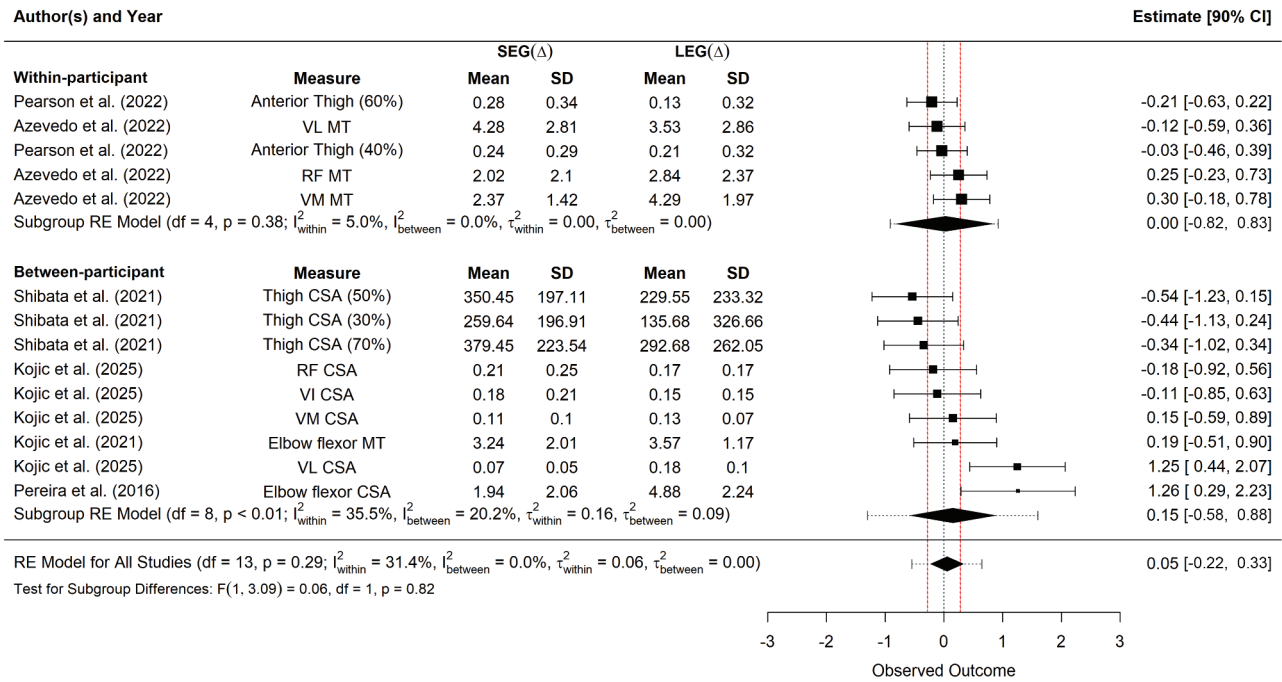
Subgroup analyses and moderator analyses found practically not worthwhile to moderate average effects with very poor precision and large effects in both directions (Tables 2 and 3), indicating highly uncertain results warranting further research. These results were robust to sensitivity analyses (Supplementary file 6).

