Arch Physioter 2025; 15: 297-313
ISSN 2057-0082 | DOI: 10.33393/aop.2025.3533
REVIEW

OPEN ACCESS

Is resistance training with external loads superior to unloaded exercise in the management of chronic low back pain? A systematic review and meta-analysis

Marco Ranzani[1], **Andrea Pozzi**[2], **Daniele Fornasari**[2], **Diego Ristori**[2], **Marco Testa**[2]

[1] Casa di Cura Igea – Department of Neurorehabilitation Sciences, Milan - Italy
[2] Department of Neuroscience, Rehabilitation, Ophthalmology, Genetics, Maternal and Child Health, University of Genova, Campus of Savona, Savona - Italy

ABSTRACT

Introduction: Chronic non-specific low back pain is a leading cause of disability worldwide. While resistance training using external loads is common in rehabilitation, its added value over unloaded exercise remains uncertain, particularly across physical and psychological variables.

Method: This systematic review and meta-analysis, registered on PROSPERO (CRD42022366975), included randomized controlled trials comparing externally loaded resistance training to unloaded exercise in adults with chronic non-specific low back pain. Primary outcomes were pain intensity and disability. Secondary outcomes included back muscle endurance, maximal strength, fear-avoidance beliefs, and pain catastrophizing. Random-effects meta-analyses were conducted, stratified by follow-up duration.

Results: Thirteen randomized trials (778 participants) were included. At follow-up periods beyond seven weeks, externally loaded resistance training showed a small but statistically significant reduction in pain compared to unloaded exercise (mean difference = –0.52 on a 0-10 scale; 95% confidence interval [–0.92, –0.08]). No significant differences were found at short-term or post-washout follow-ups. Effects on disability were inconsistent and highly variable. Resistance training was associated with improvements in back muscle endurance and suggested a possible effect on long-term maximal strength, although wide prediction intervals prevent definitive conclusions. No meaningful differences were found for psychological variables, and pain catastrophizing was assessed in only one trial, limiting conclusions.

Conclusion: Externally loaded resistance training is safe and feasible for chronic non-specific low back pain, but its effects on pain, disability and psychosocial outcomes are comparable to unloaded exercise. In line with the multifactorial nature of chronic pain, improvements appear driven more by exposure, adherence and therapeutic context than by load intensity alone. Exercise prescription should therefore remain individualized and embedded within a biopsychosocial framework.

Keywords: Low back pain, Chronic, Exercise therapy, Resistance training, Weight training, Load

What's already known about this topic?

- *RT can enhance both strength and endurance. The specific role of load as a variable in RT for managing chronic NS-LBP, particularly its impact on pain and disability, remains not fully established.*

What does the study add?

- *While loaded exercises induce greater neuromuscular adaptations, they do not provide better improvements in pain or disability compared to unloaded exercises in individuals with chronic NS-LBP. Exercise volume and adherence may play a more significant role in symptom management.*

Received: April 16, 2025
Accepted: November 3, 2025
Published online: December 5, 2025

This article includes supplementary material

Corresponding author:
Marco Ranzani
email: m.ranzani@casadicuraigea.it

Introduction

Low back pain (LBP) is the most prevalent musculoskeletal disorder (1), affecting approximately 540 million people worldwide at any given time (2). When no specific patho-anatomical cause can be identified, LBP is classified as non-specific (NS-LBP) (3). Among all musculoskeletal conditions, chronic NS-LBP represents the leading cause of disability, as measured in disability-adjusted life-years (4), posing a significant burden on healthcare systems and affected individuals.

Traditionally conceptualized through a biomechanical lens, chronic NS-LBP is now widely recognized as a multifactorial condition in which pain and disability arise from dynamic interactions among biological, psychological, and social factors (5). This paradigm shift has supported the adoption of the biopsychosocial (BPS) model as the best practice for its understanding and management (6).

Exercise is widely recommended as the first-line treatment for chronic NS-LBP, as highlighted by the National Institute for Health and Care Excellence (NICE) guidelines (7).

Beyond its physical effects, exercise can be conceptualized as a multidimensional therapeutic intervention, capable of modulating psychological and behavioral processes (8). Evidence suggests that physical exercise may positively influence factors such as anxiety, mood, fear-avoidance, and pain-related beliefs (9,10), reinforcing its role within the BPS model.

Despite its recognized value, the optimal characteristics of exercise interventions for chronic NS-LBP remain unclear. Current literature shows limited differences in effectiveness between various exercise modalities, with generally modest improvements in pain and disability (11,12). This suggests a need to move beyond broad exercise categories and instead focus on specific intervention components that may drive better outcomes.

One such component is the type and intensity of resistance, or load, used during training. Resistance training (RT) is a form of physical exercise involving internal (e.g., body weight) or external (e.g., free weights, machines, bands) resistance to stimulate skeletal muscle contractions, aiming to enhance strength, power, muscular endurance, and muscle mass (13,14). Although RT is commonly applied in rehabilitation settings, the optimal dosage and resistance parameters for chronic musculoskeletal conditions remain poorly defined (15-17). In research, the term “load” typically refers to external resistance, distinguishing “loaded” from “unloaded” exercises (18).

Loaded exercises may induce adaptations across multiple, interrelated domains. They have been associated with greater gains in muscle strength (19), soft tissue capacity (20), cartilage turnover (21), as well as enhanced neurochemical responses which have been linked to increases in pain thresholds (22,23). Incorporating external load may serve as a graded exposure stimulus, helping patients confront fears, rebuild confidence in movement, and challenge beliefs related to fragility or harm (7). Such mechanisms may be particularly valuable for targeting maladaptive responses such as fear-avoidance, kinesiophobia, and pain catastrophizing, which are known to contribute to the persistence of chronic NS-LBP (24).

Although the addition of external load to an exercise program may influence the adaptations described above, its specific contribution to clinical outcomes remains poorly understood (25,26). Available studies are hindered by inconsistent terminology, insufficiently described loading protocols and inadequate control conditions lacking active comparators (17,27). Therefore, it remains unclear to what extent the inclusion of external resistance affects the multifaceted nature of chronic NS-LBP.

This systematic review and meta-analysis consequently seeks to address the following question: “To what extent does the use of external load in resistance training influence symptoms, function, and psychosocial factors in chronic NS-LBP management?”

The primary objective of this systematic review and meta-analysis was to assess the effects of RT with external resistance compared to unloaded exercises on pain and disability. Secondary outcomes included physical performance metrics (muscle endurance, maximal strength) and psychosocial variables (fear-avoidance, kinesiophobia, and pain catastrophizing).

Methods

This study followed the guidelines outlined in the ‘Cochrane Handbook for Systematic Reviews of Interventions’ (28) and was structured in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement (29). The PRISMA checklist is reported in ‘Appendix A’.

Eligibility criteria

The eligibility criteria were developed based on a research question structured according to the Population–Intervention–Comparison–Outcome (PICO) framework. The population of interest comprised adults (≥18 years) diagnosed with chronic NS-LBP. Eligible Interventions included RT programs that incorporated external loads, either alone or in combination with internal resistance (bodyweight). To isolate the effect of external loads in RT, studies were excluded if the experimental group received multimodal interventions involving additional exercise modalities (e.g., aerobic training, motor control exercises) or therapies (e.g., manual therapy).

For the Comparison group, only exercise interventions without any form of external resistance—hereafter referred to as unloaded exercises (UE)—were considered eligible. Eligible studies had to report on at least one of the primary Outcomes.

Only randomized controlled trials (RCTs) were included. Studies were excluded if they included individuals with specific LBP (e.g., fractures, radicular pain, radiculopathies, spinal stenosis, or axial spondylarthritis) or with a history of spinal surgery. Finally, while studies not available in English or Italian were excluded, no restrictions were applied regarding publication date or methodological quality.

Information sources and search strategy

Two independent reviewers (MR and DF) each developed and conducted a separate literature search, working in a blinded manner without any prior agreement on which databases to search. The search strategies were based on the previously defined PICO framework, although no terms were included for the Comparison component to reduce the risk of missing relevant studies.

As recommended by the Cochrane Handbook (28), three core electronic databases were searched: PubMed, Cochrane

Library, and EMBASE. Filters for “Randomized Controlled Trial” in PubMed and “Trial” in the Cochrane Library were applied to restrict the results to study types relevant to the review’s objective. To enhance comprehensiveness, two multidisciplinary databases (Scopus and Web of Science), a physical therapy-specific database (The Physiotherapy Evidence Database - PEDro) and gray literature sources (Google Scholar) were also queried.

The searches were first conducted in September 2022 and subsequently updated in October 2024 and March 2025. Full search strategies, including the specific databases, search terms, and filters used, are provided in ‘Appendix B’.

Finally, a planned citation search was also performed by screening the reference lists of previously published systematic reviews investigating the effects of exercise on LBP (11,12,25,27,30-35) to enhance the comprehensiveness of the search strategy.

Selection process

The search results were imported into Rayyan software (Online), where duplicate records were manually removed before screening (36).

Two independent reviewers (MR and DF) conducted a blinded, independent screening of titles and abstracts. Studies meeting the eligibility criteria at this stage were exported to an Excel file, and their full texts were retrieved. The reviewers then independently assessed the full texts in a blinded manner. Any discrepancies during the screening process were resolved through discussion between MR and DF or, if necessary, with the involvement of a third reviewer (AP). Inter-rater agreement was not calculated.

Data collection process and data items

Two independent reviewers (MR and DF) extracted data from each included study. To standardize the process, a structured synoptic Excel spreadsheet was developed, in line with the recommendations of the Cochrane Handbook of Systematic Reviews (28).

The extracted data included: (i) Study characteristics: lead author, publication year, sample size, duration, adverse events and follow-up. (ii) Population details: sex, age, height, weight, BMI, baseline pain, baseline disability, duration of symptoms and baseline level of activity. (iii) Intervention characteristics: exercise type and name, type of resistance, total duration of the intervention, weekly frequency, session duration, number of sets and repetitions, baseline and peak intensity and progression parameters. (iv) Outcomes: mean and standard deviations at every follow-up, as reported in the studies or, when not available, derived from other summary statistics using the conversion methods recommended in the Cochrane Handbook (28).

Outcome measures

Pain intensity and disability were the primary outcomes of the systematic review. Pain intensity was assessed based on the Visual Analog Scale (VAS) and Numeric Pain Rating Scale (NPRS), while disability was evaluated using the Oswestry Disability Index (ODI) and Roland and Morris Disability Questionnaire (RMDQ).

Secondary outcomes included measures of physical performance and psychosocial variables. For physical performance, eligible measures comprised back muscle endurance, as assessed by the Biering-Sørensen test (BST), and maximal strength, expressed in terms of muscle force (newtons, N) or joint torque (newton-meters, N·m). Psychosocial outcomes included fear-avoidance beliefs related to physical activity (Physical Activity subscale of the Fear-Avoidance Beliefs Questionnaire, FABQ-PA), kinesiophobia (Tampa Scale of Kinesiophobia, TSK) or pain catastrophizing (Pain Catastrophizing Scale, PCS). The FABQ-PA subscale was selected as a relevant measure of fear-avoidance beliefs due to its specific focus on movement and exercise (37), its established construct validity (37,38), and its documented association with disability and less favorable clinical outcomes in individuals with chronic NS-LBP (39,40).

