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Systematic Review

Does the Inclusion of Static or Dynamic Stretching in the Warm-Up Routine Improve Jump Height and ROM in Physically Active Individuals? A Systematic Review with Meta-Analysis

Paula Esteban-García [1,*], Javier Abián-Vicen [1], Jorge Sánchez-Infante [2], María Ramírez-delaCruz [1] and Jacobo Ángel Rubio-Arias [3]

[1] Performance and Sport Rehabilitation Laboratory (DEPORSALUD), Faculty of Sport Sciences, University of Castilla-La Mancha, 13001 Toledo, Spain; javier.abian@uclm.es (J.A.-V.); maria.ramirez@uclm.es (M.R.-d.)
[2] Faculty of Physical Therapy and Nursing, University of Castilla-La Mancha, 45071 Toledo, Spain; jorge.sanchezinfante@uclm.es
[3] Department of Education, Health Research Center, University of Almeria, 04120 Almeria, Spain; jararias@ual.es
* Correspondence: paula.esteban@uclm.es

Featured Application: The findings of this study have a number of important implications for future practice. The results obtained in the meta-analysis determine that dynamic stretching in the warm-up improves performance and the range of motion of the lower limbs. Furthermore, both types of stretching are considered favourable for improving ROM. Therefore, it is recommended to use dynamic stretching in warm-up routines for those sports that involve lower extremity performance and range of motion. This type of warm-up strategy will make it easier for the athlete to reach the sport-specific phase of the warm-up in a better condition.

Abstract: The effect of different stretches during warm-up on subsequent performance has been studied. However, no reviews are found in which a meta-analytical analysis is used. The aim was to synthesise the effects of different types of stretching included in the warm-up on jumping performance and ROM. The Cochrane, Sport Discus, PubMed, Scopus, and Web of Science databases were systematically searched. The inclusion criteria included studies analysing the effect of different stretching in the warm-up, on a vertical jump or lower-limb ROM. Sixteen studies were eligible for meta-analysis. In vertical jumping, SS led to a non-significant decrease in jump height (SMD = −0.17 95%CI [−0.39, 0.04]; I^2 = 16%; Z = 1.57; p = 0.30), and DS led to a non-significant increase in jump height (SMD = 0.12, 95%CI [−0.05, 0.29]; I^2 = 4%; Z = 1.34; p = 0.41). Statistically significant differences were observed between stretches (p = 0.04). Regarding ROM, both stretches showed improvements compared to the control intervention (SS:SMD = 0.40, 95%CI [0.05, 0.74]; SD:SMD = 0.48, 95%CI [0.13, 0.83]). However, no differences were observed (p = 0.73) between static and dynamic stretching. A greater presence of dynamic stretching is recommended in the warm-up of those sports that require a good jump height and range of motion.

Keywords: vertical jump; ROM; stretch

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1. Introduction

The warm-up in sport is defined as a period of preparatory exercise to improve subsequent training or competitive performance [1]. There are many effects associated with warming up, such as increased muscle and tendon flexibility [2–4], the stimulation of peripheral blood flow [2,3], increased muscle temperature, and improved joint movement [4] in a free and co-ordinated manner [2,3].

Studies established that the warm-up process could be divided into several parts: first, a sub-maximal aerobic activity, followed by the stretching of the main muscle groups, and ending with the performance of sport-specific exercises [5,6]. There is controversy about the effect of stretching in the warm-up on subsequent performance, as well as which type of stretching is the most effective depending on subsequent activities. Stretching can take many different forms including static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation (PNF) [7]. SS involves lengthening the muscle and holding it in a slightly awkward position for some time between 15 and 60 s; DS uses momentum and active muscular effort to lengthen the muscle, such as swinging, jumping, or other movements in which the limbs are moved up to or slightly past the regular limits of the range of motion (ROM), holding for less than 3 s; and PNF involves a passive stretching combined with isometric muscle contraction either throughout the joint ROM or at the end of the ROM after the muscle is relaxed and rested before it is stretched again [8].

Throughout the 1960s, SS was used in warm-up routines [9]. Subsequent studies have shown the negative influence of SS on subsequent performance [10,11]. Currently, the inclusion of DS in the warm-up is more popular [12]. However, the effects and type of stretching within the warm-up are unclear. Studies reflect warm-up protocol biases, such as including an aerobic part before stretching, sport-specific dynamic activities after sport, or only acute effects [10].

Extensive research has studied the effect of the warm-up stretching on performance. The performance has been associated with ROM and vertical jumping [13–20]. It is considered that vertical jump values can be very important for assessing performance in some sports [21]. Maximum jump height is an indicator of leg muscle power [22] and is related to peak strength, sprinting ability, and change of direction [23,24]. Moreover, ROM measurements quantify the joint mobility and the status of joint hyper- or hypomobility [25]. Correlations have been established between the changes produced by stretching in the ROM and improvement in performance, [10,26] and these changes and reductions in the incidence of injuries [27].

Several systematic reviews have been published about the effects of stretching in the warm-up on performance and ROM [9,10]. These studies relate mean effects of acute SS and DS on performance; however, none of them used a meta-analytic analysis. Therefore, the aim of this systematic review with meta-analysis was to synthesise and compare the effects of different types of stretching in the warm-up on jumping performance and the ROM of lower limbs.

2. Materials and Methods

2.1. Study Design

The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [28]. All phases of the meta-analysis were conducted in duplicate. The International Prospective Register of Systematic Reviews (PROSPERO) registration number is (CRD42022246214).