### Countermovement jump height

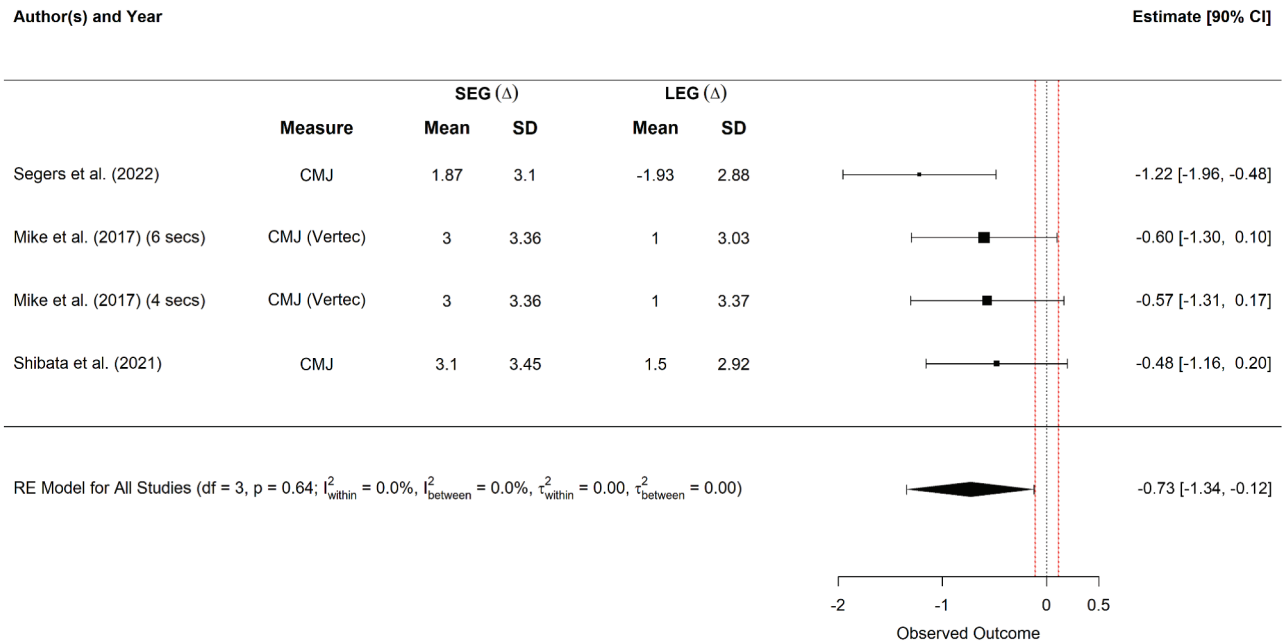
The pooled analysis for CMJ revealed that the average effect most compatible with our data, given our statistical model, was a large effect, ranging from large to small effects favouring SEG ( $g = -0.73$  [90% CI = -1.34, -0.12, 90% PI = -1.34, -0.12]  $I^2_{within} = 0\%$ ,  $I^2_{between} = 0\%$ ,  $\tau^2_{within} = 0.00$ ,  $\tau^2_{between} = 0.00$ ) (Figure 5, Table 2). Considering our ROPE ( $\pm 0.11$ ), the 90% CI and 90% PI, there is evidence to support that SEG enhances CMJ improvement by a practically worthwhile degree, compared to LEG. These results were robust to sensitivity analyses (Supplementary file 6).

### Discussion

The aim of this systematic review was to quantitatively explore the effects of manipulating eccentric tempo



**Figure 4.** Forest plot for pooled muscle hypertrophy analysis, including subgroup and moderator analysis for study design. Estimates are Hedge’s g. The red lines represent the lower and upper bounds of our region of practical equivalence ( $\pm 0.28$ ). *SEG* shorter eccentric group, *LEG* longer eccentric group, *CI* confidence interval, *SD* standard deviation, *CSA* cross-sectional area, *MT* muscle thickness, *VL* vastus lateralis, *RF* rectus femoris, *VM* vastus medialis.



**Figure 5.** Forest plot for pooled countermovement jump height analysis. Estimates are Hedge’s g. The red lines represent the lower and upper bounds of our region of practical equivalence ( $\pm 0.11$ ). *SEG* shorter eccentric group, *LEG* longer eccentric group, *CI* confidence interval, *SD* standard deviation, *CMJ* countermovement jump height.

duration on indices of muscular performance and hypertrophy. Three outcomes were sufficiently reported to enable meta-analysis: 1RM strength, muscle hypertrophy and CMJ. The main results from the meta-analysis

indicated that RT performed with shorter eccentric durations, with moderate certainty of evidence, result in larger and practically worthwhile increases in countermovement jump height than when performed with

longer eccentric actions. For strength and hypertrophy, results were generally too uncertain to statistically support or reject the presence or absence of a practically worthwhile impact of eccentric duration, highlighting the need for further research. Notably, when participants are trained or when volume-load is matched, RT performed with longer eccentric duration may, with moderate certainty of evidence, lead to practically similar or higher strength gains compared to shorter eccentric durations. Thus, more research exploring the effects of training status and programming style on adaptations to eccentric duration manipulation is needed.