Study risk of bias assessment and certainty of evidence grading

Two independent reviewers (MR and DF) conducted a blinded risk of bias assessment for each primary and secondary outcome using the revised version of the Cochrane Risk of Bias Assessment Tool (RoB2) (41). Risk-of-bias plots were generated using the Robvis tool (42). The Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) system was used to assess the certainty of evidence at each follow-up for each outcome. The grading process was conducted using ‘GRADEpro’ (43).

Effect measures

The effect size used for the meta-analysis was calculated as the standardized mean difference (SMD) with a 95% confidence interval (95%CI) for outcomes reported in non-convertible units or assessed using different rating instruments. When all studies employed the same measurement scale for a given outcome, the mean difference (MD) with a 95%CI was used instead. Pain intensity scores reported on 100-point scales were rescaled to 0–10, and BST times were converted from seconds to minutes to ensure comparability across studies.

To explore treatment effects within each study, we also calculated within-group changes using pre- and post-intervention data (SMDs with 95%CI), where available. In addition, we computed between-group differences at post-intervention using SMDs based on post-treatment means and standard deviations (SDs). These results are presented descriptively in ‘Appendix D’, along with indications of statistical significance, to facilitate interpretation of individual study findings.

Unit-of-analysis issues in trials with shared comparison groups were addressed by splitting the shared group’s sample size evenly, while retaining the original means, SDs, and participant counts, in accordance with the Cochrane Handbook guidelines (28).

Synthesis methods

To generalize the findings beyond the included studies, an unconditional inference model was employed. The restricted maximum likelihood estimation method (REML) was used to estimate between-study variance in the random-effects model. Post-intervention results were categorized based on the duration of the exercise program. ‘Short training programs’ (STP) were defined as those with follow-up data collected within 6 weeks or less, while ‘extended training programs’ (ETP) were defined as those with follow-up data collected after at least 7 weeks. This cutoff was based on evidence suggesting that programs lasting at least 7 weeks may be more effective for managing chronic pain (44). Additionally, results were analyzed, where applicable, at the final follow-up to assess long-term differences between loaded and unloaded interventions. For inclusion in the ‘Post-Washout’ (PW) follow-up analysis, data had to be collected at least 6 months after the study’s initiation, following a washout period (i.e., a treatment-free interval to minimize carryover effects). When multiple eligible follow-ups were reported, data from the most distant follow-up were used. Heterogeneity was assessed using Cochran’s Q test (χ^2), I^2 statistic, and tau^2. These metrics were reported descriptively, without applying fixed thresholds for interpretation. In addition, 95% prediction intervals (95%PI) were calculated and used as the primary indicator of the expected dispersion of true effects across comparable future settings (45,46). Meta-analyses were conducted using R version 4.2.3 for Mac OS (47), with the ‘meta’ package and its “metagen” function (48). The complete analysis output (RStudio report) is publicly available on the Open Science Framework (OSF) at Online.

Post-hoc sub-group and sensitivity analysis

To explore potential sources of heterogeneity in the primary outcomes, post hoc subgroup analyses were performed based on: (i) methodological quality, classified using the RoB2 tool as high or low risk of bias; (ii) baseline pain intensity, categorized according to the Pain Monitoring Model (49) as low (<2/10), acceptable (2–5/10), or high (>5/10); and (iii) the type of resistance used in the intervention, comparing programs using only external resistance versus those combining internal and external resistance. Results of these analyses are presented in ‘Appendix F’.

Sensitivity analyses were conducted to assess the robustness of the findings and to examine the influence of individual studies on overall estimates and heterogeneity. These analyses were performed only for meta-analyses that included data from at least five RCTs, to ensure sufficient statistical power and stable estimation of heterogeneity parameters (50). Following Viechtbauer (2010), a leave-one-out approach was applied, iteratively excluding each study from the model and assessing changes in the pooled effect size and heterogeneity parameters (I^2, tau^2, and Q) (50). A study was considered influential if its removal resulted in: (a) a substantial reduction in heterogeneity (≥25% reduction in tau^2 or I^2), or (b) a meaningful change in the direction or magnitude of the pooled effect. Studies meeting one or both of these criteria were excluded in subsequent analyses to evaluate whether they had a disproportionate impact on the overall results. This approach allowed for a cautious and transparent assessment of the stability of the conclusions in the presence of statistical heterogeneity.

Reporting bias assessment

Publication bias was assessed using contour-enhanced funnel plots, which illustrate the relationship between the size of the studies and effect sizes (51). For meta-analyses with at least 10 comparisons (52), Egger’s regression test was used as a quantitative measure of reporting bias. The “funnel.meta” and “metabias” (47) functions in RStudio (47) were used to evaluate the reporting bias.

Results

Registration and Protocol

The review protocol was registered in PROSPERO (CRD42022366975), but several amendments were made during the review process. Due to the limited number of available studies and incomplete reporting of intervention data, the planned meta-regression analyses, as specified in the original protocol, could not be performed. Consequently, modifications were made to both the title and statistical analyses in this manuscript.

Study selection

The search strategy identified a total of 1710 records, of which 1609 were retrieved from databases and 101 from citation search. After removing 555 duplicates using Rayyan, 1155 unique records remained. These were screened based on titles and abstracts, resulting in the exclusion of 1082 records for not meeting the inclusion criteria. Overall, 73 records were identified for retrieval. Of those, one (53) could not be retrieved despite attempts to contact the authors. The remaining 72 full-texts were screened for eligibility. Among them, 12 studies identified from database searches (54-65) and 3 from citation searching (66-68) met the eligibility criteria, totaling 15 papers included in the review (Fig. 1). However, Michaelson et al. (62) and Mannion et al. (68) reported supplementary data from the same participant samples described in Aasa et al. (54) and Mannion et al. (67), respectively. These reports were therefore integrated into the original studies, resulting in a final count of 13 unique RCTs included in the meta-analysis.

A total of 57 full-text articles were excluded following the eligibility assessment. Four records were excluded as they were conference abstracts (69–72). An additional four studies were excluded due to the absence of participant randomization; three were published studies (73-75), and one was an unpublished thesis (Costa K. Effects of a trunk strengthening program on pain perception, strength, and flexibility in patients with non-specific low back pain. Doctor of Physiotherapy thesis, Bond University; 2010. Online. Last accessed on 22/09/2025). Four studies were excluded because they enrolled participants with specific forms of LBP (76-79). Eighteen studies were excluded for failing to incorporate external resistance into their exercise protocols

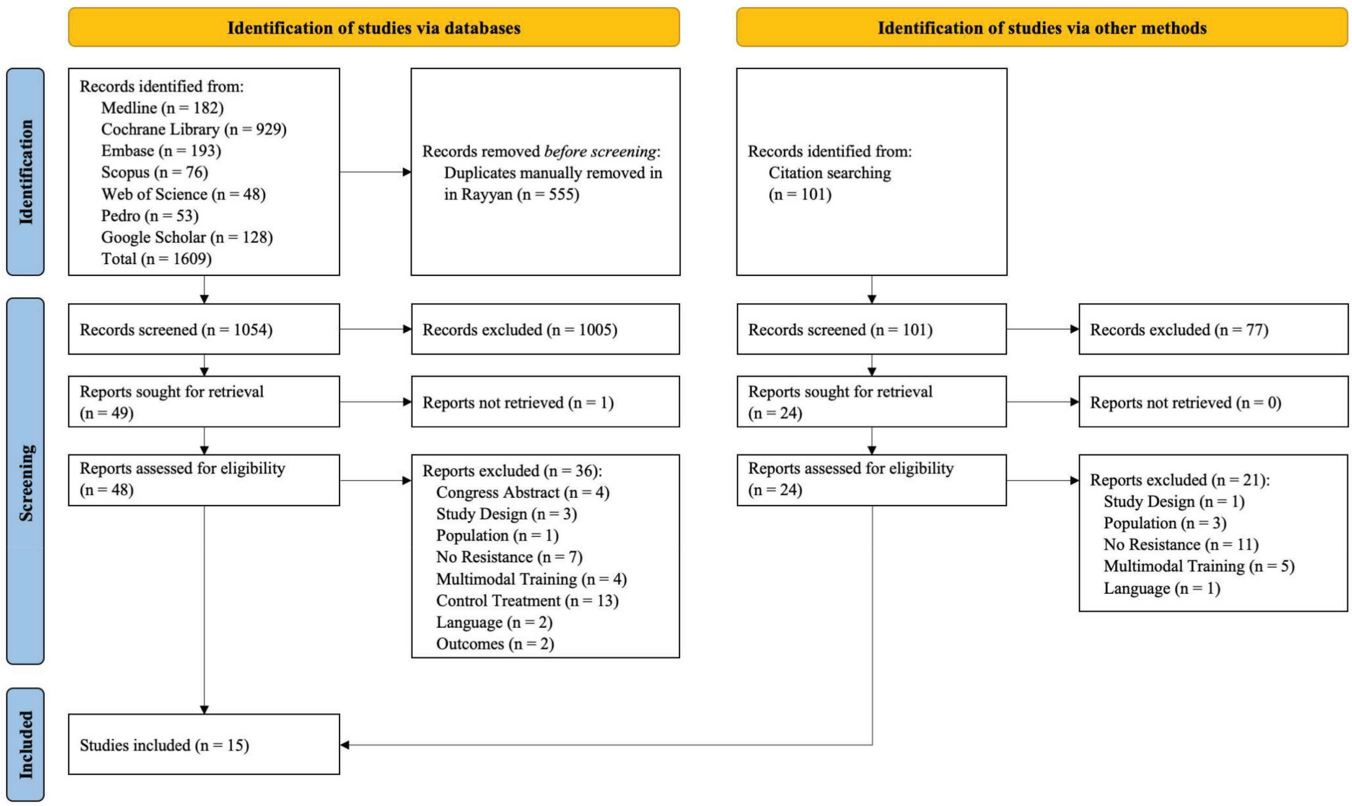

FIGURE 1 - Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) flow diagram of study selection.

(80-97), and nine were excluded because they did not isolate resistance training from other concurrent interventions (98-106). Thirteen studies were excluded for employing either passive control conditions or applying resistance training to both study groups (107-119). Finally, three studies were excluded due to language restrictions (120-122), and two were excluded because the outcomes assessed were not relevant to the review question (123-124).

Description of Study Populations

This systematic review included 13 studies published between 1999 and 2022 involving a total of 778 subjects with chronic NS-LBP. Among them, 395 individuals participated in an RT program incorporating external loads. Participants in the Resistance Training Group (RTG) had an average age of 39.3 years (range: 20.2-61.5 years) and a mean symptom duration of 3.96 years (range: 3.9 months to 13 years). The Unloaded Exercise Group (UEG) had a similar average age of 39.3 years (range: 20.8-57.2 years) and a mean symptom duration of 3.21 years (range: 4.1 months to 9.7 years). The average height and weight were 168.5 cm (range: 159-183 cm) and 74.4 kg (range: 61.7-88.4 kg), respectively, in the RTG, and 167.5 cm (range: 156-182 cm) and 72.3 kg (range: 60.3-86.2 kg), respectively, in the UEG. Perceived pain levels during activities averaged 5.4/10 (range: 2.9-8) in the RTG and 5.7/10 (range: 2.7-7.4) in the UEG. Gender distribution was reported in 10 of the 13 included RCTs. In RTG, 198 men (61.9%) and 122 women (38.1%) were enrolled, while in UEG, 218 men (64.1%) and 122 women (35.9%) were included. Detailed participants' characteristics are presented in Table 1.

