Received: 4 May 2021 | Accepted: 20 May 2021

DOI: 10.1111/sms.14006

REVIEW

WILEY

Effects of range of motion on resistance training adaptations: A systematic review and meta-analysis

Jesús G. Pallarés[1] | **Alejandro Hernández-Belmonte[1]** | **Alejandro Martínez-Cava[1]** | **Tomas Vetrovsky[2]** | **Michal Steffl[2]** | **Javier Courel-Ibáñez[1]**

[1]Human Performance and Sports Science Laboratory, Faculty of Sport Sciences, University of Murcia, Murcia, Spain

[2]Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic

Correspondence
Jesús García Pallarés, Faculty of Sport Sciences, University of Murcia, C/ Argentina s/n. Santiago de la Ribera, Murcia, Spain.
Email: jgpallares@um.es

Background: Nowadays, there is a lack of consensus and high controversy about the most effective range of motion (ROM) to minimize the risk of injury and maximize the resistance training adaptations.

Objective: To conduct a systematic review and meta-analysis of the scientific evidence examining the effects of full and partial ROM resistance training interventions on neuromuscular, functional, and structural adaptations.

Methods: The original protocol (CRD42020160976) was prospectively registered in the PROSPERO database. Medline, Scopus, and Web of Science databases were searched to identify relevant articles from the earliest record up to and including March 2021. The RoB 2 and GRADE tools were used to judge the level of bias and quality of evidence. Meta-analyses were performed using robust variance estimation with small-sample corrections.

Results: Sixteen studies were finally included in the systematic review and meta-analyses. Full ROM training produced significantly greater adaptations than partial ROM on muscle strength (ES = 0.56, $p = 0.004$) and lower-limb hypertrophy (ES = 0.88, $p = 0.027$). Furthermore, although not statistically significant, changes in functional performance were maximized by the full ROM training (ES = 0.44, $p = 0.186$). Finally, no significant superiority of either ROM was found to produce changes in muscle thickness, pennation angle, and fascicle length (ES = 0.28, $p = 0.226$).

Conclusion: Full ROM resistance training is more effective than partial ROM to maximize muscle strength and lower-limb muscle hypertrophy. Likewise, functional performance appears to be favored by the use of full ROM exercises. On the contrary, there are no large differences between the full and partial ROM interventions to generate changes in muscle architecture.

KEYWORDS
health, injury, performance, range of movement, sport, strength training

1 | INTRODUCTION

There is solid evidence regarding the many benefits of resistance training for different ages, from children[1,2] to older adults.[3,4] Resistance training has been proven as an effective strategy to reduce the negative impact of some diseases, such as sarcopenia,[5] osteoporosis,[6] diabetes,[7] or cáncer,[8] as well as to increase daily physical activity levels and sports performance.[9,10] Nevertheless, neuromuscular, functional, and structural adaptations in response to a given strength training program mainly depend on the manipulation of the type of exercises,[11] relative intensity,[12] training frequency[13,14] and volume,[15,16] rest intervals,[17] and movement velocity.[18,19]

In addition, training effects can be modulated by the range of motion (ROM), defined as the degree of movement that occurs at a specific joint during the execution of an exercise.[20] In daily practice, the ROM can be modified by altering the body posture[21] or grip width,[22,23] using external materials like security bars or wood boards[24,25] or by voluntarily reducing the degree of movement at the beginning or end of the execution.[26,27] Thus, resistance training with no restrictions in the degree of movement is commonly defined as "full ROM," while training using any displacement reduction is considered as "partial ROM."[28] On this matter, the specific ROM influences different biomechanical aspects that affect, among others, the development of force, motor units activation, and dynamic joint stability.[25,29] More specifically, the ROM used in each repetition determines the zone of the force-length relationship on which the stimulus is applied.[30] Thus, providing this stimulus at a longer or shorter muscle length, as well as avoiding specific zones within this force-length relationship (eg, zone of maximal active or passive force),[31] could modulate the neuromuscular and functional adaptations.[32] Similarly, applying the training stimulus on muscle lengths that exceed those required by the daily activities could generate a restructuring of the muscular architecture (eg, an increment in fascicle length),[33] thus altering the force-length and force-velocity relationships.[34] These aspects together would suggest that two resistance training programs conducted at full or partial ROMs could generate distinct long-term neuromuscular, functional, and structural adaptations, even when all other training variables (eg, relative intensity, volume, recovery) are matched.

To date, only one study has gathered the literature to compare the training adaptations produced by the resistance training at different ROMs.[35] This study concludes that full ROM executions would provide superior hypertrophy than partial ROM ones, especially on the lower-limb musculature.[35] Nevertheless, evidence about the neuromuscular and functional adaptations produced by the different ROMs is still lacking.

Therefore, the current study aimed to systematically review the scientific evidence examining the effects of full and partial ROM resistance training interventions on neuromuscular, functional, and structural adaptations. Furthermore, to address this issue comprehensively, a meta-analysis was conducted to synthesize the outcomes of comparative studies. These findings may provide insight into whether there is merit for increasing or limiting the ROM of resistance exercises to produce specific adaptations and maximize performance.

2 | METHODS

2.1 | Registration of systematic review protocol

This systematic review and meta-analysis was conducted according to the Cochrane Handbook for Systematic Reviews of Interventions[36] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[37] The review protocol was preregistered in PROSPERO (CRD42020160976).

2.2 | Eligibility criteria

The PICOS (population, intervention, comparators, outcomes, study design) criteria for the eligibility of studies[38] were used to determine the inclusion and exclusion criteria.

2.2.1 | Participants

Healthy adults (aged 18 or older) with no restrictions of sex, health, and socio-economic status, ethnicity, or geographical area. Studies including people suffering from musculoskeletal disorders, injuries, or diseases were excluded.

2.2.2 | Intervention

Investigations implementing training programs based on dynamic resistance exercises performed by means of a measurable external load were included. Isometric training was excluded as this type of contraction is characterized by the application of force at a single point of the ROM and not along its length. Moreover, because of previous experimental studies reporting significant changes in muscle size and structure after only 10 days of strength training,[39] no duration restriction was set.

2.2.3 | Comparators

The ROM used during the resistance training intervention was considered as the main independent variable. Eligible investigations should compare experimental groups that trained the same exercise using a different ROM. For example, <110° of knee flexion (full squat group), ~90° of knee flexion (half squat group), and ~60° of knee flexion (quarter squat group). The current systematic review compared the effects of resistance training at full ROM against the group training at the shortest ROM. Considering the abovementioned example, we compared the full squat group against the quarter squat. Studies in which one intervention group trained with more than one ROM (ie, full ROM combined with partial ROM) were excluded. Investigations without a control group (ie, a group that fully refrained from any type of training) were also included.

2.2.4 | Outcomes

This review evaluated three main outcomes: i) changes in strength measured by dynamic, isometric, or isokinetic tests, ii) changes in functional performance measured by jump height, acceleration, agility, or specific tests, and iii) changes in muscle size (cross-sectional area [CSA] or volume) and architecture (muscle thickness, pennation angle or fascicle length). Regarding the changes in muscle size, we only considered measurements collected by using magnetic resonance imaging or ultrasound scans to ensure the reliability of the outcomes.[40-43]

2.2.5 | Study design

This systematic review included reports on the efficacy of training at full or partial ROMs from randomized controlled trials (RCTs).

2.3 | Identification and selection of studies

Medline, Scopus, and Web of Science (core collection) databases were searched using a combination of keywords to identify relevant articles from the earliest record up to and including March 2021. The following search strategy was adapted for each database and applied to the title, abstract, and keyword search:

> ("range of movement" OR "range of motion") AND ("resistance training" OR "strength training" OR "weight training" OR "weightlifting") AND (“neuromuscular" OR “functional" OR "strength” OR “performance” OR "hypertrophy" OR "musc* mass" OR "musc* thickness" OR "musc* volume" OR "CSA" OR "cross-sectional area" OR "musc* architecture" OR "musc* geometry”)

English language articles were included at the screening level. To ensure a relatively complete census of relevant literature, we performed a backward-forward search, reviewing the references and citations of studies included.[44] Moreover, a second-level backward reference search was done by pulling the references of the references.[45] Records retrieved from the database search were imported to Mendeley (v1.19.6, Elsevier, UK) and processed in Microsoft Excel 2016 (Microsoft Corporation, USA) by AHB. After the removal of duplicates, two investigators (AHB and AMC) independently screened the titles and abstracts. References not eliminated were subjected to a second-stage screening of the full text. To ensure a quality appraisal of the review process, we assessed the agreement between the two researchers using an inter-rater reliability test.[46] Discrepancies at any stage were resolved by discussion with a third investigator (JGP).