2.2. Data Sources and Searches

The Cochrane, Sport Discus, PubMed, Scopus, and Web of Science (WOS) databases were systematically searched to identify the effectiveness of warm-ups that include lower extremity stretching on ROM and jump height. A comprehensive search of the literature was performed from database inception through to March 2023. A manual search was performed using a combination of the following terms: warm-up, stretching, performance, vertical jump, and range of motion. These concepts were applied using the search operator "AND" and "OR". The following keyword strategy was used: (("Warm-up" OR "Warm up" OR "Warm up exercise" OR "Warmup" OR "Warming-up" OR "Warming up") AND ("Static" OR "Dynamic" OR "Passive" OR "Ballistic stretching" OR "PNF" OR "Flexibility" OR "Stretching") AND ("performance" OR "performance improvement" OR "improved performance" OR "jump" OR "vertical jump" OR "ROM" OR "range of motion" OR "joint flexibility" OR "passive range of motion" OR "acute effects" OR "prior exercise" OR "CMJ" OR "strength" OR "1RM" OR "1-RM")).

Authors A and B independently analysed the titles and abstracts, read the full articles, extracted the study properties, and assessed the methodological quality of the clinical trials. If there was no agreement between them, a third author (C) analysed the study to reach a consensus.

2.3. Study Selection, Data Extraction, and Selection Criteria

The specific inclusion criteria were: (1) studies analysing the effect of different stretching in the warm-up, on a vertical jump or lower-limb ROM; (2) studies that included assessment before and after warm-up; (3) warm-ups including an aerobic general warm-up followed by SS or DS; (4) experimental studies with a control situation; and (5) studies carried out on adult men and/or women (≥18 years) without pathologies or health problems. Studies were excluded if they: (1) were review articles, editorials, letters to the editor, or case reports; (2) were not performed on humans; (3) were not available in English or Spanish; and (4) did not provide or detail numerical data on the specified variables.

The studies that met the inclusion criteria were coded and stored in a spreadsheet. The data extracted were the site and country of the study, name of the first author and year of publication, and characteristics of the population with the total sample and groups (gender of participants, age (years), weight (kg), height (cm) and physical fitness). The information about the characteristic programme included total warm-up duration (min), time of aerobic warm-up (min), sets, repetitions, stretching time (sec), rest stretching (sec), and stretched muscle groups. The reference lists of included articles were screened to add possible relevant articles and, in the absence of essential data in the original studies, authors were contacted for the necessary information. Two reviewers (A and B) independently extracted data from the included studies.

2.4. Variables

Traditionally, it has been considered that pre-exercise stretching will promote better performance [29]. However, several studies have suggested that stretching may reduce performance with, more importantly, a reduction in maximal and explosive muscular efforts [11]. Therefore, the vertical jump was used as a measure of explosive muscular efforts. For the jump outcomes, the variable considered was height during the countermovement jump (CMJ). To evaluate ROM, they considered the cm measured in the hamstring ROM during sit and reach or another similar test because SS is considered an effective method for increasing ROM [30] and is often thought to improve performance [26].

2.5. Study Quality

The risk of bias (ROB) was assessed using the Cochrane Robins 2.0 tool for randomised trials [31]. Bias was assessed based on judgment (high, low, or unclear) for each study. These tools evaluated: (1) random sequence generation (selection bias); (2) allocation concealment (selection bias); (3) blinding of participants and personnel (performance bias); (4) blinding of outcome assessment (detection bias); (5) incomplete outcome data (attrition bias); (6) selective reporting (reporting bias); and (7) other bias. When a study scores a "+" in all subdomains, the overall judgement is "low risk of bias". When a study obtains "?" on one or more subdomains, the overall judgement is "some concerns". When a study scores a "−" in one or more subdomains, the overall assessment is "high risk of bias", giving rise to substantial doubts about the quality of the research. The ROB was independently assessed by two authors (A and B).

Those studies that obtained the high-risk assessment in tool (1) of the ROB were assessed with the Newcastle–Ottawa[67] quality assessment for cohort studies. The items assessed were: Selection: (1) Representativeness of the exposed cohort; (2) Selection of the non-exposed cohort; (3) Ascertainment of exposure; and (4) Demonstration that outcome of interest was not present at start of study; Comparability: (5) Comparability of cohorts on the basis of the design or analysis controlled for confounders; and Outcome: (6) Assessment of outcome; (7) Was followed-up long enough for outcomes to occur; and (8) Adequacy of follow-up of cohorts. Study quality was obtained based on good quality: 3 or 4 stars in the domain of selection and 1 or 2 stars in the domain of comparability and 2 or 3 stars in the domain of outcome/exposure; Fair quality: 2 stars in the area of selection and 1 or 2 stars in the area of comparability and 2 or 3 stars in the area of performance/exposure; and Poor quality: 0 or 1 star in the area of selection OR 0 stars in the area of comparability OR 0 or 1 stars in the area of performance/exposure. The Newcastle–Ottawa assessment was independently performed by two authors (A and B).

In the absence of agreement between authors A and B, when both tools were applied, a third author (C) analysed the study to reach a consensus.

2.6. Moderating Effect of Variables

A meta-regression model was used to analyse the impact of the continuous moderating variables. Total warm-up (min), time of aerobic warm-up (min), number of sets, number of repetitions, stretching time (s), and rest stretching (s) were considered as moderating variables. Meta-regression was analysed with a random-effects model using the Jamovi Project Software (Jamovi, 2.2.13, Sydney, Australia). A restricted maximum residual verisimilitude method was used to measure the variance between studies ($\tau 2$).