Description of Exercise Interventions

Both RTG and UEG followed equivalent training periods and weekly frequencies. Training duration typically lasted for eight weeks, ranging from three (64) to sixteen weeks (59). Participants trained an average of three sessions per week, ranging from one (65) to seven sessions per week (66), including both supervised and unsupervised formats. The median number of sessions across studies was 12 (interquartile range: 12-16) and was comparable between groups.

Training intensity and Resistance modalities

The RTG program intensity was quantified using various metrics. Five studies used an estimated percentage of One Repetition Maximum (1RM) (54,55,58,59,66). One study employed repetition in reserve (RIR) (57). One study used an estimated percentage of maximal voluntary isometric contraction (66). Resistive modalities included: free weights (54,57,59,63,66), weight-stack machines (58,59, 63,65,67), elastic bands (55,56) and isokinetic machines (60,61,64). Seven studies used multi-joint exercises (54-57,59,63,66), while six targeted the lumbopelvic muscles (58,60,61,64, 65,67).

TABLE 1 - Characteristics of the included participants

Study	G	n	Male/ Female, n	Age, Years	Weight, Kg	Height, Cm	Baseline pain	Baseline Disability	Type of LBP	Adverse events*, n	Duration of Symptoms, Years
Aasa et al., (54)	RTG	35	15/20	42 ± 10	74 ± 13	174 ± 8	43 (0-100) ± 24	7 (0-24) ± 4	C	2 (related)	5.98 ± 5.96
	UEG	35	16/19	42 ± 11	78 ± 15	172 ± 10	47 (0-100) ± 28	7 (0-24) ± 5	C	0	6.52 ± 3.64
Cai et al., (66)	RTG (a)	28	14/14	28.9 ± 5.3	61.7 ± 12.6		3.5 (0-10) ± 1		C	1 (unrelated)	1.19 ± 0.67
	RTG (b)	28	14/14	26.1 ± 4.1	61.7 ± 10.8		3.4 (0-10) ± 0.9		C	1 (unrelated)	1.24 ± 0.63
	UEG	28	14/14	26.9 ± 6.4	60.3 ± 12.1		3.6 (0-10) ± 1.1		C	2 (unrelated)	1.32 ± 0.52
Calatayud et al., (55)	RTG	42		52 ± 11	76 ± 19	164 ± 10	6.2 (0-10) ± 2	4.3 (0-24) ± 2	C		
	UEG	43		50 ± 12	72 ± 14	165 ± 7	6.3 (0-10) ± 2	5.1 (0-24) ± 3	C		
Castro et al., (56)	RTG	12	0/12	61.5 ± 7.5	73.2 ± 13.3	159± 13	6.75 (0-10) ± nr	13.8 (0-24) ± nr	C		
	UEG	13	0/12	57.2 ± 10	67.3 ± 11	156 ± 7	6.1 (0-10) ± nr	13.2 (0-24) ± nr	C		
Gibbs et al. (57)	RTG	32	19/13	35.6 ± 12.4			5.6 (0-10) ± 2.1	18.8 (0-100) ± 7.8	C	1 (related)	4.42± 3.68
	UEG	32	17/15	33.5 ± 11.9			5.8 (0-10) ± 2.2	15.4 (0-100) ± 8.7	C	1 (related)	4.79 ± 5.62
Helmhout et al. (58)	RTG	71	69/3	37 ± 11	85 ± 12	183± 8		8.3 (0-24) ± 4.8	SA, C	1 (related)	
	UEG	56	54/2	35 ± 11	86 ± 11	182 ± 7		7.9 (0-24) ± 4.4	SA, C	0	
Kell et al., (59)	RTG	9	6/3	40.1 ± 8.7	88.4 ± 22.4	174 ± 8	5.4 (0-10) ± 0.9	40.4 (0-100) ± 2.4	C		2.29 (range 0.5 - 8)
	UEG	9	5/4	36.7 ± 8.9	81.7 ± 11.5	173 ± 10	5.1 (0-10) ± 0.8	39.8 (0-100) ± 2.3	C		2.29 (range 0.5 - 8)
Mannion et al., (67)	RTG	49	22/27	43.7 ± 10.1	70.3 ± 13.4	172 ± 9	4.2 (0-10) ± 1.8	8 (0-24) ± 5.1	C	0	13 ± 10
	UEG	50	23/27	45.2 ± 9.7	68 ± 12.3	170 ± 11	4.1 (0-10) ± 1.8	7.7 (0-24) ± 4.7	C	2 (related)	9.7 ± 9.1
Nambi et al., (60)	RTG	20	20/0	21.1 ± 1.4	66.8 ± 1.5	167 ± 14	7.2 (0-10) ± 0.4		C		0.325 ± 0.06
	UEG (a)	20	20/0	22.1 ± 1.3	66.8 ± 1.5	166 ± 15	7.3 (0-10) ± 0.3		C		0.35 ± 0.05

Study	G	n	Male/ Female, n	Age, Years	Weight, Kg	Height, Cm	Baseline pain	Baseline Disability	Type of LBP	Adverse events*, n	Duration of Symptoms, Years
	UEG (b)	20	20/0	21.4 ± 1.4	66.4 ± 1.4	165 ± 13	7.4 (0-10) ± 0.6		C		0.367 ± 0.06
Nambi et al., (61)	RTG	15	15/0	20.2 ± 1.6	65.6 ± 1.4	168 ± 14	7.3 (0-10) ± 0.5		C		0.342 ± 0.05
	UEG (a)	15	15/0	21.3 ± 1.2	66.2 ± 1.4	165 ± 18	7.1 (0-10) ± 0.6		C		0.342 ± 0.03
	UEG (b)	15	15/0	20.8 ± 1.6	65.5 ± 1.5	168 ± 15	7.3 (0-10) ± 0.6		C		0.358 ± 0.04
Santos et al., (63)	RTG (a)	14		49.1 ± 7.1	78.2 ± 17.8	161± 7	7 (0-10) ± 1.7	14.8 (0-24) ± 3.2	C		6.2 ± 5.4
	RTG (b)	15		43.3 ± 12.1	79.1 ± 12.4	163± 7	8 (0-10) ± 1.3	16.8 (0-24) ± 5	C		3.7 ± 2.4
	UEG	14		46.7 ± 15.3	86.2 ± 11.4	160 ± 6	6.53 (0-10) ± 1.2	16.1 (0-24) ± 5.4	C		5 ± 3.88
Sertpoyraz et al., (64)	RTG	20	4/16	38.8 ± 7.8			4.9 (0-10) ± 0.9	16.6 (0-100) ± 8.1	C		2.4 ± 2.1
	UEG	20	5/15	38.3 ± 7.4			5.4 (0-10) ± 1.3	18.8 (0-100) ± 7.8	C		3.8 ± 4.3
Smith et al., (65)	RTG (a)	16					30.1 (0-100) ± 17.2	39.2 (0-100) ± 14.7	C		
	RTG (b)	17					28.7 (0-100) ± 17.4	35.7 (0-100) ± 12.6	C		
	UEG	13					26.8 (0-100) ± 9	32.7 (0-100) ± 5.9	C		

Data are presented as Mean ± Standard Deviation (SD), unless otherwise stated.
* Total number of adverse events of any type. Parentheses indicate whether events were reported as "related" or "unrelated" to the intervention.
Legend: G = group; RTG = Resistance Training Group; UEG = Unloaded Exercise Group; n = number; Cm = centimeters; BMI = Body Mass Index; SA = Subacute; C = Chronic; nr = not reported;

Adverse events related to the exercise intervention

Reporting of adverse events was heterogeneous and predominantly descriptive. Overall, the RTG did not demonstrate a higher incidence of events compared with the UEG. Aasa et al. (54) and Helmhout et al. (58) each reported one withdrawal in the RTG due to symptom aggravation, with no corresponding events in the UEG. In contrast, Mannion et al. reported two dropouts in the UEG due to LBP flare-ups, with none in the RTG (67). Gibbs et al. observed one transient flare-up in each group, which was managed through temporary reduction of load or repetitions (57). Cai et al. documented three musculoskeletal injuries, equally distributed across groups and deemed unrelated to the training interventions (66). The remaining RCTs did not provide explicit information regarding adverse events associated with the interventions. Taken together, adverse events were infrequent, mild in nature, and evenly distributed between groups. The number of adverse events reported in each group is summarized in Table 1.

Progressive overload strategies

While studies using isokinetic machines (60,61,64) did not incorporate progressive overload, all other RT programs implemented progressive overload methods.

Aasa et al. (54), Helmhout et al. (58), and Smith et al. (65) increased the load by 2.5 kg or 5% when participants exceeded the target repetitions. Cai et al. (66) and Kell et al. (59) adjusted load based on planned 10RM reassessments.

Gibbs et al. (57) focused on progressing movement complexity for four weeks before increasing intensity to 1RM in the final week. Castro et al. (56) and Calatayud et al. (55) progressively increased elastic resistance every two weeks, starting from 20RM and reaching 10RM. Santos et al. (63) applied linear periodization, gradually increasing intensity while decreasing training volume. Further details on the training programs used in the RTG and the UEG are presented in 'Appendix C'.

Results of individual studies

The results of the individual studies categorized into STP, ETP and PW follow-ups, along with the calculated within-group improvements, are presented in Appendix D. Notably, none of the included studies reported post-intervention scores for kinesiophobia, and only one study (57) provided data on pain catastrophizing.

Short Training Program (STP) Follow-up

At the STP follow-up, improvements in pain intensity (59,60,61,63), disability (59,63), and muscle endurance (63) were generally greater in the RTG than in the UEG. Most studies reported within-group improvements in pain and disability, though gains in muscle endurance and strength were smaller. One UE program (63) demonstrated a significant improvement in VAS scores despite a slight decline in BST performance.

Extended Training Program (ETP) Follow-up

At the ETP follow-up, pain intensity (66,59,65) and disability (54,55,57-59) improved more in the RTG, whereas muscle endurance and strength showed similar changes in both groups. Calatayud et al. (55) reported a mean BST performance change of 44.39 seconds, although pain and disability improvements were only a minimal clinically important difference (MCID) (125). Gibbs et al. (57) found reductions in pain catastrophizing on the PCS (0-52) in both groups at post-intervention. RTG improved from 16.0± 10.3 to 8.5 ± 9.6. UEG improved from 18.0 ± 11.7 to 8.9 ± 8.5.

Post-Washout (PW) Follow-up

At the PW follow-ups, primary outcomes generally continued to improve. Aasa et al. (54) reported a slight worsening in pain intensity and disability, but muscle endurance and strength improved. Helmhout et al. (58) found that the UEG experienced a slight decline in maximal strength, with no change in disability at 8 and 14 months. Regarding PCS scores, Gibbs et al. (57) reported a slight increase in pain catastrophizing in both groups: RTG from 8.5 ± 9.6 to 9.8 ± 10.1. UEG from 8.9 ± 8.5 to 10.8 ± 10.5.

Between-Group Comparisons

Seven studies (54-58,64,66) found no significant differences between RTG and UEG after treatment. Five studies (59,60, 63-65) concluded that RT led to superior outcomes. Conversely, Nambi et al. (61) reported that UE was superior to RT.