2.4 | Data extraction

Two reviewers (TV and JCI) independently collected the data of all included studies using standardized forms in Microsoft Excel, including author/s, year, sample characteristics (age, sex, training experience), intervention groups (full and partial ROMs trained), configuration of the resistance training program (exercise/s, duration, frequency, relative intensity, contraction type, movement velocity, and rest intervals), dependent variables of interest (neuromuscular, functional, and structural outcomes), and assessment tests. For quantitative analyses (meta-analyses), we collected the group size and mean differences of the aforementioned outcomes with a 95% confidence interval (CI) or standard deviations (SD) for both intervention groups. Disagreements were adjudicated by JGP.

2.5 | Dealing with missing data

Corresponding authors were contacted to provide missing data of relevant variables. Otherwise, data were obtained from figures when possible using WebPlotDigitizer.[47] Studies with missing mean values were excluded from the meta-analysis but discussed in the review. Missing SD were calculated or estimated from relevant statistics provided (eg, from CI, standard errors, p values) or imputed from an appropriate pretest.[48]

2.6 | Risk-of-bias and quality of evidence assessments

Two reviewers (JCI and AHB) used the Cochrane Collaboration Risk-of-Bias Tool (RoB 2)[49] and the GRADE

(Grading of Recommendations, Assessment, Development, and Evaluations)[50] to judge the level of bias and quality of evidence. The GRADE quality rating was downgraded one level for each of the following limitations: the 95% CI includes both appreciable benefit and harm (imprecision); high variability and heterogeneity across studies (inconsistency); and the presence of high risk of bias. Disagreements were resolved by discussion with JGP.

2.7 | Statistical analysis

The effect sizes (ESs) were calculated as the standardized mean differences between the full and partial ROM groups. The sample size and mean ES across all studies were used to calculate the variance around each ES. Meta-analyses were performed using robust variance estimation (RVE) with small-sample corrections.[51,52] RVE is a form of random-effects meta-regression for multilevel data structures, which allows for multiple effect sizes from the same study to be included in a meta-analysis, even when information on the covariance of these effect sizes is unavailable. Instead, RVE estimates the variance of meta-regression coefficient estimates using the observed residuals. It does not require distributional assumptions and does not make any requirements on the weights.[51,52] A study was used as the clustering variable to account for correlated effects within studies. Observations were weighted by the inverse of the sampling variance. A sensitivity analysis, using alternative correlational values to calculate the standard error, revealed that the choice of correlational value did not impact the overall results of the meta-analysis. Between-study heterogeneity was evaluated using the I^2 index. Values of I^2 more than 25%, 50%, and 75% were selected to reflect low, moderate, and high heterogeneity, respectively.[36] All analyses were performed using packages robumeta (version 2.0) and metafor (version 2.4-0) in R version 3.5.2 (The R Foundation for Statistical Computing, Vienna, Austria).

3 | RESULTS

The initial search yielded 1810 studies from the electronic database search and four from other sources (reference lists) (Figure 1). After removing duplicates, 1365 titles and abstracts were screened, resulting in 29 potentially eligible full texts. After the full-text screening, 16 studies were considered for qualitative analysis and meta-analyses.[53-68] Two authors provided missing data not published in the original studies.[54,60]

3.1 | Study characteristics

Details from the 16 RCTs (n = 551 participants) included in the final analysis are presented in Table 1. Resistance training interventions were conducted on male-only samples in ten studies,[54,56-59,61-63,66,67] female-only in two studies,[55,65]

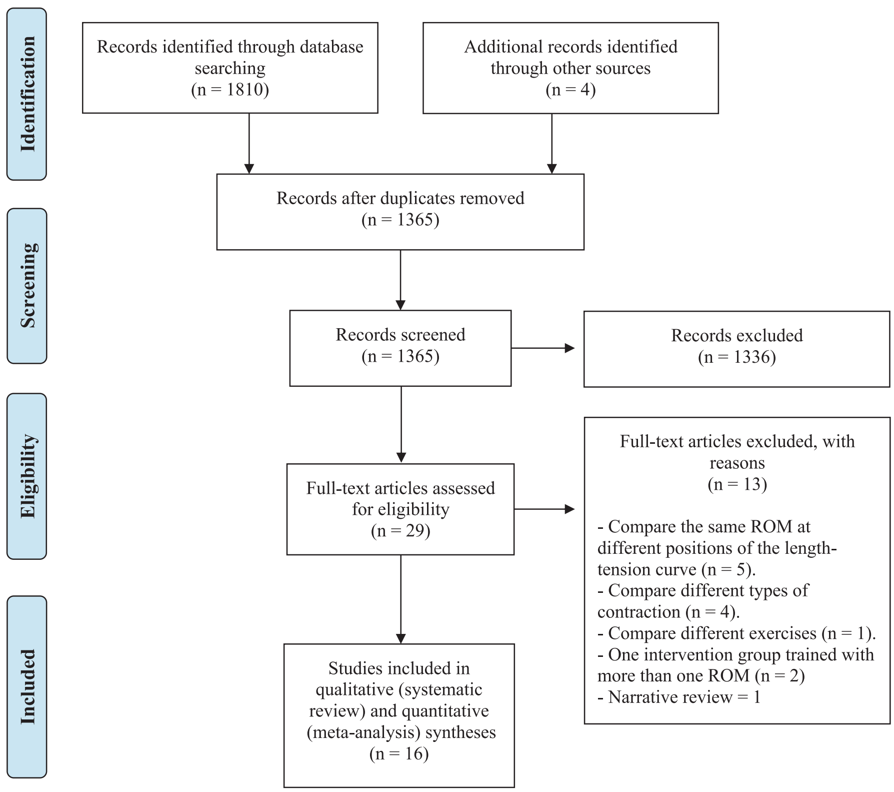

FIGURE 1 Flowchart illustrating the different phases of the search and study selection, according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statements

TABLE 1 Summary of included studies

Study	Exercise, groups and sample	Resistance training intervention	Outcomes: Muscle strength	Outcomes: Functional performance	Outcomes: Muscle hypertrophy	Outcomes: Muscle architecture
Bloomquist et al.,[56]	Back squat (free weight) Deep SQ: 60° k.flex ($n = 8$) Shallow SQ: 120° k.flex ($n = 9$) 24 ± 5 y 100% males, students	12 wk, 3 d/wk 2 blocks of 6 wk Load from 3 × 10 RM to 5 × 3 RM 2–4 s eccentric and max concentric	1RM (loading test): 1RM Deep SQ 1RM Shallow SQ Isometric (dynamometer): MVC Torque 40°* MVC Torque 75°* MVC Torque 105°	Jump (Force plate): CMJ height* SJ height*	MRI: CSA front thigh CSA back thigh CSA patellar tendon*	Ultrasound: Pennation angle vastus lateralis Muscle thickness vastus lateralis
Cale-Benzoor et al.,[55]	Unilateral push-pull (dynamometer) Full ROM ($n = 15$) Limited ROM 1/3 full ROM ($n = 15$) 18–50 y 100% females, healthy adults	6 wk, 2 d/wk 5 sets, 10 reps Nondominant side, both pull and push motion. Limited ROM: 12.22 cm/s, Full ROM: 36.67 cm/s. Load adjusted each set by barbell velocity monitoring	Isokinetic (dynamometer): Peak force push Peak force pull	—	—	—
Goto et al.,[58]	Lying elbow extension (free weight) Full EX: 0º - 120º EX ($n = 22$) Partial EX: 45º - 90º EX ($n = 22$) 20.6 ± 0.9 y (FRE) / 21.6 ± 1.3 y (PRE) 100% males, resistance-trained	8 wk, 3 d/wk 3 sets of 8RM Load increased 2.5 kg to complete the target 8RM	Isometric (dynamometer): Torque 90º elbow Isokinetic (dynamometer): Torque at 120º/s Torque at 200º/s		Ultrasound × circumference: CSA triceps brachii	
Hartmann et al.,[67]	Front/back squat (Smith machine) Deep front SQ: <60° k.ext ($n = 20$) Deep back SQ: <60 k.ext ($n = 20$) Quarter back SQ: 120° k.ext ($n = 19$) Control ($n = 16$) 24 ± 3 y 100% males, students	10 wk, 2 d/wk 3 blocks 5 sets from 8–10 RM to 2–4 RM Load adapted 2.5 to 10 kg between sets/ sessions. Each set included 2 last forced repetitions	1RM loading test): 1RM Deep front SQ 1RM Deep back SQ 1RM Quarter back SQ Isometric (Forceplate): MVC Unilateral leg press MRFD Unilateral leg press	Jump (Force plate): CMJ height SJ height	—	—
Kubo et al.,[66]	Back squat (free weight) Full SQ: 140° k.flex ($n = 8$) Half SQ: 90° k.flex ($n = 9$) 21 ± 1 y 100% males, physically active	10 wk, 2 d/wk 3 sets, 8 reps Load from 60% to 90% 1RM	1RM (loading test): 1RM Full SQ 1RM Half SQ	—	MRI: Vol. rectus femoris Vol. vastus lateralis Vol. vastus intermedius Vol. vastus medialis Vol. biceps femoris Vol. semitendinosus Volume gluteus maximus* Volume adductor*	—