2.7. Heterogeneity

We evaluated statistical heterogeneity using the Cochran chi-square, the I^2 statistic, and the between-study variance using the tau-square (Tau2) [32,33]. I^2 values of 30 to 60% represented a moderate level of heterogeneity, 50% to 90% represented substantial heterogeneity, and 75% to 100% represented considerable heterogeneity. A p-value < 0.1 for chi-square was considered for the presence of heterogeneity. Tau2 > 1 determines the presence of substantial statistical heterogeneity. Publication bias was assessed with the funnel plot. Egger's test for funnel plot skewness was used to test whether a minimum of 10 $\approx$ studies were available. A value of $p \leq 0.05$ was statistically significant [34]. To determine the publication bias, Egger's test was computed, and funnel plots were visually inspected. The risk assessment was performed on the difference between the control and experimental groups. Finally, a sensitivity analysis was performed using the "leave-one-out" method [35].

2.8. Data Synthesis and Statistical Analysis

The meta-analysis and statistical analysis were performed using Review Manager Software (RevMan 5.3; Cochrane Collaboration, Oxford, UK) [36]. A random-effects meta-analysis was conducted to determine summary effects. Effects sizes of outcomes between the training group and control situation were expressed as mean difference (MD) and standardised mean differences (SMDs), and a 95% confidence interval (95%CI); 0.2 represents a small effect, 0.5 is a moderate effect, and 0.8 is a large effect [37]

3. Results

3.1. Study Selection/Search Results

The initial electronic search identified 4723 articles from the databases. A total of 1724 duplicates were removed. After the evaluation of the abstract and titles from the primary source, 1712 were removed and 1287 full-text articles were read. After applying the inclusion and exclusion criteria, 1238 articles were excluded and, for 8 articles, the data were requested for statistical analysis and were not available. Finally, 49 articles were analysed. The Kappa correlations test showed a high level of agreement between the authors (Kappa = 0.8125). Two authors (A and B) selected the total number of studies included in the meta-analysis. Both authors said "Yes" in 15 studies; both authors said "No" in 32 studies. In 2 studies, the authors did not agree; therefore, the third author (C) was asked to evaluate. Only one of the studies was accepted. Finally, 16 articles were included in the meta-analysis (Figure 1).

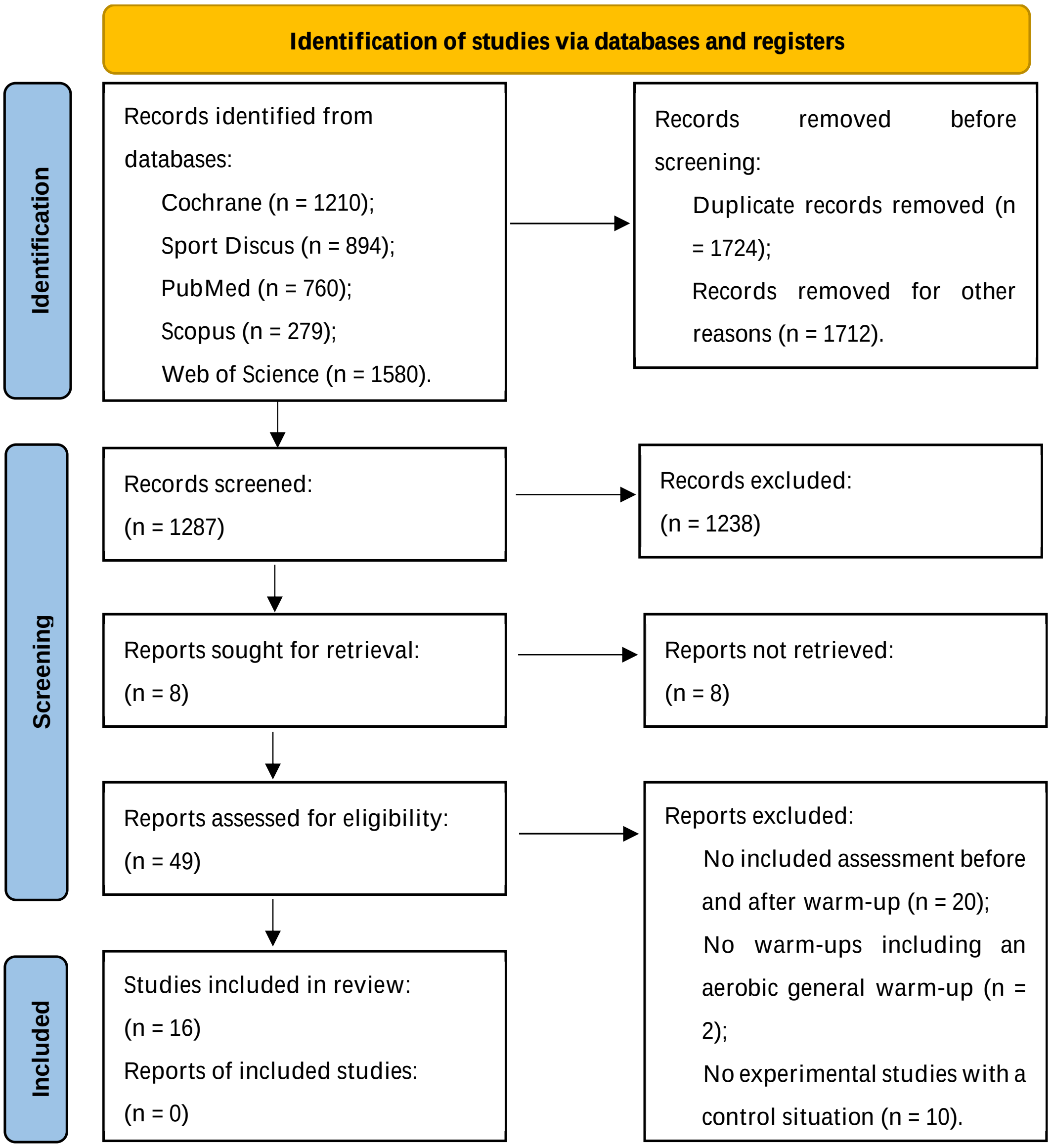


Figure 1. Flow diagram.