Risk of bias in studies

The detailed ROB2 assessment is provided in Appendix E, including a summary and traffic light plots for each outcome. None of the ROB2 domains were rated as having a high risk of bias. However, five RCTs (58-60,65,66) were judged to have a high overall risk of bias due to the cumulative impact of multiple domains rated as "Some Concerns."

Primary outcomes meta-analyses

Data on pain intensity were reported in 12 RCTs, while data on disability were available from 10 RCTs. One study (56) was excluded from the quantitative synthesis due to the unavailability of summary statistics, despite attempts to contact the authors.

Pain intensity

At the STP follow-up (6 RCTs, n = 282), the MD was -0.48/10 (95%CI: [-1.15, 0.18]; p = 0.15), indicating no clear average between-group difference. The 95%PI (-3.25 to 2.44) suggests a wide range of possible effects, including the possibility of both meaningful pain reduction and no benefit. Heterogeneity statistics were $I^2 = 97\%$ and $tau^2 = 1.02$ (Fig. 2 – Forest Plot 1a). At ETP follow-up (7 RCTs, n = 474), the pooled MD was −0.52/10 (95%CI: [−0.92, −0.08]; p = 0.022), suggesting a small average reduction in pain favoring RTG. The 95%PI (–1.88-0.83) includes the null, indicating that future studies may still find no effect in some settings. Heterogeneity statistics were $I^2 = 67\%$ and $tau^2 = 0.28$ (Fig. 2 – Forest Plot 1b). At PW follow-up (5 RCTs, n = 345), the pooled MD was −0.36/10 (95%CI: [−1.18, 0.47]; p = 0.40), again showing no clear average difference. The 95%PI (–3.25-2.54) indicates a broad distribution of possible effects across studies, consistent with the variability captured by I^2 = 97% and tau^2 = 1.09 (Fig. 2 – Forest Plot 1c).

Disability

At STP follow-up (3 RCTs, n = 206), the pooled SMD was −2.04 (95%CI: [−3.92, −0.16]; p = 0.033), suggesting a large average reduction in disability favoring the RTG. The 95%PI (−4.43-0.35) indicates that future studies could observe effects ranging from very large improvements favoring the RTG to moderate effects favoring the UEG. Heterogeneity statistics were I^2 = 93% and tau^2 = 4.18 (Fig. 2 – Forest Plot 2a). At the ETP follow-up (7 RCTs, n = 505), the pooled SMD was –0.40 (95%CI: [-1.00, 0.20]; p = 0.19), indicating that the average improvement in disability was similar between groups. The 95%PI (–1.68-0.88) suggests that future studies may find results ranging from large improvements favoring either the RTG or the UEG. Heterogeneity statistics were I^2 = 82% and tau^2 = 0.63 (Fig. 2 – Forest Plot 2b). At the PW follow-up (4 RCTs, n = 331), the pooled SMD was 0.06 (95%CI: [−0.16, 0.28]; p = 0.59), suggesting that the degree of improvement in disability was comparable between groups. The 95%PI (–0.43 to 0.55) indicates that future studies are likely to observe small to moderate effects in either direction. Heterogeneity statistics were I^2 = 0% and tau^2 = 0 (Fig. 2 – Forest Plot 2c).

Post hoc Subgroup Analyses

Subgroup effects were observed only in the STP meta-analysis for disability, where greater treatment effects

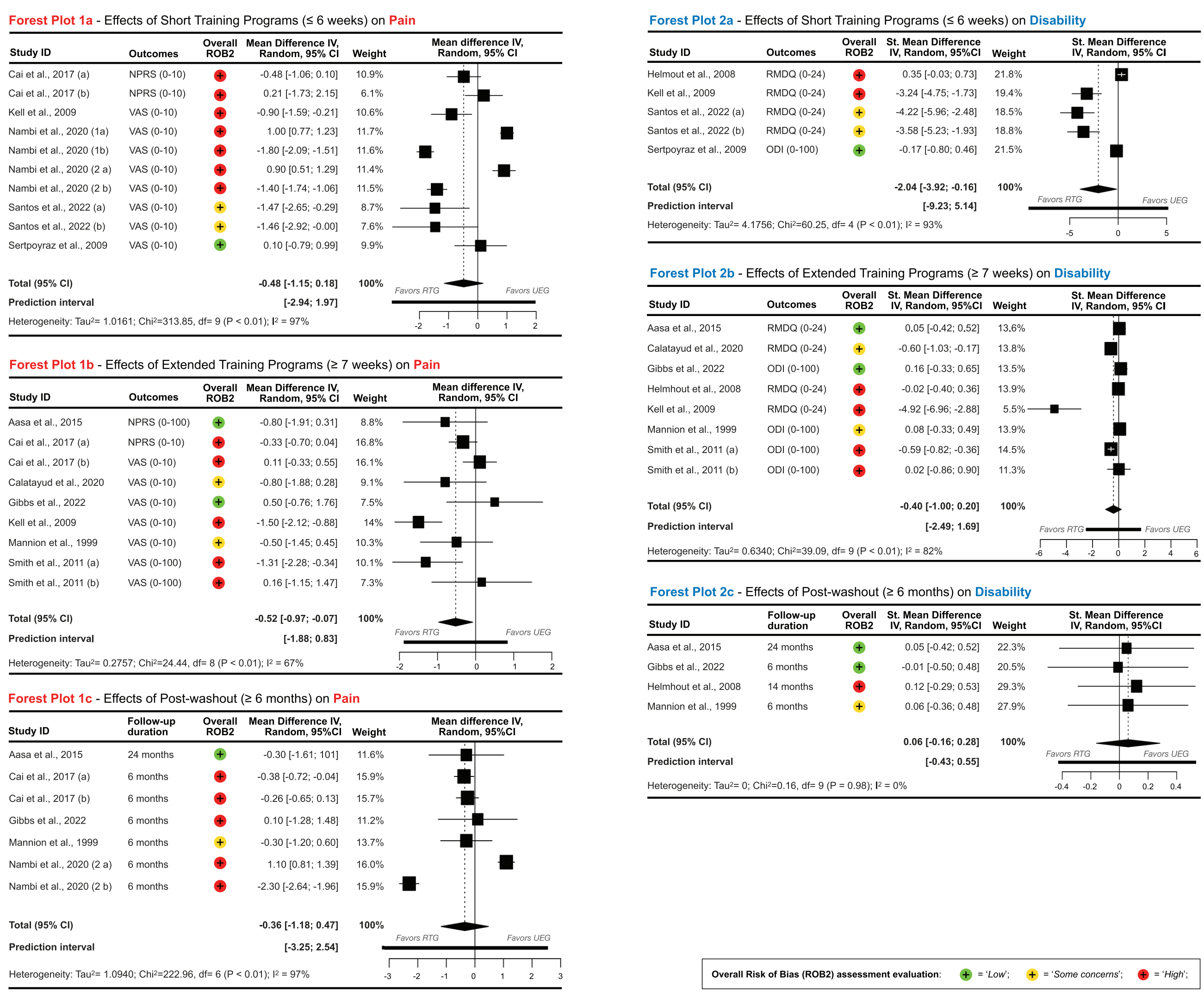

FIGURE 2 - Primary Outcomes Forest Plots: Effects of Loaded and Unloaded Exercise on Pain and Disability .
ROB2: Risk of Bias Tool 2; CI: Confidence Interval; PI: Prediction Interval; LL: Lower Limit; UL: Upper Limit; IV: Inverse Variance; W: Weight; MD: Mean Difference; SMD: Standardized Mean Difference; VAS: Visual Analog Scale; ODI: Oswestry Disability Index; RMDQ: Roland and Morris Disability Questionnaire; RTG: Resistance Training Group; UEG: Unloaded Exercise group

were found among participants with high baseline pain ($Q = 59.55$; $df = 2$; $p < 0.0001$), and in interventions combining internal and external resistance ($Q = 49.02$; $df = 1$; $p < 0.0001$). Full subgroup results are reported in Appendix F.

Sensitivity analyses were performed only for pain STP, ETP and PW follow-ups and the disability ETP follow-up, as these were the only meta-analyses including data from more than five RCTs. In the pain STP analysis, the studies by Nambi et al. (60,61) were identified as influential, as their exclusion resulted in a statistically significant pooled effect (MD = −0.53/10; 95%CI: [−1.06, −0.05]; p = 0.0478) and a marked reduction in heterogeneity statistics ($I^2 = 58\%$, $tau^2 = 0.24$). At the PW follow-up, Nambi et al. (61) were again identified as influential due to the reduction of the I^2 and tau^2 statistics to zero and the emergence of a significant pooled effect (MD = −0.31/10; 95%CI: [−0.55, −0.07]; p = 0.01). The study by Kell et al. (59) was influential in both the ETP pain and disability analysis. In the pain ETP analysis, its exclusion reduced tau^2 from 0.276 to 0.091 and I^2 from 67.3% to 37.8%, and the pooled effect became non-significant (MD = −0.33/10; 95% CI: [−0.69, 0.02]; p = 0.687). In the disability ETP follow-up, tau^2 dropped from 0.634 to 0.081 and I^2 from 82.1% to 68.9%, although the effect direction and significance remained unchanged (SMD = −0.169; 95%CI: [−0.44, 0.10]; p = 0.223). These findings suggest that the identified trials contributed disproportionately to between-study heterogeneity and, in some cases, to the statistical significance of the pooled effects.

Secondary outcomes meta-analyses

Although meta-analyses were planned for all secondary outcomes, pooling for the PCS was not feasible, as data were available from only one study (57). Consequently, quantitative syntheses were conducted only for back muscle endurance (4 RCTs), maximal strength (3 RCTs), and FABQ-PA (2 RCTs).

Back Muscle Endurance

At STP follow-up (2 RCTs, n = 56), the pooled MD was 0.50 minutes (95%CI: [0.26, 0.74]; $p < 0.001$), indicating a statistically significant improvement in the performance of the BST, favoring the RTG. The 95%PI (–1.80 to 2.80) suggests that future studies could observe large effects favoring either treatment. Heterogeneity statistics were $I^2 = 38\%$ and $tau^2 = 0.018$ (Fig. 3 – Forest Plot 3a). At ETP follow-up (3 RCTs, n = 173), the pooled MD was 0.47 minutes (95%CI: [0.09, 0.85]; p = 0.015), again indicating a statistically significant improvement in the BST performance favoring the RTG. The very wide 95%PI (–3.80 to 4.73) reflects the considerable uncertainty about the generalizability of the pooled effect. Heterogeneity statistics were $I^2 = 69\%$ and $tau^2 = 0.075$ (Fig. 3 – Forest Plot 3b). At PW follow-up, Aasa et al. (54) also reported a significant effect on the BST favoring the RTG (MD = 0.35 minutes; 95%CI: [0.03, 0.67]).

Maximal strength

At STP follow-up (2 RCTs, n = 150), the pooled SMD was 0.00 (95%CI: [–0.30, 0.30]; p = 0.998), indicating that the average change in maximal strength was similar between the RTG and UEG. The 95%PI (–1.96-1.96) suggests that future studies may observe large effects on maximal strength, favoring either the RTG or the UEG. Heterogeneity statistics were $I^2 = 0\%$ and $tau^2 = 0$ (Fig. 3 – Forest Plot 4a). At the ETP follow-up (2 RCTs, n = 176), the pooled SMD was 0.22 (95%CI: [–0.70, 0.26]; p = 0.38), again suggesting that average changes were comparable between RTG and UEG. Heterogeneity statistics were $I^2 = 20\%$ and $tau^2 = 0.033$ (Fig. 3 – Forest Plot 4b). At PW follow-up (2 RCTs, n = 176), the pooled SMD was 0.40 (95%CI: [0.08, 0.71]; p = 0.013), suggesting a moderate and statistically significant effect favoring the RTG. Heterogeneity statistics were $I^2 = 0\%$ and $tau^2 = 0.0$ (Fig. 3 – Forest Plot 4c). The 95%PI was not calculated for ETP and PW due to the limited number of comparisons included.