(Continues)

TABLE 1 (Continued)

Study	Exercise, groups and sample	Resistance training intervention	Outcomes: Muscle strength	Outcomes: Functional performance	Outcomes: Muscle hypertrophy	Outcomes: Muscle architecture
Martínez-Cava et al.,[59]	Bench press (Smith machine) Full BP: chest contact ($n = 11$) 2/3 BP: 2/3 full ROM ($n = 13$) 1/3 BP: 1/3 full ROM ($n = 13$) Control ($n = 12$) 24 ± 5 y 100% males, resistance-trained men	10 wk, 2 d/wk 4–5 sets, 8–4 reps Load from 60% to 80% 1RM Load adjusted each set by barbell velocity monitoring	1RM (loading test): 1RM Full BP 1RM 2/3 BP 1RM 1/3 BP Barbell velocity (Encoder) MPV Full BP MPV 2/3 BP MPV 1/3 BP	—	—	—
Massey et al.,[57]	Bench press Full BP: chest contact ($n = 11$) 1/3 BP:1/3 of the Full BP ($n = 15$) Control: combinate these two ($n = 30$) 100% males, students, recreational weightlifters	10 wk, 2 d/wk 3 sets, 15 reps Load started 65% 1RM (Full BP) and 100% 1RM (2/3 BP) Allowed to increase 5 pounds per session. Routine included a variety of lower-limb strength exercises in addition to the bench press	1RM (loading test): 1RM Full BP	—	—	—
Massey et al.,[65]	Bench press Full BP: chest contact ($n = 11$) 1/3 BP: 1/3 of the Full BP ($n = 8$) Control: combinate these two ($n = 8$) 100% females, students, recreational weightlifters		1RM (loading test): 1RM Full BP	—	—	—
McMahon et al.,[64]	Knee flexion (dynamometer) Long ROM: 90° k.flex ($n = 8$) Short ROM: 50° k.flex ($n = 8$) Control ($n = 10$) 18 to 36 y 54% males, students	8 wk, 3 d/wk (2 supervised, 1 home-based) 3 sets, 10 reps, 80% 1RM + 1 d 30 reps 2 s load hold (using metronome) 1RM test each 2wk for load adjustment Routine included a variety of lower-limb strength exercises in addition to the k.flex	Isometric (dynamometer): MVC Torque 30° to 90° knee flexion	—	Ultrasound: CSA vastus lateralis	Ultrasound: Pennation angle vastus lateralis Fascicle length vastus lateralis
Pallarés et al.,[63]	Back Squat (Smith machine) Full SQ: thighs and calves contact ($n = 12$) Parallel SQ: inguinal crease aligned with knee ($n = 13$) Half SQ: 90° k.flex ($n = 11$) Control ($n = 14$) 23 ± 4 y 100% males, resistance-trained men	10 wk, 2 d/wk 4–5 sets, 8–4 reps Load from 60% to 80% 1RM Load adjusted each set by barbell velocity monitoring	1RM (loading test): 1RM Full SQ 1 RM Parallel SQ 1RM Half SQ Barbell velocity (Encoder) MPV Full SQ MPV Parallel SQ MPV Half SQ	Jump (Infrared system): CMJ height Sprint (Timing gates): Sprint 20 m Endurance (ergometer): Wingate peak power	—	—

(Continues)

TABLE 1 (Continued)

Study	Exercise, groups and sample	Resistance training intervention	Outcomes: Muscle strength	Functional performance	Muscle hypertrophy	Muscle architecture
Pinto et al.,[62]	Elbow flexion (curl bench) Full EF: 0° to 130° e.flex ($n = 15$) Half EF: 50° to 100° e.flex ($n = 15$) Control ($n = 10$) 23 ± 3 y 100% males, no resistance training experience	10 wk, 2 d/wk 2–4 sets, from 20RM to 8RM	1RM (loading test): 1RM Full EF 1RM Half EF	—	—	Ultrasound: Muscle thickness elbow flexors
Rhea et al.,[61]	Back squat (free weight) Full SQ: >110° k.flex ($n = 10$) Half SQ: 95–95° k.flex ($n = 9$) Quarter SQ: 55–65° k.flex ($n = 9$) 100% males, highly train athletes	16 wk, 2 d/wk 4–8 sets Load from 8, 6, 4, 2 RM then reverting to 8 RM. Same relative loads per group	1RM (loading test): 1RM Full SQ 1RM Half SQ 1RM Quarter SQ	Jump (Vertec system) CMJ height Sprint (Timing gates): Sprint 40 yards	—	—
Steele et al.,[60]	Lumbar extension (machine) Full ROM ($n = 10$) Lim ROM 50% ($n = 7$) Control ($n = 7$) 43 ± 15 y 55% males, physically active	12 wk; 1 d/wk 1 set 80% RM until concentric volitional fatigue Load increased 5% once the set took >105 s. 2 s concentric, 1s extension and 4 s eccentric	Isometric (dynamometer): Lumbar extension	ROM (Standing tests): Schober's flexion Schober's extension Lumbar ROM	—	-—
Valamatos et al.,[54]	Isokinetic knee extensions (machine) Full ROM: 100° k.flex ($n = 11$)[a] Partial ROM: 60° k.flex (same than FULL)[a] Control ($n = 8$) 18 to 34 y 100% males, physically active	15 wk; 3 d/wk 5 blocks of 3 wk 2–7 sets of 6–15 reps Load increased 30°/s every block Time under tension increased from 50 s to 55 s. Kick as fast as possible	Isokinetic (dynamometer): Torque from 30° to 100° Isometric (dynamometer): MVC torque Quadriceps force Vastus lateralis fascicle force Vastus specific tension	—	MRI CSA vastus lateralis Volume vastus lateralis	Ultrasound: Pennation angle vastus lateralis Fascicle length vastus lateralis
Weiss et al.,[53]	Squat (Bear machine) Deep SQ: thighs parallel to floor ($n = 6$) Shallow SQ: 50% Deep SQ ($n = 7$) Control ($n = 6$) 24 ± 6 y 55% males, students	9 wk, 3 d/wk 2–4 sets from 9–10 RM to 3–4 RM 1 wk of active rest between, after which 1 d of Leg Press was included due to severe shoulder girdle discomfort	1RM (loading test): 1RM Deep SQ 1RM Shallow SQ Power (dynamometer): Peak power at 1.43 m/s* Peak power at 0.51 m/s*	Jump (Vertec system) Depth Jump height* DJ height from 20 cm* SVJ height* RVJ jump height*	—	—

(Continues)

TABLE 1 (Continued)

Study	Exercise, groups and sample	Resistance training intervention	Outcomes: Muscle strength	Functional performance	Muscle hypertrophy	Muscle architecture
Werkhausen et al.,[68]	Leg press (machine) Full ROM: 90° to 0° k.flex (n = 15)[a] Partial ROM: 90° to 81° k.flex (n = 15)[a] 25 ± 4 y 67% males, resistance-trained men	10 wk, 3 d/wk 3–6 sets of 4–8 reps (4-8RM). Only concentric action Training loads adjusted using a scale (1–10). Weight increased when effort was rated below 8	Leg press power test: Peak power Isokinetic (dynamometer): Torque at 30, 60, 180, and 300°/s Isometric (dynamometer): Torque at 50, 100, and 150 ms	—	—	Ultrasound: Pennation angle vastus lateralis Fascicle length vastus lateralis Muscle thickness vastus lateralis

Abbreviations: 1RM, one-repetition maximum; Bm, Body mass; BP, Bench press; CMJ, Countermovement jump; CSA, Muscle cross-sectional area; DJ, Drop jump; e.flex, elbow flexion; EF, Elbow flexor; EX, Elbow extensor; k.ext, Knee extension; k.flex, Knee flexion; MPV, Mean propulsive velocity; MRFD, isometric maximal rate of force development; MRI, Magnetic Resonance Imaging; MVC, Maximal isometric voluntary contraction; RVJ, Restricted vertical jump; SJ, Squat jump; SQ, Squat. SVJ, Standing vertical jump.

*Results not included in the meta-analysis due to missing data. [a]Dominant vs. nondominant legs randomly selected.

and mixed-samples in four studies.[53,60,64,68] Nine studies investigated lower-limb exercises,[53,54,56,61,63,64,66-68] with five of them training the squat,[53,56,63,66,67] two a combination of lower-limb exercises,[61,64] one the leg press exercise,[68] and one the knee extension exercise.[54] Seven studies performed upper-limb exercises,[55,57-60,62,65] with three studies training the bench press[57,59,65] and the other the elbow flexion,[62] elbow extension,[58] arm push-and-pull[55] and lumbar extension[60] exercises. The main strength outcome analyzed was the one-repetition maximum (1RM), [53,56,57,59,61-63,65-67] followed by isometric tests,[54,56,58,60,64,67,68] isokinetic evaluations,[54,55,68] and barbell velocity assessments.[59,63] Functional tests included vertical jumps,[53,56,61,63,67] sprints,[61,63] Wingate anaerobic test[63] and flexibility assessment.[60] Four and two studies assessed changes in muscle hypertrophy using the cross-sectional area[54,56,58,64] and muscle volume,[54,66] respectively. Five studies included variables of muscle architecture measured by means of ultrasound scans, including the pennation angle,[54,56,64,68] fascicle length,[54,64,68] and muscle thickness.[56,62,68] Results for the GRADE certainty of the evidence of particular outcomes are presented in Table 2.