Shorter eccentric durations (1–2 vs. 4–6 s) lead to larger improvements in CMJ across 4–6 weeks of squat training (Mike et al., 2017; Segers et al., 2022; Shibata et al., 2021). This suggests that prolonging the eccentric phase's duration may not maximise stretch-shortening cycle (SSC) performance, at least in the short term. This effect may be due to reduced residual force enhancement (van Hooren & Zolotarjova, 2017) and lower eccentric forces (resulting from decreased loads and accelerations) during longer eccentric durations. These factors may attenuate SSC-specific training adaptations associated with shorter eccentric duration, such as an increased rate of force development (RFD) (Stasinaki et al., 2019), greater tendon stiffness and CSA (Douglas et al., 2017a; Lazarczuk et al., 2022; Martínez et al., 2022), higher firing rates and lower recruitment thresholds for larger motor units (Douglas et al., 2017a), alongside favourable adaptations in muscle architecture (e.g., greater fascicle length) (Stasinaki et al., 2019) and contractile properties (e.g., contraction time) (Douglas et al., 2017a; Kojic et al., 2025). However, direct evidence on the muscle, tendon and neural adaptations to combined eccentric-concentric RT with varying eccentric durations remains limited.

While, although not significantly different, Shibata et al. (2021) did report larger CMJ effects after shorter eccentric durations (LEG = 1.5 cm [4.2%], SEG = 3.1 cm [8.4%]), they also found larger effects for squat jump height (i.e., concentric-only) after longer eccentric durations (LEG = 2.4 cm [7.2%], SEG = 1.9 cm [5.3%]). Given that SEG experienced greater strength gains than LEG in this study, the reason for this discrepancy remains unclear. One possible explanation is that prolonging the eccentric phase duration reduces residual force enhancement and lowers the velocity of the subsequent early concentric phase (van den Tillaar, 2019). As a result, athletes may rely less on the countermovement to develop an active muscle state (Bobbert & Casius, 2005; Bobbert et al., 1996; van Hooren & Zolotarjova, 2017) and more on developing rapid concentric rate of force development (RFD) (Bobbert & Casius, 2005; Kozinc et al., 2024; van Hooren & Zolotarjova, 2017), which could

lead to better squat jump performance over time. More simply, it could also be due to the increased exertion per repetition from prolonging the eccentric duration, resulting in a decreased number of performed repetitions (i.e., concentric actions) (Kojic et al., 2025; Kojić et al., 2021; Shibata et al., 2021), ultimately leading to a lower volume of specific practice. However, it is important to note that Shibata et al. (2021) conducted the only study to investigate squat training and jump height in untrained participants, making it unclear whether these findings would be replicable or generalisable to trained athletes. As such, further research is warranted to explore the effects of different eccentric durations on various strength and conditioning outcomes.

For maximal strength, longer eccentric durations led to practically similar or larger improvements in strength than shorter eccentric durations in trained participants and when volume-load was matched (Table 2). It should be recognised that decisions regarding the ROPE are context-dependent (Lakens et al., 2018), and we chose these values as they were likely representative of typical study participants. However, it could be argued that given the low real-world cost of tempo manipulation, any measurable effect may be relevant, particularly in highly trained athletes (Hopkins et al., 1999). For example, by converting our trained subgroup 90% CI into percentages ( $\Delta M_{\%} = \Delta SD_{\%} \times ES$ ), using the only study that employed free-weight back squats in trained participants (Segers et al., 2022), prolonging the eccentric phase duration enhances strength gains by an additional ~0.3–2.7% over 4–12-weeks compared to shorter eccentric duration. These values range from 0.6–1.1% to 5.0–9.2% in the remaining studies involving trained participants (Mike et al., 2017; Pearson et al., 2022; Pereira et al., 2016); however, their exercise selections may be less practically relevant for highly trained athletes. Through this lens, longer eccentric durations could be viewed as beneficial, or at least not harmful. However, it is important to note that these effects are small and based on a limited number of studies, so they should be interpreted with caution, warranting further research.

Some explanations for why longer eccentric durations may enhance strength gains in trained participants may be that they i) lead to enhanced neural adaptations (Siddique et al., 2020), ii) produce similar or larger training stimuli (Table 2), and/or iii) incur less fatigue (Gepfert et al., 2021; Mike et al., 2017). First, Siddique et al. (2020) found that metronome-paced RT with a higher time under tension (T4–0–3–0) reduced short-interval intracortical inhibition and increased corticospinal excitability compared to self-paced RT (mean repetition duration: 3 s). This effect could be due to the greater cognitive

effort required to maintain the prescribed tempo. However, it is important to note that this study did not directly compare eccentric duration manipulation and further research is needed to determine whether different neural adaptations arise from combined eccentric-concentric RT with varying eccentric durations. Given we only found equal or higher strength gains for trained participants, it may be that self-paced or shorter eccentric durations provide sufficient motor learning for less trained populations; however, as skill increases, additional movement challenge may be needed to progress motor skill (Czyż & Coker, 2023). This should not be interpreted as evidence that eccentric tempo manipulation is unsuitable for untrained participants, but rather that its efficacy in this population remains uncertain. It is possible that short eccentric durations add a degree of movement difficulty and future research is needed to explore the effects of eccentric duration on changes in kinematics (i.e., technical execution) over time, and how it interacts with exercise execution/selection and training status.