Fear-avoidance beliefs related to physical activity

At ETP follow-up (2 RCTs, 2 comparisons), the pooled MD was –0.09/24 (95%CI: [–0.88, 0.71]; p = 0.82), indicating that average FABQ-PA scores were similar between RTG and UEG. Heterogeneity statistics were $I^2 = 0\%$ and $tau^2 = 0$ (Fig. 3 – Forest Plot 5a).

At PW follow-up (2 RCTs, 2 comparisons), the pooled MD was –0.24/24 (95%CI: [–1.58, 1.09]; p = 0.72), again suggesting no clear difference in FABQ-PA scores between groups. Heterogeneity statistics were $I^2 = 0\%$ and $tau^2 = 0$ (Fig. 3 – Forest Plot 5b). The 95%PI could not be estimated at either follow-up due to the restricted number of comparisons available.

Reporting biases

Reporting bias was assessed using funnel plots (Appendix G). The plots showed no significant signs of bias (126). Due to the limited number of comparisons, Egger's test was applied only to the STP meta-analysis for pain, yielding an intercept of 0.20 (t = –0.57, p = 0.58), suggesting no funnel plot asymmetry.

Quality of the evidence (GRADE Assessment)

The overall certainty of the evidence for primary outcomes was rated as 'very low', due to methodological limitations and inconsistency across studies. For back muscle endurance, certainty was rated "moderate" at both STP and ETP follow-ups, suggesting probable benefits of externally loaded resistance training over unloaded interventions. At the PW follow-up, the certainty decreased to "very low" due to the limited number of trials and imprecision. For maximal strength, the certainty was consistently rated "low" across all follow-ups, primarily due to the small number of included studies and risk of bias. For fear-avoidance beliefs related to physical activity, the evidence was judged as "low" certainty at both ETP and PW timepoints, reflecting imprecision and methodological concerns. For pain catastrophizing, certainty was rated as "very low" at both time points, as only one study provided data, limiting confidence in the estimate. A detailed evidence quality assessment is provided in Appendix H.

Discussion

Main findings

This systematic review evaluated current evidence on the effectiveness of RT interventions involving external loads in

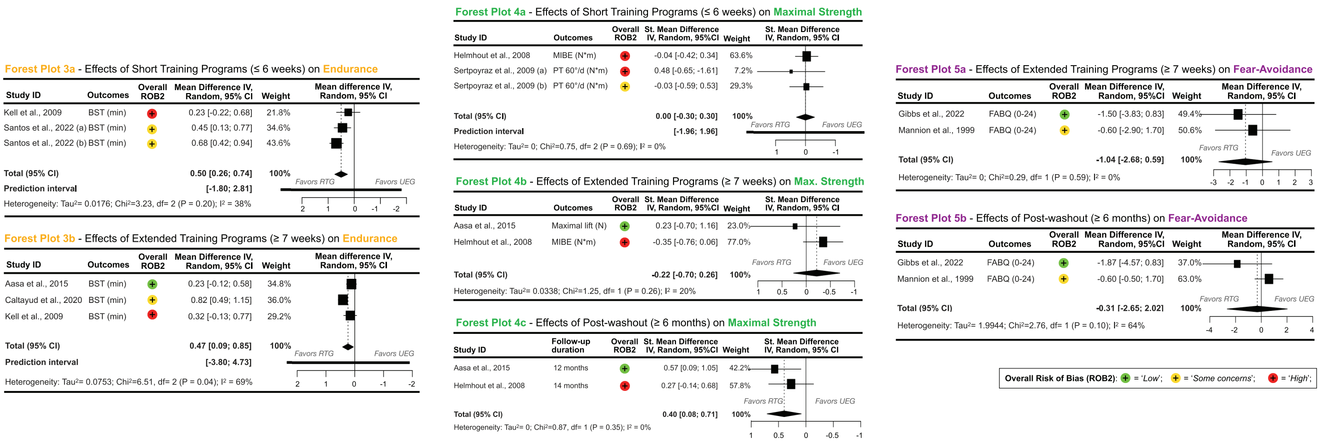

FIGURE 3 - Secondary Outcomes Forest Plots: Effects of Loaded and Unloaded Exercise on Muscle Endurance, Maximal Strength and Fear-Avoidance Beliefs related to Physical Activity.
ROB2: Risk of Bias Tool 2; CI: Confidence Interval; PI: Prediction Interval; LL: Lower Limit; UL: Upper Limit; IV: Inverse Variance; W: Weight; MD: Mean Difference; SMD: Standardized Mean Difference; BST: Biering-Sørensen Test; MIBE: Maximal Isometric Back Extension; PT: Peak Torque; n: newton; nm: newton meters; RTG: Resistance Training Group; UEG: Unloaded Exercise group.

the management of chronic NS-LBP. Thirteen studies were included, comprising 395 participants enrolled in exercise programs utilizing various external load modalities such as free weights, elastic bands, weight stack machines, and isokinetic devices.

Across studies, both RTG and UEG were associated with reductions in pain intensity and disability, but between-group differences were generally modest and inconsistent across follow-ups. At ETP follow-up, the RTG showed a small but statistically significant advantage over the UEG in improving pain intensity (MD = –0.52/10; 95%CI: [–0.92, –0.08]). However, the magnitude of this effect did not exceed the MCID (125), questioning its clinical relevance. For disability, only the STP meta-analysis indicated superiority of the RTG (SMD = −2.04; 95%CI: [−3.92, −0.16]), though this estimate was accompanied by very high inconsistency and was strongly influenced by small-sample trials. Importantly, the 95% PI for both outcomes was wide at every follow-up, suggesting that in future comparable settings, true effects may range from clinically meaningful benefit to no added value of external load. Taken together, these findings indicate that even when significant, the average between-group differences remain small, and the variability across contexts makes strong generalizations premature.

For secondary outcomes, signals in favor of RTG were observed for physical performance measures, although these results should be interpreted cautiously. Back muscle endurance improved more consistently with RTG, with significant effects reported at both STP (MD = 0.50 min; 95%CI: [0.26, 0.74]) and ETP (MD = 0.47 min; 95%CI: [0.09, 0.85]).

The very wide 95%PI calculated for these analyses largely reflects the small number of contributing RCTs. At PW, one trial (54) showed maintenance of these benefits (MD = 0.35 min; 95%CI: [0.03, 0.67]) one year after baseline. For maximal strength, the effects of RT became significant only at PW follow-up (SMD = 0.40; 95%CI: [0.08, 0.71]), potentially reflecting a delayed recovery of physical capacity consistent with the Fitness-Fatigue model (127). Yet, for both ETP and PW follow-ups, 95%PI could not be calculated due to the limited number of comparisons.

In contrast, psychosocial variables were rarely reported. Two RCTs assessed the FABQ-PA (57,67) and only one the PCS (57), without showing any clear between-group difference. The underreporting of psychosocial outcomes likely reflects the historical dominance of biomechanical perspectives in LBP research (5,6). This narrow emphasis limits our ability to determine to what extent training variables, such as load, exert effects beyond neuromuscular adaptations.

Interpretations and Clinical Implications

This meta-analysis examined whether adding external load to RT could enhance the effectiveness of exercise-based treatment for chronic NS-LBP, compared to unloaded approaches. While our findings suggest that external loads may promote measurable neuromuscular adaptations, these benefits do not consistently translate into superior outcomes in pain or disability, nor into clear advantages on psychosocial variables such as fear-avoidance or catastrophizing.

This dissociation reinforces the notion that improvements in physical capacity alone are not sufficient, on their own, to drive meaningful change in chronic NS-LBP—a condition shaped by complex and interacting biological, psychological, and social processes (5,6). The modest and inconsistent effects observed here are in line with accumulating evidence that challenges the assumption of a linear relationship between biomechanical gain and symptom relief (24,128).

Rather than being determined by tissue status or physical capacity, changes in pain and disability may often reflect modifications in pain-related beliefs, behaviors, and emotional responses (129). Although external load may serve as a means of graded exposure or a catalyst for behavioral re-signification (130,131), current data suggest that its effectiveness is not inherently superior. Simply increasing load, without integrating a therapeutic narrative, may be insufficient to influence the multidimensional experience of pain (132,133). It is probable that its effectiveness depends on being embedded within a broader psychological or contextual framework.

From a clinical perspective, this implies that the value of load should be seen less as a mechanical input, but as a potential behavioral signal—the meaning of which depends on patient interpretation, context, and clinical communication (133). In this sense, the delivery and contextual framing of exercise may be more impactful than its intensity or volume.

Given the current heterogeneity in exercise protocols and outcomes, and the limited added value associated with higher intensities, we believe that providing specific dosage prescriptions (e.g., frequency, sets, repetitions) falls beyond the scope of this meta-analysis. However, our subgroup analyses also suggest that exposure consistency and volume, rather than training intensity, may play a more central role in symptom modulation (134). This supports growing interest in low-intensity, high-frequency strategies, such as "exercise snacks," which may provide similar benefits while enhancing adherence, reducing perceived threat, and improving safety (135).

Ultimately, load can be a useful tool—but not a universally necessary one. Its clinical relevance depends on how it is integrated into a person-centred, biopsychosocial framework that acknowledges not only tissue adaptation, but also individual experience, meaning, and the therapeutic alliance.

Study limitations

While interpreting the findings of this review, several limitations should be considered.

The search and selection strategy introduced some limitations. Restricting eligibility to studies published in English and Italian may have introduced language bias, potentially excluding relevant evidence in other languages. The use of an RCT filter increased the specificity of the search but may also have reduced its sensitivity, with the risk of omitting relevant trials. Notably, no eligible studies published between 2022 and March 2025 were identified. However, similar or even longer publication gaps had occurred in earlier periods, suggesting that this pattern was more likely related to the specificity of the inclusion criteria. In addition, although independent screening was conducted by two reviewers, inter-rater agreement was not formally calculated, which is acknowledged as a methodological limitation of the study selection process.

The characteristics of the included populations also limit the generalizability of the findings. The age range of included participants (20.2 to 52 years) limits the applicability of these results to younger and older individuals with chronic NS-LBP. In addition, sex distribution was imbalanced, with men comprising the majority of participants (62–64% across groups). This imbalance may in part reflect the specific populations investigated in certain trials rather than systematic recruitment bias: for instance, Helmhout et al. (58) enrolled military personnel, and Nambi et al. (60,61) studied male soccer players—both predominantly male populations. While this contextualizes the skewed sex distribution, it nonetheless constrains the transferability of our findings, particularly to women with chronic NS-LBP.

Considerable clinical and methodological heterogeneity was observed across studies, particularly in terms of exercise type, loading modalities, intensity, progression strategies, and baseline symptom severity. This variability, together with the lack of standardized intervention protocols, may have influenced treatment effects and contributed to statistical inconsistency. In addition, although available data suggest a favorable safety profile for externally loaded RT, with event rates comparable to unloaded exercise and mostly mild, transient adverse events, harm reporting was inconsistent and largely descriptive, preventing reliable estimation of event incidence.