3.2. Characteristics of Included Studies

This review analysed the effects of different stretching in the warm-up on physical performance variables such as jump height in CMJ and ROM. Fourteen of the included articles analysed the CMJ [38–51] and five analysed the ROM [39,41,50,52,53]. The characteristics of the participants are summarised in Table 1. All studies were published between 2008 and 2023. There was a total of 363 participants (mean ± SD: age 22 ± 2 years; weight 74.24 ± 10.22 kg; height 175.97 ± 6.76 cm), 31.95% women and 68.04% men, and they were students or active individuals. The characteristics of the warm-up protocol are presented in Table 2. The warm-up protocols had an average total time duration of 825.6 ± 349.2 s, an average time of aerobic warm-up of 366 ± 142.2 s, an average of stretching time of 22.0 ± 11.8 s, an average rest stretching of 14.4 ± 7.7 s, with a range of 1–2 set and 1–12 repetitions. All subjects were evaluated immediately after a warm-up intervention. The warm-up protocols started with an aerobic warm-up for 5–10 min and continued with the stretching protocol. The subject executed all experimental conditions on different days.

Table 1. Characteristics of included studies in the meta-analysis.

Study ID	Group	n	Sex	Activity/Sport	Age (Years)	Weight (kg)	Height (cm)
Bacurau et al. [52]	CG (NI)	14	female	physical education students	23.1 ± 3.6	64.9 ± 5.9	169.3 ± 8.2
	EG (SS)	14	female				
	EG (DS)	14	female				
Baklouti et al. [38]	CG (NI)	11	male	physical education students	21.5 ± 1.5	73.3 ± 7.5	177.0 ± 5.0
	EG (SS)	11	male				
	EG (DS)	11	male				
Ceylan et al. [39]	CG (NI)	10	female	Athletes of futsal			
	EG (SS)	10	female				
	EG (DS)	10	female				
Christensen and Nordstrom [40]	CG (NI)	68	both	athletes of basketball	20.5 ± 1.4	100.7 ± 17.7	186.9 ± 7.7
	EG (DS)	68	both				
Curry et al. [41]	CG (NI)	23	female	recreationally active university students	26.0 ± 3.0	61.5 ± 8.1	165.1 ± 8.8
	EG (SS)	23	female				
	EG (DS)	23	female				
Dalrymple et al. [42]	CG (NI)	12	female	university volleyball players	19.5 ± 1.1	71.3 ± 8.5	171.0 ± 6.0
	EG (SS)	12	female				
	EG (DS)	12	female				
de Oliveira and Rama [43]	CG (NI)	22	male	amateur athletes of different sports	23.2 ± 5.0	82.8 ± 12.6	178.0 ± 6.0
	EG (SS)	22	male				
Galdino et al. [44]	CG (NI)	25	female	active strength training	28.2 ± 3.5	56.9 ± 1.1	162.2 ± 1.4
	EG (SS)	25	female				
Fletcher (2010) [45]	CG (NI)	24	male	collegiate games players	21.0 ± 0.3	77.0 ± 8.2	176.0 ± 6.17
	EG (DS1)	24	male				
	EG (DS2)	24	male				
Fletcher and Monte-Colombo [46]	CG (NI)	27	male	semiprofessional soccer players	20.5 ± 2.2	74.8 ± 2.2	180.3 ± 5.9
	EG (SS)	27	male				
	EG (DS)	27	male				
Fletcher and Monte-Clombo [47]	CG (NI)	21	male	semiprofessional soccer players	20.8 ± 2.3	75.6 ± 8.1	179.8 ± 6.4
	EG (SS)	21	male				
	EG (DS)	21	male				
Kurt and Firtin [53]	CG (NI)	20	male	professional football players	25.3 ± 4.3	79.1 ± 4.2	183.0 ± 3.0
	EG (SS)	20	male				
	EG (DS)	20	male				
Maeda et al. [48]	CG (NI)	15	male	active	23.5 ± 2.3	67.2 ± 9.9	172.1 ± 6.4
	EG (SS)	15	male				
Pagaduan et al. [49]	CG (NI)	29	male	college football players	19.4 ± 1.1	73.1 ± 8.0	179.0 ± 5.1
	EG (SS)	29	male				
	EG (DS)	29	male				
Perrier et al. [50]	CG (NI)	21	male	recreationally active	24.4 ± 4.5	81.1 ± 14.0	180.0 ± 6.0
	EG (SS)	21	male				
	EG (DS)	21	male				
Pojskic et al. [51]	CG (NI)	21	male	soccer players	20.14 ± 1.65	74.4 ± 13.0	179.9 ± 8.34
	EG (DS)	21	male				

CG, control group; EG, experimental group; NI, no intervention; SS, static stretching; DS, dynamic stretching.

Table 2. Characteristics of warm-up with stretching of studies included in the meta-analysis.