3.2 | Quality of studies and risk of bias

A summary of the risk-of-bias assessment is shown in Figure 2. No study was considered as a low risk of bias in all categories. The greatest biases were found in the randomization process, measurement of the outcomes, and selection of the reported results. No study provided a trial preregistration. Three studies showed a high risk of bias in the selection of the reported results since they only presented one dependent variable.[55,57,65]

3.3 | Muscle strength

Meta-analysis showed that exercise training at full ROM produced a significantly greater effect on the muscle strength with moderate effect size (ES [95% CI] = 0.56 [0.20 to 0.91], p = 0.004, I^2 = 77.6%, studies: n = 16, Figure 3). Specifically, separate variables analysis (Table 2) revealed that the full ROM training produced significantly greater improvements than partial ROM in 1RM Full ROM lower-limb strength (ES = 1.53, n = 6, p = 0.001) and nonsignificant but notably higher enhancements in 1RM Full ROM upper-limb strength (ES = 0.69, n = 4, p = 0.078) and isometric lower-limb strength (ES = 0.74, n = 5, p = 0.194).

3.4 | Functional performance

Meta-analysis showed that training at full ROM produced a greater but not-statistically significant effect on the functional performance (ES [95% CI] = 0.44 [−0.32 to 1.20], $p = 0.186$, $I^2 = 63.1\%$, studies: $n = 5$, Figure 4). Likewise, separate variables analysis (Table 2) revealed greater but not-statistically significant improvements in jump capability after full ROM training (ES = 0.55, $n = 4$, $p = 0.164$) (Table 2). No conclusive evidence was found for the sprint time and Wingate test.

3.5 | Muscle hypertrophy

Meta-analysis showed that exercise training at full ROM produced significantly greater muscle hypertrophy on lower-limb muscles, compared to partial ROM training (ES [95% CI] = 0.88 [0.19 to 1.57], $p = 0.027$, $I^2 = 80.3\%$, studies: $n = 4$, Figure 5).

3.6 | Muscle architecture

Meta-analysis showed no large differences in muscle architecture (ES [95% CI] = 0.28 [−0.26 to 0.82], $p = 0.226$, $I^2 = 74.6\%$, studies: $n = 5$, Figure 6). No conclusive evidence was found when variables of muscle architecture were analyzed separately, although fascicle length tended to be favored by the full ROM training (ES = 0.87, $n = 3$, $p = 0.327$).

4 | DISCUSSION

This systematic review found that full ROM resistance training is more effective than partial ROM in improving some training adaptations. In particular, full ROM produced significantly greater improvements in muscle strength and lower-limb muscle hypertrophy. Moreover, although not statistically significant, our results suggest that functional performance could be favored by the use of full ROM exercises. On the contrary, although fascicle length tended to be favored by the full ROM training, we did not detect significant differences between ROM interventions to produce changes in muscle architecture. To the best of our knowledge, this is the first systematic review and meta-analysis reporting the effects of resistance training with full ROM exercises compared to partial or restricted variants. The results of our investigation contribute to clarify the effectiveness of commonly used exercises during resistance training. The synthesis of the available literature aids a better understanding of the methods used and the identification of research gaps and future challenges.

4.1 | Muscle strength

Full ROM repetitions during resistance training were found more effective than partials to enhance muscle strength, particularly lower-limb 1RM Full ROM (ES = 1.53, $p = 0.001$). The results seemed to be homogeneous in a broad variety of exercises (squat, knee extension, bench press, elbow flexion, arm push-and-pull, and lumbar extension).

Traditionally, resistance training at partial ROM has been suggested as a good strategy to reduce neural inhibition and improve the coordination of primary and stabilizing muscles.[69,70] However, this meta-analysis has not found any longitudinal intervention that supports these superior neural benefits in favor of the partial ROM. Moreover, partial ROM resistance training has been believed to produce greater strength adaptations, since it allows us to lift a higher absolute weight, as a result of evading the critical region of the movement (ie, the sticking region).[25,71] However, this was not supported by the current meta-analysis, with most of the studies reporting greater neuromuscular adaptations after a full ROM training, both in the upper [59,60,62,65] and lower limbs,[56,63,64,67] even using lower absolute loads (ie, kg) (Table 1, Figure 3). The sticking region would be caused by an interaction between the muscle force-length relationship and the external torque.[31] On this matter, the sticking region would be the zone at which the maximal amount of contractile material is involved, due to two main reasons: i) the optimal (or close to optimal) muscle length (ie, not excessive stretched or contracted position of the sarcomeres),[30] and ii) the minimal velocity (ie, the number of cross-bridges attached increases as the shortening velocity decreases).[72,73] Therefore, the fact that partial repetitions systematically avoid this zone of maximal active tension could be the reason behind the lower effectiveness of partial ROM in enhancing strength.[59,63] However, future research is needed to understand the kinematics and physiological mechanisms that underlie these findings. On the contrary, the lack of studies executing the partial ROM training at long muscle lengths limited the current research to examine whether there are differences between full and partial ROMs according to the muscle length trained by the latter. Specifically, except for one group that trained by using partial repetitions executed at a long muscle length,[68] and three studies that executed partial repetitions at an intermediate region of the force-length relationship,[55,60,62] the rest of the investigations trained the partial ROM at short muscle lengths. Nevertheless, since the muscle length trained would be closely related to the moment arm (eg, smaller moment arms at more flexed knee angles, and so at longer muscle lengths),[74] it would be of great practical value that future investigations compare the full and partial ROM interventions including partial repetitions executed at short and long muscle lengths.

The present review found some controversy about the specificity training principle, which states that responses to training will be adapted in a similar manner to that employed

TABLE 2 Summary of quality of evidence synthesis (GRADE) for the efficacy of full vs. partial ROM resistance training in particular outcomes

Outcomes	No of participants (studies)	Certainty of the evidence (GRADE)	Effect size (95% IC)	*p*-value	I^2
Muscle Strength					
Lower-limb 1RM Full ROM	127 (6 RCTs)[53,56,61,63,66,67]	⊕⊕⊕◯ MODERATE[a]	1.53* (0.94 to 2.11)	0.001	40.1
Lower-limb 1RM Partial ROM	127 (6 RCTs)[53,56,61,63,66,67]	⊕⊕⊕◯ MODERATE[a]	−0.27 (−1.03 to 0.50)	0.412	6.3
Lower-limb isometric strength	124 (5 RCTs)[54,56,64,67,68]	⊕⊕◯◯ LOW[a,b]	0.74 (−0.58 to 2.06)	0.194	84.3
Upper-limb 1RM Full ROM	101 (4 RCTs)[52,57,59,62]	⊕⊕⊕◯ MODERATE[a]	0.69 (−0.14 to 1.52)	0.078	30.1
Upper-limb isokinetic strength	74 (2 RCTs)[55,60]	⊕⊕◯◯ LOW[a,b]	0.24 (−2.18 to 2.66)	0.424	18.8
Functional performance					
Jump height	98 (4 RCTs)[50,54,56,61]	⊕⊕◯◯ LOW[a,b]	0.55 (−0.41 to 1.51)	0.164	59.7
Sprint	42 (2 RCTs)[50,61]	⊕⊕◯◯ LOW[a,b]	0.10 (−9.89 to 10.08)	0.923	83.2
Muscle Architecture					
Vastus lateralis pennation angle	84 (4 RCTs)[54,56,64]	⊕⊕◯◯ LOW[a,b]	−0.01 (−1.53 to 1.51)	0.984	79.6
Vastus lateralis fascicle length	67 (3 RCTs)[54,64,68]	⊕⊕◯◯ LOW[a,b]	0.87 (−2.04 to 3.77)	0.327	84.6
Vastus lateralis muscle thickness	76 (3 RCTs)[56,62,68]	⊕⊕◯◯ LOW[a,b]	0.05 (−0.30 to 0.39)	0.605	0.0

Note: Significant differences in favor to the full ROM: $^*p < 0.01$.
[a]Evidence limited by heterogeneity between studies.
[b]Evidence limited by imprecise data (small sample size or lack of a clear effect).