Additionally, psychosocial variables such as fear-avoidance, catastrophizing, and kinesiophobia were rarely reported, limiting insights into the cognitive-affective impact of externally loaded exercise. Lastly, subgroup and sensitivity analyses were conducted post hoc and were not based on predefined hypotheses; thus, their findings should be interpreted with caution. Finally, some deviations from the original protocol, including the omission of planned meta-regression analyses due to insufficient data, limited the possibility of exploring potential dose–response relationships.

Implications for future research

To better support person-centered care, future research should investigate how RT variables interact not only with physical adaptations but also with psychological and behavioral responses. It remains unclear whether higher training loads confer meaningful benefits beyond strength gains, particularly when not embedded within a therapeutic narrative that addresses pain-related fear or perceptions of fragility. Similarly, increased exercise variety or task complexity may act as a form of graded exposure, helping to reshape pain-related beliefs and improve self-efficacy, rather than solely enhancing motor control. Total RT volume—including frequency, intensity, and duration—should be examined in relation to adherence, perceived safety, and emotional responses, not merely physiological outcomes. Future trials should incorporate validated psychosocial variables to clarify how exercise influences the full spectrum of pain experience and whether individualized interventions can optimize outcomes through mechanisms beyond tissue-level adaptations.

Conclusion

This review highlights that both loaded and unloaded resistance training can lead to reductions in pain and disability among individuals with chronic NS-LBP, although the magnitude and consistency of these effects remain modest. Notably, symptom improvement does not appear to be solely dependent on load intensity. While high-load RT (85-100% 1RM) may be safe and effective when appropriately progressed—even in individuals with elevated pain levels—clinical outcomes likely depend more on how exercise is structured, delivered, and interpreted than on mechanical intensity alone. Variables such as total training volume, consistency of exposure, and therapeutic framing may play a more substantial role in driving meaningful improvements. From a biopsychosocial perspective, exercise should not be prescribed merely to restore physical capacity, but also as a behavioral intervention aimed at challenging maladaptive beliefs, reducing fear, and fostering movement confidence. Accordingly, exercise programs should be individualized, progressive, and tailored to the patients' needs. Clinicians may consider incorporating both internal and external resistance, along with multi-joint exercises and adequate variation, in order to promote neuromuscular adaptation, enhance psychological engagement, and support long-term adherence.

Declaration of generative AI in scientific writing

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, version GPT-4o) for language editing and improving the clarity of some sections. The tool was used solely to improve readability and language clarity. All outputs were reviewed, and the authors take full responsibility for the final content.

Disclosures

Conflict of interest: The authors declare that they have no conflicts of interest.

Financial support: No funding was awarded for this project.

Data availability statement: All data extracted and analyzed in this systematic review are provided in the appendices of this manuscript. Their inclusion ensures transparency and facilitates the reproducibility of our findings. Additional information can be obtained by contacting the corresponding author.

Ethical compliance: Ethical approval was not required for this study, as it involved the collection and synthesis of data from previously conducted clinical trials in which informed consent had already been obtained by the original investigators.

Author contribution role: All authors contributed equally to the conceptualization and study methodology. MR and DF played equal roles in the data collection and curation. MR conducted the analyses. MR, DR and AP worked on data interpretation and drafted the manuscript. MR edited the manuscript, and MT reviewed the manuscript.

Reference

1. GBD 2021 Low Back Pain Collaborators. Global, regional, and national burden of low back pain, 1990-2020, its attributable risk factors, and projection to 2050: a systematic analysis of the Global Burden of Disease Study 2021. Lancet Rheumatol 2023;22;5(6):e316-e329. CrossRef
2. Hartvigsen J, Hancock MJ, Kongsted A, et al.; Lancet Low Back Pain Series Working Group. What low back pain is and why we need to pay attention. Lancet. 2018;391(10137):2356-2367. CrossRef PubMed
3. Maher C, Underwood M, Buchbinder R. Non-specific low back pain. Lancet. 2017;389(10070):736-747. CrossRef PubMed
4. Wu A, March L, Zheng X, et al. Global low back pain prevalence and years lived with disability from 1990 to 2017: estimates from the Global Burden of Disease Study 2017. Ann Transl Med. 2020;8(6):299. CrossRef PubMed
5. Smith BE, Hendrick P, Bateman M, et al. Musculoskeletal pain and exercise-challenging existing paradigms and introducing new. Br J Sports Med. 2019;53(14):907-912. CrossRef PubMed
6. Bunzli S, Smith A, Schütze R, et al. Making sense of low back pain and pain-related fear. J Orthop Sports Phys Ther. 2017;47(9):628-636. CrossRef PubMed
7. National Institute for Health and Care Excellence. Low back pain and sciatica in over 16s: assessment and management. NICE Clinical Guideline 59. 2016 (updated December 2020). Online (Accessed April 2025)
8. Liu R, Menhas R, Saqib ZA. Does physical activity influence health behavior, mental health, and psychological resilience under the moderating role of quality of life? Front Psychol. 2024;15:1349880. CrossRef PubMed
9. Jadhakhan F, Sobeih R, Falla D. Effects of exercise/physical activity on fear of movement in people with spine-related pain: a systematic review. Front Psychol. 2023;14:1213199. CrossRef PubMed
10. Marshall PWM, Schabrun S, Knox MF. Physical activity and the mediating effect of fear, depression, anxiety, and catastrophizing on pain related disability in people with chronic low back pain. PLoS One. 2017;12(7):e0180788. CrossRef PubMed
11. Owen PJ, Miller CT, Mundell NL, et al. Which specific modes of exercise training are most effective for treating low back pain? Network meta-analysis. Br J Sports Med. 2020;54(21):1279-1287. CrossRef PubMed
12. Searle A, Spink M, Ho A, et al. Exercise interventions for the treatment of chronic low back pain: a systematic review and meta-analysis of randomized controlled trials. Clin Rehabil. 2015;29(12):1155-1167. CrossRef PubMed
13. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc. 2004;36(4):674-688. CrossRef PubMed
14. Ogawa M, Hashimoto Y, Mochizuki Y, et al. Effects of free weight and body mass-based resistance training on thigh muscle size, strength and intramuscular fat in healthy young and middle-aged individuals. Exp Physiol. 2023;108(7):975-985. CrossRef PubMed
15. Herold F, Müller P, Gronwald T, et al. Dose-response matters! – A perspective on the exercise prescription in exercise – cognition research. Front Psychol. 2019;10:2338. CrossRef PubMed
16. Hansford HJ, Wewege MA, Cashin AG, et al. If exercise is medicine, why don't we know the dose? An overview of systematic reviews assessing reporting quality of exercise interventions in health and disease. Br J Sports Med. 2022;56(12):692-700. CrossRef PubMed
17. Fernández-Rodríguez R, Álvarez-Bueno C, Cavero-Redondo I, et al. Best exercise options for reducing pain and disability in adults with chronic low back pain: pilates, strength, core-based, and mind-body. A network meta-analysis. J Orthop Sports Phys Ther. 2022;52(8):505-521. CrossRef PubMed
18. Schoenfeld BJ, Grgic J, Ogborn D, et al. Strength and hypertrophy adaptations between low- vs. high-load resistance training: a systematic review and meta-analysis. J Strength Cond Res. 2017;31(12):3508-3523. CrossRef PubMed
19. Weakley J, Schoenfeld BJ, Ljungberg J, et al. Physiological responses and adaptations to lower load resistance training: implications for health and performance. Sports Med Open. 2023;9(1):28. CrossRef PubMed
20. Cook JL, Docking SI. "Rehabilitation will increase the 'capacity' of your …insert musculoskeletal tissue here…." Defining 'tissue capacity': a core concept for clinicians. Br J Sports Med. 2015;49(23):1484-1485. CrossRef PubMed
21. Maestroni L, Read P, Bishop C, et al. The benefits of strength training on musculoskeletal system health: practical applications