Author	Exercises	Total Warm Up Duration (min)	Time Aerobic Warm-Up	Sets	Repetitions	Stretching Time (s)	Rest Stretching (s)	Performance Measures	Muscle Groups
Bacurau et al. [52]	treadmill run	5	5	...	...	...	...	ROM	...
	treadmill run + static stretching	25	5	1	3	30	30		Q, HM
	treadmill run + dynamic stretching	25	5	1	...	60	...		Q, HM
Baklouti et al. [38]	submaximal cycling	5	5	...	...	...	...	CMJ	...
	submaximal cycling + static stretching	11	5	1	3	15	15		GL, HM, Q, GS
	submaximal cycling + dynamic stretching	...	5	4	...	...	30		GL, HM, Q, GS
Ceylan et al. [39]	jogging low intensity	15–20	5	...	...	...	...	CMJ ROM	...
	jogging low intensity + static stretching	15–20	5	1	2	20	10		PF, Q, HM, HF
	jogging low intensity + dynamic stretching	15–20	5	...	1	...	10		LL
Christensen and Nordstrom [40]	jogging	...	600 m	...	...	...	...	CMJ	...
	jogging + dynamic stretching	...	...	1	5	...	...		LL
Curry et al. [41]	cycle (light aerobic activity)	15	15	...	...	...	...	CMJ ROM	...
	cycle + static stretching	15	5	1	3	12	12		GL, HM, HF, Q, GS, S
	cycle + dynamic stretching	15	5	1	10	...	walk		LL
Dalrymple et al. [42]	jog (low intensity)	13	5	...	...	...	...	CMJ	...
	jog + static stretching	13	5	1	3	15	20		PL, Q, HM, HE
	jog + dynamic stretching	13	5	1	2	...	20		PL, Q, HM, HE
de Oliveira and Rama [43]	dynamic warm-up	10	10	...	...	...	...	CMJ	...
	dynamic warm-up + static stretching	15	10	1	2	30	5		TS, Q, HM, GL, QL
Galdino et al. [44]	stationary cycloergometer	20	10	...	...	...	...	CMJ	...
	stationary cycloergometer + static stretching	11	10	1	3	10	...		HF, PF, KF
Fletcher (2010) [45]	jogging treadmill	...	10	...	...	...	...	CMJ	...
	jogging treadmill + slow dynamic stretching	...	10	2	10	...	...		A, K, H, T
	jogging treadmill + fast dynamic stretching	...	10	2	10	...	...		A, K, H, T
Fletcher and Monte-Colombo [46]	jogging	...	5					CMJ	...
	jogging + static stretching	...	5	1	1–2	15	...		HM, Q, ABD, ADD, GL, HF, GS, S
	jogging + dynamic stretching	...	5	2	12	...	...		HM, Q, ABD, ADD, GL, HF, GS, S

Table 2. *Cont.*

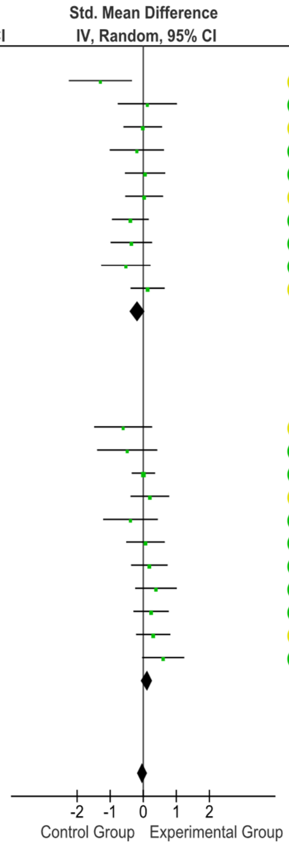
Author	Exercises	Total Warm Up Duration (min)	Time Aerobic Warm-Up	Sets	Repetitions	Stretching Time (s)	Rest Stretching (s)	Performance Measures	Muscle Groups
Fletcher and Monte-Clombo [47]	jogging	...	5	...	...	...	...	CMJ	...
	jogging + static stretching	...	5	1	1	15	5		HM, Q, ABD, ADD, GL, HF, GS, S
	jogging + dynamic stretching	...	5	2	12	...	...		HM, Q, ABD, ADD, GL, HF, GS, S
Kurt and Firtin [53]	aerobic running	5	5	...	...	...	...	ROM	...
	aerobic running + static stretching	10	5	1	1	20	10		Q, HM, HF, PI, PL
	aerobic running + dynamic stretching	10	5	1	2	20	10		LL
Maeda et al. [48]	cycling		5					CMJ	...
	cycling + static stretching		5						H, K, A
Pagaduan et al. [49]	running	5	5	...	...	...	...	CMJ	...
	running + static stretching	12	5	1	2	20	10		Q, PL, HM, ABD, ADD, HF, GL
	running + dynamic stretching	12	5	1	2	20	10		LL
Perrier et al. [50]	jogging treadmill	20	5	...	...	...	...	CMJ ROM	...
	jogging treadmill + static stretching	19	5	1	2	30	...		Q, HM, HF, ABD, ADD, PI, LB, PF
	jogging treadmill + dynamic stretching	18	5	1	2	...	...		LL
Pojskic et al. [51]	running	5	5	...	...	...	...	CMJ	...
	running + dynamic stretching	12	5	1	2	20	10		...

CMJ, counter movement jump; ROM, range of motion; PF, plantar flexors; H, hip; HF, hip flexors; Q, quadriceps; HM, hamstring; GL, gluteus; GS, gastrocnemius; ADD, adductor; ABD, abductor; LL, lower limbs; S, soleus; HE, hip extensor; TS, triceps surae; QL, quadratus lumborum; T, torso; A, ankle; K, knee; KF, knee flexion; PI, piriformis; LB, lower back.

3.3. Risk-of-Bias Assessment

The risk of bias in the trials included in this meta-analysis was "some concerns". The details of the risk of bias assessment of the included trials are shown in Figures 2 and 3. The risk of bias assessment showed that the points that received the poorest evaluations were allocation concealment and the blinding of participants and personnel. Those studies that obtained the high-risk assessment in tool (1) of the ROB were assessed with the Newcastle–Ottawa[67] quality assessment for cohort studies. The details of Newcastle–Ottawa are shown in Figure 4.