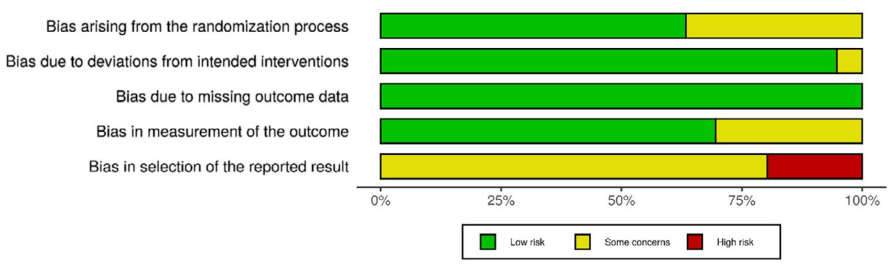

FIGURE 2 Risks of bias of the studies examining the efficacy of full vs. partial ROM resistance training. The use of exercise training makes it impossible to truly blind patients to treatment allocation; therefore, this was not considered in the overall risk-of-bias assessment of each study

during training. In this regard, some studies found that each training group obtained the greatest 1RM improvements at the specific ROM at which they trained (eg, the partial squat group achieved more 1RM enhancements in the partial squat test than in the full squat test).[56,61,66,67] Conversely, other investigations showed that, although each training group maximized the strength gains at the specific ROM they trained, the full ROM group obtained the greatest neuromuscular improvements even in the partial tests.[59,63] It should be taken into account that the specificity principle could be related to the learning effect of participants, after regular practice. For example, a participant who trained during weeks at a given ROM is expected to obtain greater post-intervention performance in this specific ROM as a consequence of the familiarization with the execution of the exercise.[75,76] An interesting approach to reduce the impact of the learning

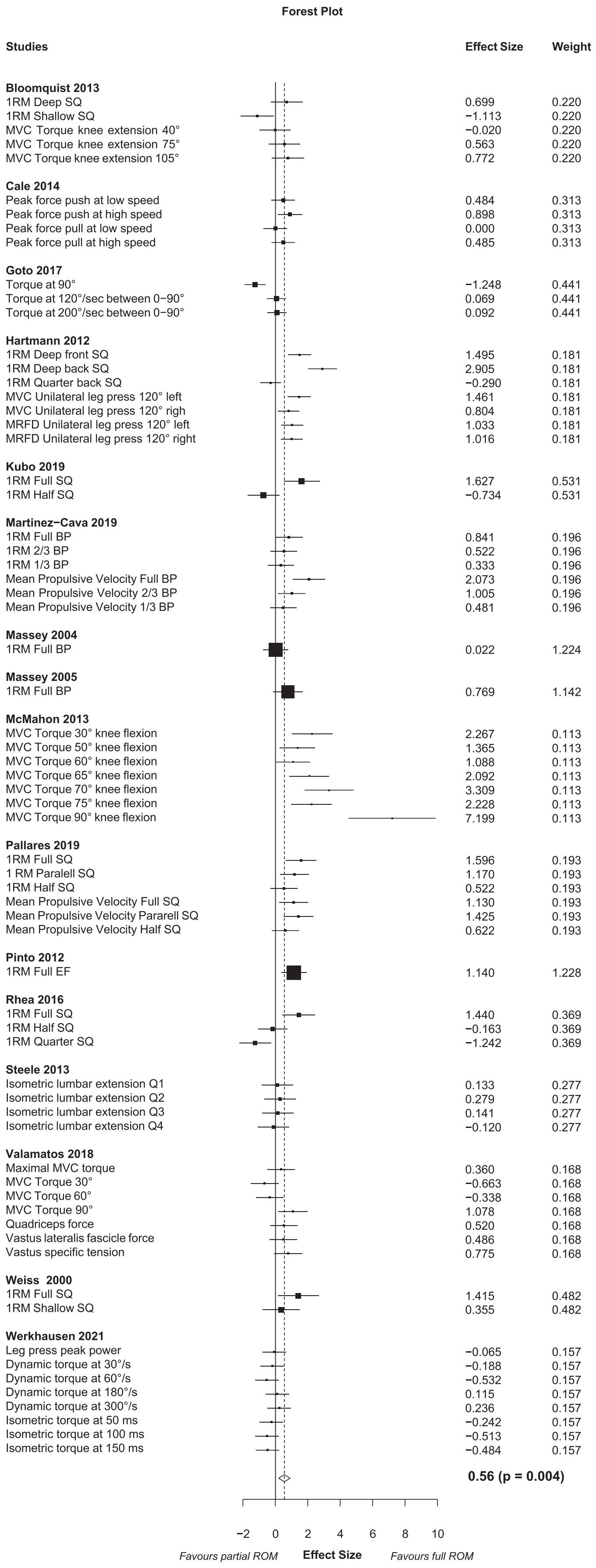

FIGURE 3 Forest plot showing comparative effect of full and partial ROMs on muscle strength

effect when interpreting the main results is the inclusion of complementary neuromuscular tests, not related to the specific resistance training performed during the intervention, for instance, maximal isometric contractions at specific angles.[56,64,67] Thus, taking into account these complementary evaluations, our results continue to support the greater efficacy of the full ROM training to enhance strength gains (Table 2).

4.2 | Functional performance

The choice of the optimal ROM to improve sports performance has been under discussion for decades.[28,77-79] According to our review, most of the research suggests full ROM resistance training as preferable to increase jump ability[53,56,63,67] (Table 2), with only one study supporting the superior effectiveness of partial ROM[61] (Figure 4). However, although effect sizes favored the full ROM, the meta-analysis was not significant. Interestingly, except for Rhea et al.,[61] studies reporting specific strength adaptations at the ROM trained (specificity principle) showed higher effectiveness of the full ROM training to increase jump height.[56,67] On the contrary, the two studies examining the sprint performance showed conflicting results[61,63] ; therefore, we cannot present a clear conclusion about the optimal ROM to maximize this functional capability. Furthermore, only one study examined sports abilities different from jumping or sprinting, by means of the Wingate anaerobic test, with positive results favoring the full ROM.[63] Future research should confirm these results.

4.3 | Muscle hypertrophy

The present study found superior effectiveness of the full ROM training to produce lower-limb muscle growth (Figure 5). Our results are in line with a previous systematic review[35] suggesting a potential greater effect of full ROM resistance training on muscle hypertrophy, especially in the lower limbs.[54,56,64,66] It is worth noting that, except for Goto et al.[58] (muscle size measured at a single point of the muscle length), the rest of the investigations used as an indicator of muscle hypertrophy either the muscle volume[54,66] or CSA measurements acquired at different lengths of the target muscle (eg, proximal-medial-distal).[54,56,64] Although the assessment of the muscle volume via MRI would be the gold-standard technique,[80] measuring the CSA at different points would allow researchers to identify regional changes which would be dependent on the exercise trained (eg, leg press and knee extension would maximize hypertrophy in the middle[81] and distal sites[39] of the muscle, respectively). Therefore, the results found by the current study regarding the superior effectiveness of the full ROM in generating

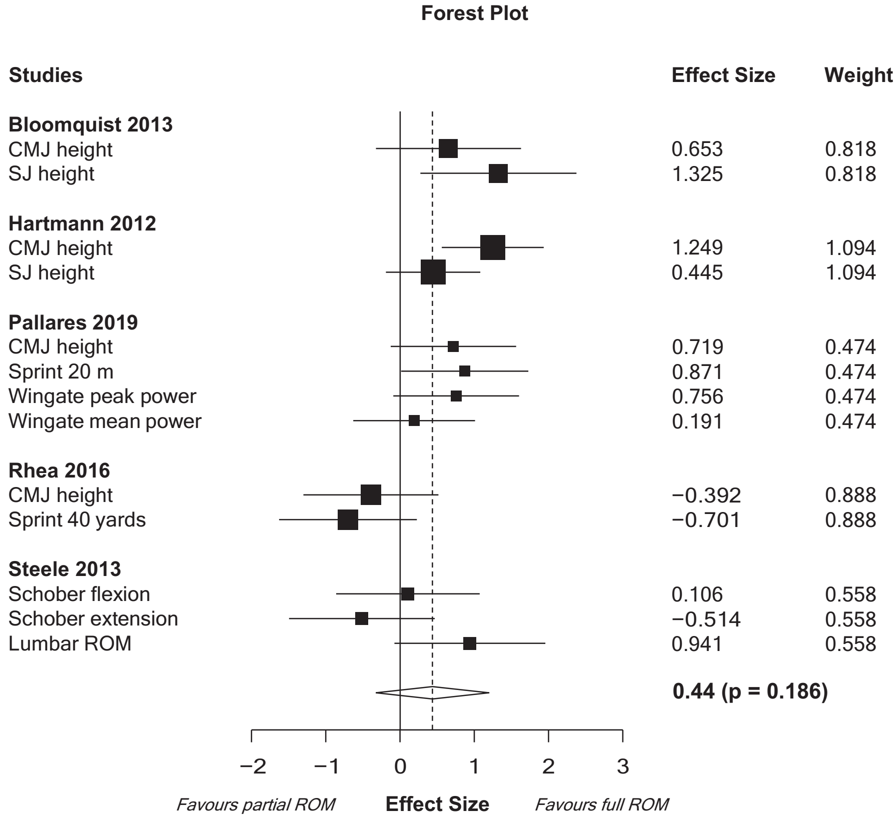

FIGURE 4 Forest plot showing comparative effect of full and partial ROMs on functional performance