for interdisciplinary care. Sports Med. 2020;50(8):1431-1450. CrossRef PubMed
22. Pacheco-Barrios K, Carolyna Gianlorenço A, Machado R, et al. Exercise-induced pain threshold modulation in healthy subjects: a systematic review and meta-analysis. Princ Pract Clin Res. 2020;6(3):11-28. CrossRef PubMed
23. Westcott WL. Resistance training is medicine: effects of strength training on health. Curr Sports Med Rep. 2012;11(4):209-216. CrossRef PubMed
24. Vlaeyen JW, de Jong J, Geilen M, et al. Graded exposure in vivo in the treatment of pain-related fear: a replicated single-case experimental design in four patients with chronic low back pain. Behav Res Ther. 2001;39(2):151-166. CrossRef PubMed
25. Steiger F, Wirth B, de Bruin ED, et al. Is a positive clinical outcome after exercise therapy for chronic non-specific low back pain contingent upon a corresponding improvement in the targeted aspect(s) of performance? A systematic review. Eur Spine J. 2012;21(4):575-598. CrossRef PubMed
26. Steele J, Fisher J, Perrin C, et al. Does change in isolated lumbar extensor muscle function correlate with good clinical outcome? A secondary analysis of data on change in isolated lumbar extension strength, pain, and disability in chronic low back pain. Disabil Rehabil. 2019;41(11):1287-1295. CrossRef PubMed
27. Tataryn N, Simas V, Catterall T, et al. Posterior-chain resistance training compared to general exercise and walking programmes for the treatment of chronic low back pain in the general population: a systematic review and meta-analysis. Sports Med Open. 2021;7(1):17. CrossRef PubMed
28. Higgins JPT, Thomas J, Chandler J, et al. eds. Cochrane Handbook for Systematic Reviews of Interventions version 6.5 (updated August 2024). Cochrane, 2024. Online (Accessed April 2025)
29. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372(71):n71. CrossRef PubMed
30. Chang WD, Lin HY, Lai PT. Core strength training for patients with chronic low back pain. J Phys Ther Sci. 2015;27(3):619-622. CrossRef PubMed
31. Ishak NA, Zahari Z, Justine M. Effectiveness of strengthening exercises for the elderly with low back pain to improve symptoms and functions: a systematic review. Scientifica (Cairo). 2016;2016:3230427. CrossRef PubMed
32. Mayer J, Mooney V, Dagenais S. Evidence-informed management of chronic low back pain with lumbar extensor strengthening exercises. Spine J. 2008;8(1):96-113. CrossRef PubMed
33. Smith BE, Littlewood C, May S. An update of stabilization exercises for low back pain: a systematic review with meta-analysis. BMC Musculoskelet Disord. 2014;15(1):416. CrossRef PubMed
34. Steele J, Bruce-Low S, Smith D. A review of the clinical value of isolated lumbar extension resistance training for chronic low back pain. PM R. 2015;7(2):169-187. CrossRef PubMed
35. Wewege MA, Booth J, Parmenter BJ. Aerobic vs. resistance exercise for chronic non-specific low back pain: A systematic review and meta-analysis. J Back Musculoskelet Rehabil. 2018;31(5):889-899. CrossRef PubMed
36. Ouzzani M, Hammady H, Fedorowicz Z, et al. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210. CrossRef PubMed
37. Waddell G, Newton M, Henderson I, et al. A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability. Pain. 1993;52(2):157-168. CrossRef PubMed
38. Calley DQ, Jackson S, Collins H, et al. Identifying patient fear-avoidance beliefs by physical therapists managing patients with low back pain. J Orthop Sports Phys Ther. 2010;40(12):774-783. CrossRef PubMed
39. Trinderup JS, Fisker A, Juhl CB, et al. Fear avoidance beliefs as a predictor for long-term sick leave, disability and pain in patients with chronic low back pain. BMC Musculoskelet Disord. 2018;19(1):431. CrossRef PubMed
40. Osuka S, Koshino Y, Watanabe K, et al. Fear-avoidance beliefs associated with non-specific chronic low back pain in college athletes. J Pain Res. 2024;17:285-292. CrossRef PubMed
41. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomized trials. BMJ. 2019;366:l4898. CrossRef PubMed
42. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and shiny web app for visualizing risk-of-bias assessments. Res Synth Methods. 2021;12(1):55-61. CrossRef PubMed
43. GRADEpro GDT: GRADEpro Guideline Development Tool [Software]. McMaster University and Evidence Prime, 2023. Online (Accessed April 2025)
44. De la Corte-Rodriguez H, Roman-Belmonte JM, Resino-Luis C, et al. The role of physical exercise in chronic musculoskeletal pain: best medicine-a narrative review. Healthcare (Basel). 2024;12(2):242. CrossRef PubMed
45. Rücker G, Schwarzer G, Carpenter JR, et al. Undue reliance on I(2) in assessing heterogeneity may mislead. BMC Med Res Methodol. 2008;8(1):79. CrossRef PubMed
46. Riley RD, Higgins JP, Deeks JJ. Interpretation of random effects meta-analyses. BMJ. 2011;342(feb10 2):d549. CrossRef PubMed
47. R Core Team. (2022). R: A Language and Environment for Statistical Computing (Version 4.2.0) [Computer software]
48. Balduzzi S, Rücker G, Schwarzer G. How to perform a meta-analysis with R: a practical tutorial. Evid Based Ment Health. 2019;22(4):153-160. CrossRef PubMed
49. Silbernagel KG, Thomeé R, Eriksson BI, et al. Continued sports activity, using a pain-monitoring model, during rehabilitation in patients with Achilles tendinopathy: a randomized controlled study. Am J Sports Med. 2007;35(6):897-906. CrossRef PubMed
50. Viechtbauer W, Cheung MW. Outlier and influence diagnostics for meta-analysis. Res Synth Methods. 2010;1(2):112-125. CrossRef PubMed
51. Peters JL, Sutton AJ, Jones DR, et al. Contour-enhanced meta-analysis funnel plots help distinguish publication bias from other causes of asymmetry. J Clin Epidemiol. 2008;61(10):991-996. CrossRef PubMed
52. Harrer M, Cuijpers P, Furukawa T, et al. Doing meta-analysis with R: a hands-on guide. Chapman and Hall/CRC; 2021, CrossRef.
53. Nambi G, Basuodan RM, Alwhaibi RM, et al. Clinical and endocrinological responses to different exercise training methods in chronic low back pain: a randomized controlled trial. Endocr Metab Immune Disord Drug Targets. 2023;23(6):801-810. CrossRef PubMed
54. Aasa B, Berglund L, Michaelson P, et al. Individualized low-load motor control exercises and education versus a high-load lifting exercise and education to improve activity, pain intensity, and physical performance in patients with low back pain: a randomized controlled trial. J Orthop Sports Phys Ther 2015;45(2):77-85, B1-4. CrossRef
55. Calatayud J, Guzmán-González B, Andersen LL, et al. Effectiveness of a group-based progressive strength training in primary care to improve the recurrence of low back pain exacerbations and function: a randomised trial. Int J Environ Res Public Health. 2020;17(22):8326. CrossRef PubMed
56. Castro JB, Lima VP, Mello DB, et al. Effects of Pilates with and without elastic resistance on health variables in

postmenopausal women with low back pain. Pain Manag. 2022;12(4):509-520. CrossRef PubMed
57. Gibbs MT, Morrison NM, Raftry S, et al. Does a powerlifting inspired exercise programme better compliment pain education compared to bodyweight exercise for people with chronic low back pain? A multicentre, single-blind, randomized controlled trial. Clin Rehabil. 2022;36(9):1199-1213. CrossRef PubMed
58. Helmhout PH, Harts CC, Viechtbauer W, et al. Isolated lumbar extensor strengthening versus regular physical therapy in an army working population with nonacute low back pain: a randomized controlled trial. Arch Phys Med Rehabil. 2008;89(9):1675-1685. CrossRef PubMed
59. Kell RT, Asmundson GJ. A comparison of two forms of periodized exercise rehabilitation programs in the management of chronic non-specific low-back pain. J Strength Cond Res. 2009;23(2):513-523. CrossRef PubMed
60. Nambi G, Abdelbasset WK, Alqahtani BA, et al. Isokinetic back training is more effective than core stabilization training on pain intensity and sports performances in football players with chronic low back pain: A randomized controlled trial. Medicine (Baltimore). 2020;99(21):e20418. CrossRef PubMed
61. Nambi G, Abdelbasset WK, Elsayed SH, et al. Comparative effects of isokinetic training and virtual reality training on sports performances in university football players with chronic low back pain-randomized controlled study. Evid Based Complement Alternat Med. 2020;2020(1):2981273. CrossRef PubMed
62. Michaelson P, Holmberg D, Aasa B, et al. High load lifting exercise and low load motor control exercises as interventions for patients with mechanical low back pain: a randomized controlled trial with 24-month follow-up. J Rehabil Med. 2016;48(5):456-463. CrossRef PubMed
63. Santos AOBD, Castro JBP, Nunes RAM, et al. Effects of two training programs on health variables in adults with chronic low back pain: a randomized clinical trial. Pain Manag. 2022;12(4):447-459. CrossRef PubMed
64. Sertpoyraz F, Eyigor S, Karapolat H, et al. Comparison of isokinetic exercise versus standard exercise training in patients with chronic low back pain: a randomized controlled study. Clin Rehabil. 2009;23(3):238-247. CrossRef PubMed
65. Smith D, Bissell G, Bruce-Low S, et al. The effect of lumbar extension training with and without pelvic stabilization on lumbar strength and low back pain. J Back Musculoskelet Rehabil. 2011;24(4):241-249. CrossRef PubMed
66. Cai C, Yang Y, Kong PW. Comparison of lower limb and back exercises for runners with chronic low back pain. Med Sci Sports Exerc. 2017;49(12):2374-2384. CrossRef PubMed
67. Mannion AF, Müntener M, Taimela S, et al. A randomized clinical trial of three active therapies for chronic low back pain. Spine. 1999;24(23):2435-2448. CrossRef PubMed
68. Mannion AF, Müntener M, Taimela S, et al. Comparison of three active therapies for chronic low back pain: results of a randomized clinical trial with one-year follow-up. Rheumatology (Oxford). 2001;40(7):772-778. CrossRef PubMed
69. Saner J, Luomajoki H, Sieben JM, et al. Movement control exercise versus general exercise to reduce disability in patients with low back pain: randomized controlled multicentre study. Physiotherapy. 2015;101(S1):e917-e918. CrossRef
70. Thomas A. Comparative analysis of motor control stability and strengthening program in treatment of chronic low back pain among male weight lifters. Physiotherapy. 2015;101(S1):e1512. CrossRef
71. Verbrugghe J, Agten A, Stevens S, et al. Effects of high intensity training on pain, disability, exercise capacity and muscle strength in persons with non-specific chronic low back pain: preliminary RCT results. Ann Phys Rehabil Med. 2018;61(suppl):e17. CrossRef
72. Vincent HK, Conrad B, Seay A, et al. Low back strength gain contributes to walking improvement in obese older adults with chronic low back pain. PM R. 2013;5(9S):S142. CrossRef
73. Agbonhalor EI, Subulade A. Effects of 10-weeks strength training program on pain intensity, muscle endurance and kinesophobia in patients with non-specific low back pain. Turkish Journal of Kinesiology. 2020;6(1):40-48. CrossRef
74. Günay S, Yildirim Y, Karadibak D. The effect of the muscle endurance training on the chronic low back pain. Turk J Physiother Rehabil. 2014;25(4):28-34. Online
75. Welch N, Moran K, Antony J, et al. The effects of a free-weight-based resistance training intervention on pain, squat biomechanics and MRI-defined lumbar fat infiltration and functional cross-sectional area in those with chronic low back. BMJ Open Sport Exerc Med. 2015;1(1):e000050. CrossRef PubMed
76. Liu-Ambrose TY, Khan KM, Eng JJ, et al. Both resistance and agility training reduce back pain and improve health-related quality of life in older women with low bone mass. Osteoporos Int. 2005;16(11):1321-1329. CrossRef PubMed
77. Manniche C, Lundberg E, Christensen I, et al. Intensive dynamic back exercises for chronic low back pain: a clinical trial. Pain. 1991;47(1):53-63. CrossRef PubMed
78. Miller ER, Schenk RJ, Karnes JL, et al. A Comparison of the McKenzie approach to a specific spine stabilization program for chronic low back pain. J Man Manip Ther. 2005;13(2):103-112. CrossRef
79. Torstensen TA, Ljunggren AE, Meen HD, et al. Efficiency and costs of medical exercise therapy, conventional physiotherapy, and self-exercise in patients with chronic low back pain. A pragmatic, randomized, single-blinded, controlled trial with 1-year follow-up. Spine. 1998;23(23):2616-2624. CrossRef PubMed
80. Andrusaitis SF, Brech GC, Vitale GF, et al. Trunk stabilization among women with chronic lower back pain: a randomized, controlled, and blinded pilot study. Clinics (Sao Paulo). 2011;66(9):1645-1650. CrossRef PubMed
81. França FR, Burke TN, Caffaro RR, et al. Effects of muscular stretching and segmental stabilization on functional disability and pain in patients with chronic low back pain: a randomized, controlled trial. J Manipulative Physiol Ther. 2012;35(4):279-285. CrossRef PubMed
82. Goldby LJ, Moore AP, Doust J, et al. A randomized controlled trial investigating the efficiency of musculoskeletal physiotherapy on chronic low back disorder. Spine. 2006;31(10):1083-1093. CrossRef PubMed
83. Highland KB, Schoomaker A, Rojas W, et al. Benefits of the restorative exercise and strength training for operational resilience and excellence yoga program for chronic low back pain in service members: a pilot randomized controlled trial. Arch Phys Med Rehabil. 2018;99(1):91-98. CrossRef PubMed
84. Kofotolis N, Kellis E, Vlachopoulos SP, et al. Effects of Pilates and trunk strengthening exercises on health-related quality of life in women with chronic low back pain. J Back Musculoskelet Rehabil. 2016;29(4):649-659. CrossRef PubMed
85. Koumantakis GA, Watson PJ, Oldham JA. Supplementation of general endurance exercise with stabilization training versus general exercise only. Physiological and functional outcomes of a randomized controlled trial of patients with recurrent low back pain. Clin Biomech (Bristol). 2005;20(5):474-482. CrossRef PubMed
86. Kumar S, Sharma VP, Shukla R, et al. Comparative efficacy of two multimodal treatments on male and female sub-groups with low back pain (part II). J Back Musculoskelet Rehabil. 2010;23(1):1-9. CrossRef PubMed