Study or Subgroup	Experimental Group Mean	SD	Total	Control Group Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Risk of Bias A B C D E F G
1.1.2 Static									
Baklouti et al. (2021) s	45.36	2.8	11	49.27	3	11	2.3%	-1.30 [-2.23, -0.36]	? ? ? + + + +
Ceylan et al. (2014) s	38.8	3.93	10	38.3	3.8	10	2.5%	0.12 [-0.75, 1.00]	+ ? ? + + + +
Curry et al. (2009) s	40.8	6.46	24	40.9	7.6	24	5.3%	-0.01 [-0.58, 0.55]	? ? ? + + + +
Dalrymple et al. (2010) s	30	5	12	31	5	12	3.0%	-0.19 [-1.00, 0.61]	+ ? ? + + + +
de Oliveira et al. (2016) s	36.09	6.56	22	35.75	5.69	22	4.9%	0.05 [-0.54, 0.65]	+ ? ? + + + +
Dos Santos Galdino et al. (2010) s	23.4	3.8	25	23.3	3.5	25	5.4%	0.03 [-0.53, 0.58]	? ? ? + + + +
Fletcher et al. (2010a) s	49.7	5	27	51.8	5.6	27	5.7%	-0.39 [-0.93, 0.15]	+ ? ? + + + +
Fletcher et al. (2010b) s	45.9	4.7	21	47.7	5.1	21	4.7%	-0.36 [-0.97, 0.25]	+ ? ? + + + +
Maeda et al. (2021) s	21.7	2.7	15	23.3	3.2	15	3.5%	-0.53 [-1.26, 0.20]	+ + + + + + +
Perrier et al. (2011) s	41.9	6.6	31	41	6.8	31	6.4%	0.13 [-0.37, 0.63]	? ? ? + + + +
Subtotal (95% CI)			**198**			**198**	**43.6%**	**-0.17 [-0.39, 0.04]**	
Heterogeneity: Tau² = 0.02; Chi² = 10.66, df = 9 (P = 0.30); I² = 16%									
Test for overall effect: Z = 1.57 (P = 0.12)									
1.1.3 Dynamic									
Baklouti et al. (2021) d	47.36	3.04	11	49.27	3	11	2.6%	-0.61 [-1.47, 0.25]	? + + + + + +
Ceylan et al. (2014) d	36.7	2.35	10	38.3	3.8	10	2.5%	-0.49 [-1.38, 0.41]	+ ? ? + + + +
Christensen et al. (2008) d	60.26	11.92	68	60.2	12.12	68	10.5%	0.00 [-0.33, 0.34]	+ ? ? + + + +
Curry et al. (2009) d	42.3	6.1	24	40.9	7.6	24	5.3%	0.20 [-0.37, 0.77]	? + + + + + +
Dalrymple et al. (2010) d	29	5	12	31	5	12	2.9%	-0.39 [-1.20, 0.42]	+ ? ? + + + +
Fletcher (2010) dslow	48.5	8.7	24	47.9	8.7	24	5.3%	0.07 [-0.50, 0.63]	+ ? ? + + + +
Fletcher et al. (2010a) d	52.8	5.1	27	51.8	5.6	27	5.7%	0.18 [-0.35, 0.72]	+ ? ? + + + +
Fletcher et al. (2010b) d	49.6	4.6	21	47.7	5.1	21	4.7%	0.38 [-0.23, 0.99]	+ ? ? + + + +
Pagaduan et al. (2012) d	39.1	4.8	29	38	4.3	29	6.0%	0.24 [-0.28, 0.75]	+ ? ? + + + +
Perrier et al. (2011) d	43	6.3	31	41	6.8	31	6.3%	0.30 [-0.20, 0.80]	? ? + + + + +
Pojskić et al. (2015) d	39.1	5	21	36	5.1	21	4.6%	0.60 [-0.02, 1.22]	+ ? ? + + + +
Subtotal (95% CI)			**278**			**278**	**56.4%**	**0.12 [-0.05, 0.29]**	
Heterogeneity: Tau² = 0.00; Chi² = 10.39, df = 10 (P = 0.41); I² = 4%									
Test for overall effect: Z = 1.34 (P = 0.18)									
Total (95% CI)			**476**			**476**	**100.0%**	**-0.01 [-0.16, 0.14]**	
Heterogeneity: Tau² = 0.03; Chi² = 25.59, df = 20 (P = 0.18); I² = 22%									
Test for overall effect: Z = 0.17 (P = 0.87)									
Test for subgroup differences: Chi² = 4.24, df = 1 (P = 0.04), I² = 76.4%									



Risk of bias legend
(**A**) Random sequence generation (selection bias)
(**B**) Allocation concealment (selection bias)
(**C**) Blinding of participants and personnel (performance bias)
(**D**) Blinding of outcome assessment (detection bias)
(**E**) Incomplete outcome data (attrition bias)
(**F**) Selective reporting (reporting bias)
(**G**) Other bias

Figure 2. Forest plot. Results of a random-effects meta-analysis for different stretching protocols. Comparison with control group; 95% standardised mean difference in CMJ jump height is shown. The mean difference in training effect with lower and upper 95%CI limits is reflected in the green boxes. The relative weight of each study in relation to the overall effect is represented in the size of the square. The black diamonds show the overall training effect in overweight and obese individuals. Overall effect −0.28 (95%CI −1.07 to 0.51), $p = 0.490$. SD: standard deviation; IV: inverse variance; CI: confidence interval.