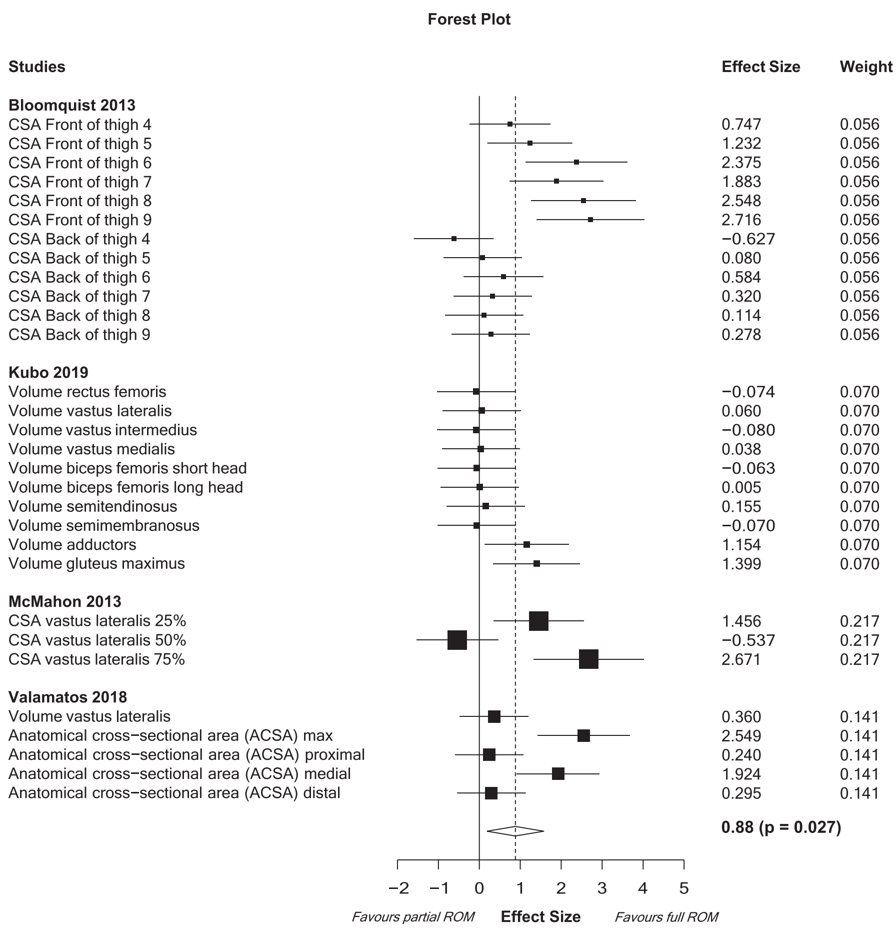

FIGURE 5 Forest plot showing comparative effect of full and partial ROMs on lower-limb muscle hypertrophy

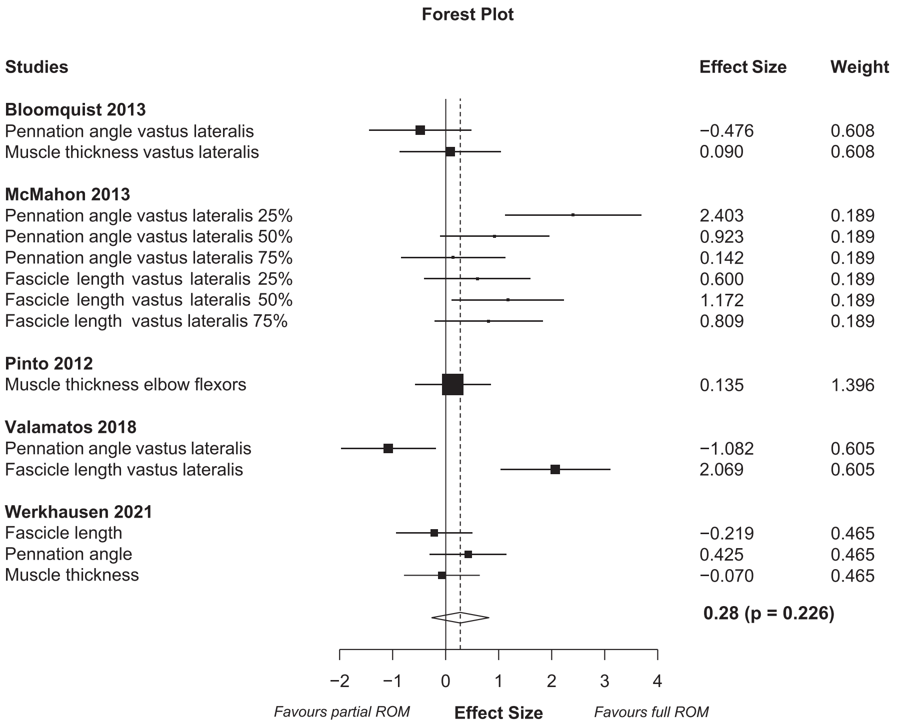

FIGURE 6 Forest plot showing comparative effect of full and partial ROMs on muscle architecture

muscle hypertrophy would be reinforced once the evaluation techniques used by the individual studies have been considered. Nevertheless, two limitations related to the muscle hypertrophy analysis should be noted. Firstly, the scarcity of scientific evidence examining the upper-limb hypertrophy through sensitive methods (ie, muscle volume or multiple CSA measurements) limits us to provide a clear conclusion about the influence of the trained ROM on muscle growth of the upper-limb muscles. Secondly, the limited duration of the training programs designed by the studies included (mean duration = 10.4 weeks; ranging from 6 to 16 weeks) would have influenced the hypertrophy values detected by the current review. Specifically, although significant increases in muscle size have been observed after only a few weeks of training (~3 weeks),[39] muscle growth has been proved to be influenced by the duration of the training program in a linear fashion (ie, the longer the duration, the more muscle hypertrophy).[82] Hence, future investigations comparing the full and partial ROMs in terms of muscle hypertrophy are encouraged to implement training programs of longer duration.

4.4 | Muscle architecture

Our results revealed large disparities in the effectiveness of full or partial ROM training to modify the muscle thickness, pennation angle, and fascicle length.[54,56,64] However, two of the three studies analyzing the fascicle length found superior adaptations after full ROM repetitions[54,64] (Table 2, Figure 6). On this matter, muscles adapt their structure by adding or removing sarcomeres as a function of different training parameters, including the range at which they are stimulated.[83-85] This may account for the higher enhancements of fascicle length after full ROM training, as a response to stimulate the muscles at lengths that exceed those required by the daily activities,[54,64] particularly during the eccentric phase of the movement.[81,86] Consequently, the changes in fascicle length would modify the muscle function due to its influence on force-length and force-velocity relationships.[34] Thus, a reduction in the number of sarcomeres in series would vary the joint angle where optimal force is produced during the activity (ie, altering the force-length relationship) and reduce the shortening velocity (ie, altering the force-velocity relationship).[87-89] Furthermore, having short fascicles has been related to the rise of microscope muscle damage after repetitive eccentric actions.[34] Therefore, athletes' risk of injury could be reduced by training at full ROM.

This study is not exempt from limitations. Firstly, we had to estimate results from studies that only reported them graphically or lacked some specific statistic (eg, SD). Secondly, most of the meta-analyses indicated moderate to high levels of heterogeneity. This fact could be explained mainly by the different variables included in each quantitative analysis (ie, clinical diversity), as well as the different methodologies (eg, programming, volume, intensity, exercise, duration) used by each study (ie, methodological diversity). Thirdly, the scarce and contradictory results about some effects, both functional (sprint, cycling) and structural (upper-limb hypertrophy and muscle architecture), limit the present study to provide a clear conclusion about these specific adaptations.

5 | PERSPECTIVE

The main findings of this study suggest that full ROM resistance training is more effective than partial ROM to maximize muscle strength and lower-limb muscle hypertrophy. Similarly, functional performance appears to be favored by full ROM exercises. On the contrary, although fascicle length tended to be favored by the full ROM training, there are no large differences between the full and partial ROM interventions to generate changes in muscle architecture. Currently, there is a wide debate and controversy about the most effective ROM to maximize the positive effects of resistance training. On this matter, the results of this systematic review and meta-analysis importantly contribute toward a better understanding of a training variable traditionally interpreted on the basis of dubious and noncontrasted beliefs.