87. Lee JS, Kang SJ. The effects of strength exercise and walking on lumbar function, pain level, and body composition in chronic back pain patients. J Exerc Rehabil. 2016;12(5):463-470. CrossRef PubMed
88. Macedo LG, Latimer J, Maher CG, et al. Effect of motor control exercises versus graded activity in patients with chronic non-specific low back pain: a randomized controlled trial. Phys Ther. 2012;92(3):363-377. CrossRef PubMed
89. Marshall PW, Kennedy S, Brooks C, et al. Pilates exercise or stationary cycling for chronic non-specific low back pain: does it matter? a randomized controlled trial with 6-month follow-up. Spine. 2013;38(15):E952-E959. CrossRef PubMed
90. Moon HJ, Choi KH, Kim DH, et al. Effect of lumbar stabilization and dynamic lumbar strengthening exercises in patients with chronic low back pain. Ann Rehabil Med. 2013;37(1):110-117. CrossRef PubMed
91. Rasmussen-Barr E, Ang B, Arvidsson I, et al. Graded exercise for recurrent low-back pain: a randomized, controlled trial with 6-, 12-, and 36-month follow-ups. Spine. 2009;34(3):221-228. CrossRef PubMed
92. Rhee HS, Kim YH, Sung PS. A randomized controlled trial to determine the effect of spinal stabilization exercise intervention based on pain level and standing balance differences in patients with low back pain. Med Sci Monit. 2012;18(3):CR174-CR181. CrossRef PubMed
93. Roche G, Ponthieux A, Parot-Shinkel E, et al. Comparison of a functional restoration program with active individual physical therapy for patients with chronic low back pain: a randomized controlled trial. Arch Phys Med Rehabil. 2007;88(10):1229-1235. CrossRef PubMed
94. Shamsi M, Sarrafzadeh J, Jamshidi A, et al. The effect of core stability and general exercise on abdominal muscle thickness in non-specific chronic low back pain using ultrasound imaging. Physiother Theory Pract. 2016;32(4):277-283. CrossRef PubMed
95. Shnayderman I, Katz-Leurer M. An aerobic walking programme versus muscle strengthening programme for chronic low back pain: a randomized controlled trial. Clin Rehabil. 2013;27(3):207-214. CrossRef PubMed
96. Suh JH, Kim H, Jung GP, et al. The effect of lumbar stabilization and walking exercises on chronic low back pain: a randomized controlled trial. Medicine (Baltimore). 2019;98(26):e16173. CrossRef PubMed
97. Unsgaard-Tøndel M, Fladmark AM, Salvesen Ø, et al. Motor control exercises, sling exercises, and general exercises for patients with chronic low back pain: a randomized controlled trial with 1-year follow-up. Phys Ther. 2010;90(10):1426-1440. CrossRef PubMed
98. Bae CR, Jin Y, Yoon BC, et al. Effects of assisted sit-up exercise compared to core stabilization exercise on patients with non-specific low back pain: a randomized controlled trial. J Back Musculoskelet Rehabil. 2018;31(5):871-880. CrossRef PubMed
99. Danneels LA, Vanderstraeten GG, Cambier DC, et al. Effects of three different training modalities on the cross sectional area of the lumbar multifidus muscle in patients with chronic low back pain. Br J Sports Med. 2001;35(3):186-191. CrossRef PubMed
100. Gatti R, Faccendini S, Tettamanti A, et al. Efficacy of trunk balance exercises for individuals with chronic low back pain: a randomized clinical trial. J Orthop Sports Phys Ther. 2011;41(8):542-552. CrossRef PubMed
101. Hurley DA, Tully MA, Lonsdale C, et al. Supervised walking in comparison with fitness training for chronic back pain in physiotherapy: results of the SWIFT single-blinded randomized controlled trial (ISRCTN17592092). Pain. 2015;156(1):131-147. CrossRef PubMed
102. Inani SB, Selkar SP. Effect of core stabilization exercises versus conventional exercises on pain and functional status in patients with non-specific low back pain: a randomized clinical trial. J Back Musculoskelet Rehabil. 2013;26(1):37-43. CrossRef PubMed
103. Kim YS, Lee NJ. The effect of progressive resistance exercise and obeisance exercise on functional disorder, back pain, and strength in middle-aged female patients with chronic low back pain for wellness. J Korea Entertain Indust Assoc. 2017;11(4):237-247. CrossRef
104. Oliveira CT, Kanas M, Wajchenberg M. Treatment of non-specific chronic low back pain: resistance training with or without using weights? Rev Bras Med Esporte. 2021;27(6):603-609. CrossRef
105. Tagliaferri SD, Miller CT, Ford JJ, et al. Randomized trial of general strength and conditioning versus motor control and manual therapy for chronic low back pain on physical and self-report outcomes. J Clin Med. 2020;9(6):1726. CrossRef PubMed
106. Verbrugghe J, Agten A, Stevens S, et al. High intensity training to treat chronic non-specific low back pain: effectiveness of various exercise modes. J Clin Med. 2020;9(8):2401. CrossRef PubMed
107. Atalay E, Akova B, Gür H, et al. Effect of upper-extremity strengthening exercises on the lumbar strength, disability and pain of patients with chronic low back pain: a randomized controlled study. J Sports Sci Med. 2017;16(4):595-603. CrossRef PubMed
108. Bates NA, Huffman A, Goodyear E, et al. Physical clinical care and artificial-intelligence-guided core resistance training improve endurance and patient-reported outcomes in subjects with lower back pain. Clin Biomech (Bristol). 2023;103:105902. CrossRef PubMed
109. Bruce-Low S, Smith D, Burnet S, et al. One lumbar extension training session per week is sufficient for strength gains and reductions in pain in patients with chronic low back pain ergonomics. Ergonomics. 2012;55(4):500-507. CrossRef PubMed
110. Cortell-Tormo JM, Sánchez PT, Chulvi-Medrano I, et al. Effects of functional resistance training on fitness and quality of life in females with chronic non-specific low-back pain. J Back Musculoskelet Rehabil. 2018;31(1):95-105. CrossRef PubMed
111. Harts CC, Helmhout PH, de Bie RA, et al. A high-intensity lumbar extensor strengthening program is little better than a low-intensity program or a waiting list control group for chronic low back pain: a randomized clinical trial. Aust J Physiother. 2008;54(1):23-31. CrossRef PubMed
112. Helmhout PH, Harts CC, Staal JB, et al. Comparison of a high-intensity and a low-intensity lumbar extensor training program as minimal intervention treatment in low back pain: a randomized trial. Eur Spine J. 2004;13(6):537-547. CrossRef PubMed
113. Iversen VM, Vasseljen O, Mork PJ, et al. Resistance band training or general exercise in multidisciplinary rehabilitation of low back pain? A randomized trial. Scand J Med Sci Sports. 2018;28(9):2074-2083. CrossRef PubMed
114. Jackson JK, Shepherd TR, Kell RT. The influence of periodized resistance training on recreationally active males with chronic non-specific low back pain. J Strength Cond Res. 2011;25(1):242-251. CrossRef PubMed
115. Kell RT, Risi AD, Barden JM. The response of persons with chronic non-specific low back pain to three different volumes of periodized musculoskeletal rehabilitation. J Strength Cond Res. 2011;25(4):1052-1064. CrossRef PubMed
116. Rittweger J, Just K, Kautzsch K, et al. Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. Spine. 2002;27(17):1829-1834. CrossRef PubMed

117. Steele J, Bruce-Low S, Smith D, et al. A randomized controlled trial of limited range of motion lumbar extension exercise in chronic low back pain. Spine. 2013;38(15):1245-1252. CrossRef PubMed
118. Vincent HK, George SZ, Seay AN, et al. Resistance exercise, disability, and pain catastrophizing in obese adults with back pain. Med Sci Sports Exerc. 2014;46(9):1693-1701. CrossRef PubMed
119. Vincent HK, Vincent KR, Seay AN, et al. Back strength predicts walking improvement in obese, older adults with chronic low back pain. PM R. 2014;6(5):418-426. CrossRef PubMed
120. Raoul T, Malferiot J, Barizien N, et al. Effects of a muscle strengthening program designed for spine extensors in triathletes with chronic back pain. Randomized controlled trial in 67 athletes. J Traumatol Sport. 2019;36(3):183-193. CrossRef
121. Yaghoubi Z, Kahrizi S, Parnianpour M, et al. Short effects of two common stabilization exercise on back and abdominal muscle recruitment and lumbar curvature in non-specific chronic low back pain patients: a crossover clinical trial study. Koomesh. 2014;15(4):e152887. Online
122. Yi T, Lee JH, Lee YJ, et al. Comparisons of spinal stabilization exercise and lumbar extensor strengthening exercise in chronic low back pain. Ann Rehabil Med. 2008;32(5):570-575. online
123. Berglund L, Aasa B, Michaelson P, et al. Effects of low-load motor control exercises and a high-load lifting exercise on lumbar multifidus thickness: a randomized controlled trial. Spine. 2017;42(15):E876-E882. CrossRef PubMed
124. Käser L, Mannion AF, Rhyner A, et al. Active therapy for chronic low back pain: part 2. Effects on paraspinal muscle cross-sectional area, fiber type size, and distribution. Spine. 2001;26(8):909-919. CrossRef PubMed
125. Kovacs FM, Abraira V, Royuela A, et al. Minimal clinically important change for pain intensity and disability in patients with non-specific low back pain. Spine. 2007;32(25):2915-2920. CrossRef PubMed
126. Sterne JA, Sutton AJ, Ioannidis JP, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomized controlled trials. BMJ. 2011;343(jul22 1):d4002. CrossRef PubMed
127. Chiu L, Barnes JL. The fitness-fatigue model revisited: implications for planning short- and long-term training. Strength Condit J. 2003;25(6):42-45. CrossRef
128. Wernli K, Tan JS, O'Sullivan P, et al. Does movement change when low back pain changes? A systematic review. J Orthop Sports Phys Ther. 2020;50(12):664-670. CrossRef PubMed
129. Raja SN, Carr DB, Cohen M, et al. The revised International Association for the Study of Pain definition of pain: concepts, challenges, and compromises. Pain. 2020;161(9):1976-1982. CrossRef PubMed
130. Booth J, Moseley GL, Schiltenwolf M, et al. Exercise for chronic musculoskeletal pain: a biopsychosocial approach. Musculoskeletal Care. 2017;15(4):413-421. CrossRef PubMed
131. Vlaeyen JWS, Crombez G. Behavioral conceptualization and treatment of chronic pain. Annu Rev Clin Psychol. 2020;16(1):187-212. CrossRef PubMed
132. Darlow B, Dowell A, Baxter GD, et al. The enduring impact of what clinicians say to people with low back pain. Ann Fam Med. 2013;11(6):527-534. CrossRef PubMed
133. Main CJ, George SZ. Psychologically informed practice for management of low back pain: future directions in practice and research. Phys Ther. 2011;91(5):820-824. CrossRef PubMed
134. Neason C, Miller CT, Tagliaferri SD, et al. Exercise prescription variables predict reductions in pain intensity in adults with chronic low back pain: secondary analysis of a randomized controlled trial. BMJ Open Sport Exerc Med. 2024;10(1):e001744. CrossRef PubMed
135. Fyfe JJ, Hamilton DL, Daly RM. Minimal-dose resistance training for improving muscle mass, strength, and function: a narrative review of current evidence and practical considerations. Sports Med. 2022;52(3):463-479. CrossRef PubMed