Second, by prolonging the eccentric phase, total and eccentric time under tension increase (Azevedo et al., 2022; Kojić et al., 2021; Shibata et al., 2021), which typically leads to lower absolute loads or less overall repetitions completed when either repetitions or loads are kept constant, respectively, at the same proximity-to-failure (Shibata et al., 2021; Wilk et al., 2019; Wilk, Golas, et al., 2020). Conversely, when repetitions per set at a submaximal load are fixed, longer eccentric duration lead to closer proximities to failure (Pearson et al., 2022), suggesting that prolonging the eccentric phase's duration makes each repetition more strenuous (Pearson et al., 2022). This increased exertion may explain why longer eccentric durations may lead to similar or greater strength gains when volume-load is matched (Table 2, subgroup analyses), while results were unclear when proximity-to-failure was matched, despite a lower number of repetitions performed (Table 2, subgroup analyses). Notably, previous studies examining eccentric durations beyond 4 s suggest diminishing returns (e.g., ES: 4 s = 1.68 vs. 6 s = 1.38 (Mike et al., 2017); 4 s = 1.69 vs. 10 s = 1.27 (Fisher et al., 2016)), maybe due to excessive cardiovascular strain. Therefore, longer eccentric durations (around 4 s) may allow for similar training stimuli with lower volume loads or enhance the stimulus with the same volume load – provided the eccentric phase is not extended to the point where it excessively impairs concentric performance (i.e., >5 s) (Wilk, Gepfert, et al., 2020; Wilk, Golas, et al., 2020). However, given the overlap of studies matching volume-load and using trained participants, distinguishing the effects of training status and programming is not possible based on the current

evidence. Further research is needed to explore the effects of eccentric duration in populations with various training backgrounds using different programming strategies, such as matching volume-load, proximity to failure or time under tension between groups – the latter of which, to our knowledge, has yet to be examined.

Third, slower eccentric velocities have been associated with less muscle damage during eccentric-only isokinetic dynamometry (Nogueira et al., 2013). Although it remains unclear whether these findings can be generalised to longer eccentric durations in traditional RT, extending the eccentric phase during traditional RT has been associated with smaller acute performance decrements (i.e., less reduction in CMJ peak power and velocity) when performing repetitions to failure with the same load (Gepfert et al., 2021), and similar or lower delayed onset muscle soreness across a 4–5-week training protocol despite matched volume loads (Mike et al., 2017; Segers et al., 2022). Considering the acute performance decrements, longer duration eccentric phase training may therefore allow trainees to reach similar or higher training stimuli with lower or similar volume-loads possibly at a lower fatigue cost, although this hypothesis requires further study. Successfully implementing eccentric tempo manipulation for maximal strength may rely on striking a balance between eccentric phase duration, volume and load to minimise unnecessary performance decrements by limiting excessive muscular and/or cardiovascular fatigue. However, more research is needed. The optimal eccentric duration may also be exercise-specific, as variations in range of motion – for example, in the back squat versus the bench press – result in different eccentric velocities. This highlights the need for further research into the effects of eccentric duration versus eccentric velocity on adaptations across different exercises.

For muscle hypertrophy, results were too uncertain to infer the absence or presence of practically worthwhile effects. While point estimates of our subgroup analyses generally followed the trends from our strength results, implying that a possible reason for improved strength could be greater rates of muscle gain in trained participants, these results were very uncertain, and more research is needed. Supporting this, Kojić et al. (2022) found that muscle thickness changes explained 51% of the variance in 1RM strength gains for a longer eccentric duration (4 secs), compared to only 13% for a shorter eccentric duration (1 secs), indicating that adaptations causing strength gains may differ depending on eccentric duration. Additionally, squats with longer eccentric duration resulted in slower muscle contraction times