CONFLICT OF INTEREST

The authors declare that they have no competing interests. No funding was received for this research.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Jesús G. Pallarés https://orcid.org/0000-0002-6087-1583
Alejandro Hernández-Belmonte https://orcid.org/0000-0002-0638-5859
Alejandro Martínez-Cava https://orcid.org/0000-0002-9435-8163
Tomas Vetrovsky https://orcid.org/0000-0003-2529-7069
Michal Steffl https://orcid.org/0000-0001-7297-8145
Javier Courel-Ibáñez https://orcid.org/0000-0003-2446-1875

REFERENCES

1. Lesinski M, Herz M, Schmelcher A, Granacher U. Effects of resistance training on physical fitness in healthy children and adolescents: an umbrella review. *Sport Med*. 2020;50:1901-1928.
2. Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: the 2014 International Consensus. *Br J Sports Med*. 2014;48:498-505.
3. Fragala MS, Cadore EL, Dorgo S, et al. Resistance training for older adults: position statement from the National Strength and Conditioning Association. *J Strength Cond Res*. 2019;33:2019-2052.
4. Hunter GR, McCarthy JP, Bamman MM. Effects of resistance training on older adults. *Sport Med*. 2004;34:329-348.
5. Ciolac EG, Rodrigues-da-Silva JM. Resistance training as a tool for preventing and treating musculoskeletal disorders. *Sport Med*. 2016;46:1239-1248.
6. Guadalupe-Grau A, Fuentes T, Guerra B, Calbet JA. Exercise and bone mass in adults. *Sport Med*. 2009;39:439-468.
7. Lee JH, Kim DH, Kim CK. Resistance training for glycemic control, muscular strength, and lean body mass in old type 2 diabetic patients: a meta-analysis. *Diabetes Ther*. 2017;8:459-473.
8. Fairman CM, Hyde PN, Focht BC. Resistance training interventions across the cancer control continuum: a systematic review of the implementation of resistance training principles. *Br J Sports Med*. 2017;51:677-685.
9. Liu CJ, Shiroy DM, Jones LY, Clark DO. Systematic review of functional training on muscle strength, physical functioning, and activities of daily living in older adults. *Eur Rev Aging Phys Act*. 2014;11:95-106.
10. Lesinski M, Prieske O, Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. *Br J Sports Med*. 2016;50:781-795.
11. Gentil P, Fisher J, Steele J. A review of the acute effects and long-term adaptations of single- and multi-joint exercises during resistance training. *Sport Med*. 2017;47:843-855.
12. Csapo R, Alegre LM. Effects of resistance training with moderate vs heavy loads on muscle mass and strength in the elderly: a meta-analysis. *Scand J Med Sci Sports*. 2016;26:995-1006.
13. Ralston GW, Kilgore L, Wyatt FB, Buchan D, Baker JS. Weekly training frequency effects on strength gain: a meta-analysis. *Sport Med Open*. 2018;4:36.
14. Grgic J, Schoenfeld BJ, Davies TB, Lazinica B, Krieger JW, Pedisic Z. Effect of resistance training frequency on gains in muscular strength: a systematic review and meta-analysis. *Sport Med*. 2018;48:1207-1220.
15. Schoenfeld BJ, Ogborn D, Krieger JW. Dose-response relationship between weekly resistance training volume and increases in muscle mass: a systematic review and meta-analysis. *J Sports Sci*. 2017;35:1073-1082.
16. Ralston GW, Kilgore L, Wyatt FB, Baker JS. The effect of weekly set volume on strength gain: a meta-analysis. *Sport Med*. 2017;47:2585-2601.
17. Grgic J, Lazinica B, Mikulic P, Krieger JW, Schoenfeld BJ. The effects of short versus long inter-set rest intervals in resistance training on measures of muscle hypertrophy: a systematic review. *Eur J Sport Sci*. 2017;17:983-993.
18. Davies TB, Kuang K, Orr R, Halaki M, Hackett D. Effect of movement velocity during resistance training on dynamic muscular strength: a systematic review and meta-analysis. *Sport Med*. 2017;47:1603-1617.
19. Hackett DA, Davies TB, Orr R, Kuang K, Halaki M. Effect of movement velocity during resistance training on muscle-specific hypertrophy: a systematic review. *Eur J Sport Sci*. 2018;18:473-482.
20. Haff GG, Triplett TN. *Essentials of Strength & Conditioning*. 4th ed. Hum Kinet; 2016; p. 320.
21. García-Ramos A, Pérez-Castilla A, Villar Macias FJ, Latorre-Román P, Párraga JA, García-Pinillos F. Differences in the one-repetition maximum and load-velocity profile between the flat and arched bench press in competitive powerlifters. *Sport Biomech*. 2018;20:1-13.
22. Wagner LL, Evans SA, Weir JP, Housh TJ, Johnson GO. The effect of grip width on bench press performance. *Int J Sport Biomech*. 1992;8:1-10.
23. Pérez-Castilla A, Martínez-García D, Jerez-Mayorga D, Rodríguez-Perea Á, Chirosa-Ríos LJ, García-Ramos A. Influence of the grip width on the reliability and magnitude of different

velocity variables during the bench press exercise. *Eur J Sport Sci*. 2020;20:1-10.

24. Swinton PA, Lloyd R, Agouris I, Stewart A. Contemporary training practices in elite British powerlifters: survey results from an international competition. *J Strength Cond Res*. 2009;23:380-384.
25. Martínez-Cava A, Morán-Navarro R, Sánchez-Medina L, González-Badillo JJ, Pallarés JG. Velocity- and power-load relationships in the half, parallel and full back squat. *J Sports Sci*. 2019;37:1088-1096.
26. Pérez-Castilla A, García-Ramos A, Padial P, Morales-Artacho AJ, Feriche B. Load-velocity relationship in variations of the half-squat exercise: influence of execution technique. *J Strength Cond Res*. 2020;34:1024-1031.
27. Clark R, Humphries B, Hohmann E, Bryant A. The influence of variable range of motion training on neuromuscular performance and control of external loads. *J Strength Cond Res*. 2011;25:704-711.
28. Hartmann H, Wirth K, Klusemann M. Analysis of the load on the knee joint and vertebral column with changes in squatting depth and weight load. *Sport Med*. 2013;43:993-1008.
29. Da Silva JJ, Schoenfeld BJ, Marchetti PN, Pecoraro SL, Greve JMD, Marchetti PH. Muscle activation differs between partial and full back squat exercise with external load equated. *J Strength Cond Res*. 2017;31:1688-1693.
30. Rassier DE, MacIntosh BR, Herzog W. Length dependence of active force production in skeletal muscle. *J Appl Physiol*. 1999;86:1445-1457.
31. Kompf J, Arandjelović O. Understanding and overcoming the sticking point in resistance exercise. *Sport Med*. 2016;46:751-762.
32. Noorkõiv M, Nosaka K, Blazevich AJ. Effects of isometric quadriceps strength training at different muscle lengths on dynamic torque production. *J Sports Sci*. 2015;33:1952-1961.
33. Marušič J, Vatovec R, Marković G, Šarabon N. Effects of eccentric training at long-muscle length on architectural and functional characteristics of the hamstrings. *Scand J Med Sci Sports*. 2020;30:2130-2142.
34. Timmins RG, Shield AJ, Williams MD, Lorenzen C, Opar DA. Architectural adaptations of muscle to training and injury: a narrative review outlining the contributions by fascicle length, pennation angle and muscle thickness. *Br J Sports Med*. 2016;50:1467-1472.
35. Schoenfeld BJ, Grgic J. Effects of range of motion on muscle development during resistance training interventions: a systematic review. *SAGE Open Med*. 2020;8:205031212090155.
36. Higgins JPT, Green S. Cochrane handbook for systematic reviews of interventions version 5.1.0. The Cochrane Collaboration. 2011; Available from [https://handbook-5-1.cochrane.org].
37. Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6:e1000097.
38. Centre for Reviews and Dissemination. *Systematic Reviews: CRD's guidance for undertaking systematic reviews in health care*. University of York; 2009.
39. Seynnes OR, De Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *J Appl Physiol*. 2007;102:368-373.
40. Scott JM, Martin DS, Ploutz-Snyder R, et al. Reliability and validity of panoramic ultrasound for muscle quantification. *Ultrasound Med Biol*. 2012;38:1656-1661.
41. Franchi MV, Fitze DP, Hanimann J, Sarto F, Spörri J. Panoramic ultrasound vs. MRI for the assessment of hamstrings cross-sectional area and volume in a large athletic cohort. *Sci Rep*. 2020;10:1-10.
42. Ahtiainen JP, Hoffren M, Hulmi JJ, et al. Panoramic ultrasonography is a valid method to measure changes in skeletal muscle cross-sectional area. *Eur J Appl Physiol*. 2010;108:273-279.
43. Tanaka NI, Ogawa M, Yoshiko A, Ando R, Akima H. Reliability of size and echo intensity of abdominal skeletal muscles using extended field-of-view ultrasound imaging. *Eur J Appl Physiol*. 2017;117:2263-2270.
44. Webster J, Watson T. Analyzing the past to prepare for the future: Writing a literature review. MIS Quaterly. 2002.
45. Levy Y, Ellis TJ. A systems approach to conduct an effective literature review in support of information systems research. *Informing Sci*. 2006;9:181-211.
46. Belur J, Tompson L, Thornton A, Simon M. Interrater reliability in systematic review methodology: exploring variation in coder decision-making. *Sociol Methods Res*. 2018;50(2):837-865.
47. Drevon D, Fursa SR, Malcolm AL. Intercoder reliability and validity of WebPlotDigitizer in extracting graphed data. *Behav Modif*. 2017;41:323-339.
48. Weir CJ, Butcher I, Assi V, et al. Dealing with missing standard deviation and mean values in meta-analysis of continuous outcomes: a systematic review. *BMC Med Res Methodol*. 2018;8:25.
49. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:4898.
50. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ*. 2008;336:924-926.
51. Hedges LV, Tipton E, Johnson MC. Robust variance estimation in meta-regression with dependent effect size estimates. *Res Synth Methods*. 2010;1:39-65.
52. Tipton E. Small sample adjustments for robust variance estimation. *Psychol Methods*. 2015;20:375-393.
53. Weiss LW, Fry AC, Wood LE, Relyea GE, Melton C. Comparative effects of deep versus shallow squat and leg-press training on vertical jumping ability and related factors. *J Strength Cond Res*. 2000;14:241-247.
54. Valamatos MJ, Tavares F, Santos RM, Veloso AP, Mil-Homens P. Influence of full range of motion vs. equalized partial range of motion training on muscle architecture and mechanical properties. *Eur J Appl Physiol*. 2018;118:1969-1983.
55. Cale'-Benzoor M, Dickstein R, Arnon M, Ayalon M. Strength enhancement with limited range closed kinetic chain isokinetic exercise of the upper extremity. *Isokinet Exerc Sci*. 2014;22:37-46.
56. Bloomquist K, Langberg H, Karlsen S, Madsgaard S, Boesen M, Raastad T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. *Eur J Appl Physiol*. 2013;113:2133-2142.
57. Massey CD, Vincent J, Maneval M, Moore M, Johnson JT. An analysis of full range of motion vs. partial range of motion training in the development of strength in untrained men. *J Strength Cond Res*. 2004;18:518-521.
58. Goto M, Maeda C, Hirayama T, et al. Partial range of motion exercise is effective for facilitating muscle hypertrophy and function through sustained intramuscular hypoxia in young trained men. *J Strength Cond Res*. 2019;33:1286-1294.
59. Martínez-Cava A, Hernández-Belmonte A, Courel-Ibáñez J, Morán-Navarro R, González-Badillo JJ, Pallarés JG. Bench press at full range of motion produces greater neuromuscular adaptations than partial executions after prolonged resistance training. *J Strength Cond Res*. 2019;1:91. https://doi.org/10.1519/jsc.0000000000003391