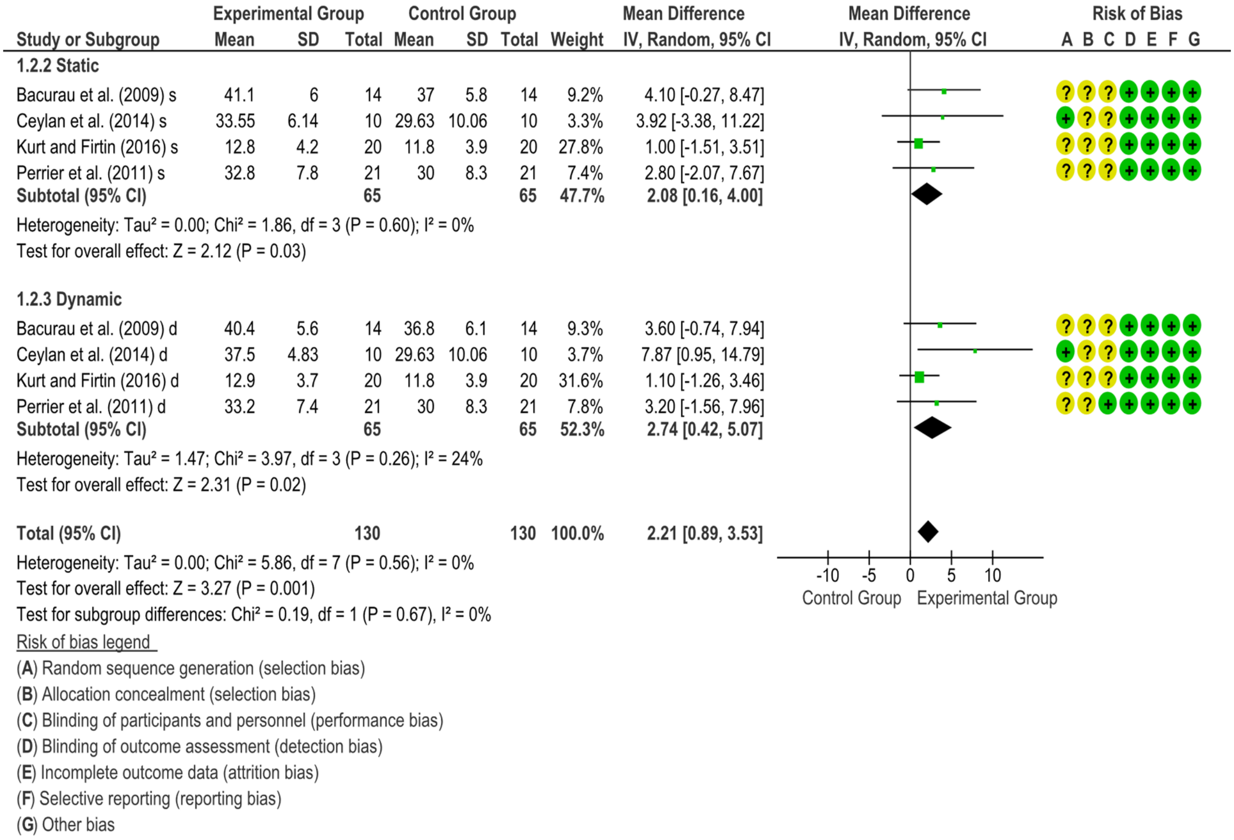


Figure 3. Forest plot. Results of a random-effects meta-analysis for different stretching protocols. Comparison with control group. Standardised mean differences with 95%CI in hamstring ROM are shown. The relative weight of each study in relation to the overall effect is reflected in the green squares. The black diamonds show the overall training effect in overweight and obese individuals. Overall effect SMD 0.44 (95%CI 0.19 to 0.69), $p < 0.001$. SD: standard deviation; IV: inverse variance; CI: confidence interval.

Study	Selection				Comparability	Outcome			Score (*)	Quality
	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration the outcome not present at start	For confounders	Assesment of outcome	Was follow-up long enough	Adequacy of follow-up		
Bacurau et al. (2009)		*	*	*	*	*	*	*	7	Good
Curry et al. (2009)		*	*	*	*	*		*	6	Good
Dos Santos Galdino et al. (2010)		*	*	*	*			*	5	Poor
Perrier et al. (2011)		*	*	*	*		*	*	6	Good
Kurt et al. (2016)	*	*	*	*	*		*	*	7	Good

Figure 4. Newcastle–Ottawa (* = is considered).

3.4. Meta-Regression and Heterogeneity

Meta-regression analysis (Table 3) showed no significant interactions between the study's dependent variables and potential moderating variables. In addition, when heterogeneity was analysed without differentiating the type of stretching used during the warm-up (Supplementary Table S1), heterogeneity was observed. Moreover, the funnel plot did not show a significant asymmetry in CMJ (Egger's test: static = −1.8, $p = 0.113$; Dynamic = 1.3, $p = 0.235$). However, Egger's test showed significant heterogeneity. Nevertheless, the test should not be applied to variables with <10 studies. The sensitivity analysis revealed that the results retained their magnitude and significance after analysing the results when each of the included studies was removed one by one.

Table 3. Effects of moderating variables.