in the rectus femoris and vastus lateralis (Kojic et al., 2025), potentially reflecting a shift towards type I fibre growth (Dahmane et al., 2005; Simunič et al., 2011), aligning with the idea that higher eccentric forces preferentially activate and damage type II fibres (Douglas et al., 2017b; Prilutsky, 2000). However, this pattern was not observed in the elbow flexors (Kojić et al., 2021), despite both the quadriceps femoris and biceps brachii being mixed-fibre muscles (Elder et al., 1982; Johnson et al., 1973; Polgar et al., 1973; Tirrell et al., 2012), leaving the reason for this discrepancy unclear. No studies explored muscle architecture, and two (Pearson et al., 2022; Shibata et al., 2021) that explored regional hypertrophy found diverging results. Therefore, further research is needed to explore how eccentric duration influences muscle morphology and topology, as well as other strength-related adaptations. Ultimately, while including an eccentric phase is essential for maximising muscle hypertrophy (Sato et al., 2022, Nakamura et al., 2025), whether the eccentric duration has a practically meaningful impact remains unclear.

It is important to note that the included number of studies and participants per study was low. This was accounted for in our effect size calculations and robust variance estimations, leading to wide confidence intervals, which, combined with our interpretative lens, lead to more cautious conclusions based on the uncertainty of results. Second, some subgroup analyses were not pre-planned and should therefore be considered exploratory. Third, the shortest eccentric duration in the current systematic review was 1 s, meaning our findings may not generalise to ballistic training with shorter eccentric durations. Fourth, all but one study restricted concentric tempo, with Segers et al. (2022) allowing the concentric phase to be performed as quickly as possible, rather than following a prescribed duration. This may have enabled the shorter eccentric group to better utilise their SSC (Pryor et al., 2011; Wilk et al., 2019; Wilk, Gempfert, et al., 2020; Wilk, Golas, et al., 2020) compared to studies that imposed a set concentric tempo, possibly leading to more detrimental effects of a longer eccentric duration. This may be the case for CMJ height (Figure 5). However, studies with restricted concentric tempos still showed significant performance decrements due to longer eccentric durations (Azevedo et al., 2022; Kojic et al., 2025; Kojić et al., 2021; Shibata et al., 2021), and Segers et al. (2022) observed strength effects similar to those in studies using restricted tempos (Mike et al., 2017). Thus, while SSC performance (e.g., CMJ height) may benefit from increased residual force enhancement during RT, maximal strength training may

not benefit in the same way (Kojic et al., 2025; Martínez-Cava et al., 2021; Segers et al., 2022). This hypothesis warrants further investigation. Fifth, no included study reported changes in body mass, relative strength or phase-specific metrics related to CMJ performance (e.g., time to take-off), which could provide important context for practitioners, particularly in weight-category sports. Given the point estimates observed, we urge researchers to conduct studies exploring the impact of training status, how volume was matched between groups, impact of relative-load and exercise selection on the effect of eccentric tempo manipulation. While outside the scope of this research, given the different adaptations from short(er) and long(er) eccentric durations, exploring the effects of combining multiple different tempos in the same protocol might be interesting.

## Conclusion

In conclusion, with moderate certainty, shorter ( $\leq 2$  s) eccentric durations are better for improving CMJ height, while relatively longer eccentric durations (3–6 s) produce similar or larger strength gains in trained participants and under volume-load matched conditions. Due to very low certainty of evidence, the absence or presence of whether a practically worthwhile effect of eccentric duration manipulation for muscle hypertrophy cannot be confidently inferred. More research is needed to explore the impact of eccentric duration on SSC vs. non-SSC ballistic performance outcomes, maximal strength and muscle morphology. Future research should aim to improve the certainty of inferences and examine the interactions with volume matching, matching of absolute load, training status, relative load, concurrent approaches and responses across different muscle groups and exercises. Additionally, further research is needed to investigate the acute effects of eccentric duration on neuromuscular fatigue and muscle damage, to better understand the potential of eccentric tempo manipulation as a fatigue-management strategy.

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## ORCID

Christian Houmann Amdi  <http://orcid.org/0000-0001-7257-2225>

Andrew King  <http://orcid.org/0000-0002-9332-6506>

## Author contributions

Both authors contributed to study conception, design, and literature search. Data extraction was performed by CA. Data analysis and visualisation was performed by AK. The first draft was written by CA and both authors provided revisions. Both authors read and approved the final manuscript.

## Ethical approval statement.

Not applicable, as this is a systematic review based on previously published data.

## Data availability statement

This project was preregistered, which along with all supplementary materials, including statistical code and dataset, can be found at Open Science Framework (<https://osf.io/s6uqn/>). This article was pre-printed on SportRxiv (<https://doi.org/10.51224/SRXIV.439>).

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