60. Steele J, Bruce-Low S, Smith D, Jessop D, Osborne N. A randomized controlled trial of limited range of motion lumbar extension exercise in chronic low back pain. *Spine*. 2013;38:1245-1252.
61. Rhea MR, Kenn JG, Peterson MD, et al. Joint-angle specific strength adaptations influence improvements in power in highly trained athletes. *Hum Mov*. 2016;17:43-49.
62. Pinto RS, Gomes N, Radaelli R, Botton CE, Brown LE, Bottaro M. Effect of range of motion on muscle strength and thickness. *J Strength Cond Res*. 2012;26:2140-2145.
63. Pallarés JG, Martínez-Cava A, Courel-Ibáñez J, González-Badillo JJ, Morán-Navarro R. Full squat produces greater neuromuscular and functional adaptations and lower pain than partial squats after prolonged resistance training. *Eur J Sport Sci*. 2020;20:115-124.
64. McMahon GE, Morse CI, Burden A, Winwood K, Onambélé GL. Impact of range of motion during ecologically valid resistance training protocols on muscle size, subcutaneous fat, and strength. *J Strength Cond Res*. 2014;28:245-255.
65. Massey CD, Vincent J, Maneval M, Johnson JT. Influence of range of motion in resistance training in women: early phase adaptations. *J Strength Cond Res*. 2005;19:409-411.
66. Kubo K, Ikebukuro T, Yata H. Effects of squat training with different depths on lower limb muscle volumes. *Eur J Appl Physiol*. 2019;119:1933-1942.
67. Hartmann H, Wirth K, Klusemann M, Dalic J, Matuschek C, Schmidtbleicher D. Influence of squatting depth on jumping performance. *J Strength Cond Res*. 2012;26:3243-3261.
68. Werkhausen A, Solberg CE, Paulsen G, Bojsen-Møller J, Seynnes OR. Adaptations to explosive resistance training with partial range of motion are not inferior to full range of motion. *Scand J Med Sci Sports*. 2021;31(5):1026-1035.
69. Clark RA, Bryant AL, Humphries B. An examination of strength and concentric work ratios during variable range of motion training. *J Strength Cond Res*. 2008;22:1716-1719.
70. Mookerjee S, Ratamess N. Comparison of strength differences and joint action durations between full and partial range-of-motion bench press exercise. *J Strength Condition Res*. 1999;13:76-81.
71. Martínez-Cava A, Morán-Navarro R, Hernández-Belmonte A, et al. Range of motion and sticking region effects on the bench press load-velocity relationship. *J Sport Sci Med*. 2019;18:645-652.
72. Alcazar J, Csapo R, Ara I, Alegre LM. On the shape of the force-velocity relationship in skeletal muscles: the linear, the hyperbolic, and the double-hyperbolic. *Front Physiol*. 2019;10:769.
73. Chin L, Yue P, Feng JJ, Seow CY. Mathematical simulation of muscle cross-bridge cycle and force-velocity relationship. *Biophys J*. 2006;91:3653-3663.
74. Reeves ND, Narici MV, Maganaris CN. In vivo human muscle structure and function: adaptations to resistance training in old age. *Exp Physiol*. 2004;89:675-689.
75. Ploutz-Snyder LL, Giamis EL. Orientation and Familiarization to 1RM strength testing in old and young women. *J Strength Cond Res*. 2001;15:519-523.
76. Ritti-Dias RM, Avelar A, Salvador EP, Cyrino ES. Influence of previous experience on resistance training on reliability of one-repetition maximum test. *J Strength Cond Res*. 2011;25:1418-1422.
77. Zatsiorsky VM, Kraemer WJ. Science and practice of strength training. *Human Kinetics*. 2006;122-123.
78. Wilson GJ. Strength and power in sport. In: Bloomfield J, Ackland TR, Elliot BC, eds. *Appl Anat Biomech Sport*, 3rd edn. Berlin, Germany: Blackwell; 1998:110-208.
79. Young W, Benton D, Duthie G, Pryor J. Resistance training for short sprints and maximum-speed sprints. *Strength Cond J*. 2001;23:7.
80. Sarto F, Spörri J, Fitze DP, Quinlan JI, Narici MV, Franchi MV. Implementing ultrasound imaging for the assessment of muscle and tendon properties in elite sports: practical aspects, methodological considerations and future directions. *Sports Med*. 2021;51:1-20.
81. Franchi MV, Atherton PJ, Reeves ND, et al. Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. *Acta Physiol*. 2014;210:642-654.
82. Narici MV, Hoppeler H, Kayser B, et al. Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training. *Acta Physiol Scand*. 1996;157:175-186.
83. Goldspink G. Malleability of the motor system: a comparative approach. *J Exp Biol*. 1985;115:375-391.
84. Goldspink G. Changes in muscle mass and phenotype and the expression of autocrine and systemic growth factors by muscle in response to stretch and overload. *J Anat*. 1999;194:323-334.
85. Williams PE, Goldspink G. The effect of immobilization on the longitudinal growth of striated muscle fibres. *J Anat*. 1973;116:45.
86. Walker S, Trezise J, Haff GG, Newton RU, Häkkinen K, Blazevich AJ. Increased fascicle length but not patellar tendon stiffness after accentuated eccentric-load strength training in already-trained men. *Eur J Appl Physiol*. 2020;120:2371-2382.
87. Lieber RL, Fridén J. Functional and clinical significance of skeletal muscle architecture. *Muscle Nerve*. 2000;23:1647-1666.
88. Wickiewicz TL, Roy RR, Powell PL, Perrine JJ, Edgerton VR. Muscle architecture and force-velocity relationships in humans. *J Appl Physiol Respir Environ Exerc Physiol*. 1984;57:435-443.
89. Davis JF, Khir AW, Barber L, et al. The mechanisms of adaptation for muscle fascicle length changes with exercise: implications for spastic muscle. *Med Hypotheses*. 2020;144:110199.

How to cite this article: Pallarés JG, Hernández-Belmonte A, Martínez-Cava A, Vetrovsky T, Steffl M, Courel-Ibáñez J. Effects of range of motion on resistance training adaptations: A systematic review and meta-analysis. *Scand J Med Sci Sports*. 2021;31:1866–1881. https://doi.org/10.1111/sms.14006