		Effect	Lower Limit	Upper Limit	Z	*p*	Tau	Tau^2 (SE)	I^2	R^2	df	Q	*p*
Static													
Total warm-up	Constant	−0.9355	−2.728	0.857	−1.34	0.237	0.002	0.000	0%	0.0%	6	6.1	0.301
	Moderator	0.0591	−0.059	0.177	1.29	0.254		(SE = 0.0695)					
Time aerobic warm-up	Constant	−0.5098	−1.296	0.276	−1.5	0.173	0.045	0.002	2%	0.0%	9	9.6	0.298
	Moderator	0.055	−0.065	0.175	1.06	0.321		(SE = 0.0514)					
Set	Constant		not enough data										
	Moderator												
Repetitions	Constant	−0.143	−1.232	0.947	−0.30958	0.766	0.109	0.012	10%	0.0%	8	9.9	0.196
	Moderator	-6.84×10^{-4}	−0.46	0.459	−0.00352	0.997		(SE = 0.0588)					
Stretching time	Constant	−0.4401	−1.156	0.276	−1.45	0.19	0.001	0.000	0%	0.7927	8	8.5	0.293
	Moderator	0.0162	−0.019	0.052	1.08	0.317		(SE = 0.0535)					
Rest stretching	Constant	0.0125	−1.22	1.245	0.0282	0.979	0.264	0.070	35%	0	5	6.7	0.143
	Moderator	−0.0228	−0.129	0.083	−0.5968	0.583		(SE = 0.1391)					
Dynamic													
Total warm-up	Constant	0.6314	−1.977	3.239	0.672	0.538	0.167	0.028	21%	0	5	5.8	0.214
	Moderator	−0.0315	−0.208	0.145	−0.495	0.647		(SE = 0.0933)					
Time aerobic warm-up	Constant		not enough data										
	Moderator												
Set	Constant	−0.0292	−0.651	0.592	−0.106	0.918	0.002	0	0%	0	10	10.091	0.343
	Moderator	0.1159	−0.35	0.582	0.563	0.587		(SE = 0.0353)					
Repetitions	Constant	0.0518	−0.317	0.421	0.317	0.758	0.001	0	0%	0	10	10.186	0.336
	Moderator	0.011	−0.041	0.063	0.48	0.643		(SE = 0.0344)					
Streching time	Constant		not enough data										
	Moderator												
Rest streching	Constant		not enough data										
	Moderator												

3.5. Meta-Analysis

The quantitative analysis only included studies analysing the effects of static and dynamic stretching. From the different protocols used, SS led to a non-significant decrease in jump height (SMD = −0.17, 95%IC [−0.39, 0.04]; I^2 = 16%; Z = 1.57; p = 0.12). In addition, DS led to a non-significant increase in jump height (SMD = 0.12, 95%IC [−0.05, 0.29]; I^2 = 4%; Z = 1.34; p = 0.18). However, statistically significant differences were observed between types of stretching in favour of dynamic stretching (p = 0.04) (Figure 2).

Regarding ROM, an increase was observed after SS (SMD = 0.40, 95%IC [0.05, 0.74]) and DS (SMD = 0.48, 95%IC [0.13. 0.83]) stretching when compared to the control intervention. However, no differences were observed (p = 0.73) between static and dynamic stretching (Figure 3).

4. Discussion

The present systematic review and meta-analysis aimed to synthesise and compare the effects of different types of stretching included in the warm-up on jumping performance and ROM. The main finding of this meta-analysis determines that SS in the warm-up decreased the height in the vertical jump; however, DS improved the height. Furthermore, both static and dynamic stretching in the warm-up improved the range of motion of lower-limb joints.

Regarding CMJ (height), the meta-analysis shows significant differences between static and dynamic stretching in the warm-up, with DS showing an improved tendency and SS a negative tendency. The percentage of change in the jump was 1.8% with respect to DS and −1.6% to SS. The findings of the meta-analysis in DS confirm the results shown in previous studies. Positive effects of DS are shown on force and power, increasing the height of the vertical jump with a percentage of change of 5.04% and 2.32% [54,55]. Several studies have concluded that vertical jump performance can be very relevant for evaluating performance in some sports [21]. It is considered a motor skill closely related to maximal strength, sprinting ability, and change of direction [23,24,56]. These improvements can be attributed to the voluntary, active, and rhythmic contractions of the muscles associated with dynamic stretching that can aid the warm-up process [57]. DS could contribute to warm-up effects by increasing muscle temperature, leading to a decrease in the viscous resistance of the muscles and, thus, an increase in tissue extensibility [7]. Several studies suggest that the increase in body temperature achieved by the warm-up is strongly related to jumping performance [58,59].

The results obtained in the meta-analysis related to the negative tendency of the SS in the warm-up in the height of jump (percentage of change −0.04%) are in agreement with those obtained by Stevanovic (2019), who reported a significantly decreased vertical jump height after SS in the warm-up (percentage of change −2.6%) [15]. The negative effects of SS could be due to an inhibited production of force in the contractile component of the muscle [60], changes in viscoelastic properties of the tendon, and increasing elasticity [61]. After SS, both muscle and tendon production and force transfer are less effective [15]. However, the findings of the current study do not support the previous research of Samson (2012) and Christensen (2020), who observed that SS did not lead to a decrement in vertical jump performance [20,62]. This rather contradictory result may be due to the exposure time of SS. Prior studies show that the amount of SS could affect strength loss less or more, revealing that larger volumes of SS have a greater negative effect on subsequent performance compared with smaller volumes of SS, thus explaining the different results in the literature [63]. The literature determines that exposures of up to 1 min do not negatively affect performance in sports requiring high levels of strength; however, breaks of at least 4 min after stretching are recommended [64]. Therefore, previous studies suggest that the duration of SS can increase the distensibility and reduce the stiffness of the muscle–tendon unit. Nevertheless, our meta-regression results did not show any association variables. In our study, a meta-regression was carried out to establish the relationship between training protocols (series, repetitions, and rest) and their influence on the variable jump height.

No relationship was found to corroborate that the duration of SS in the warm-up can be an influential factor in subsequent vertical jump performance. These findings suggest that further studies are needed to analyse the impact of training variables on jumping performance [65].

The results of our meta-analysis about the effect of static and dynamic stretching on ROM show no significant differences between types of stretching. A percentage change of 10.0% and 12.5% was obtained for static and dynamic stretching, respectively. These results confirm the previous studies. These studies have not identified significant differences between static and dynamic stretching. A percentage change of static and dynamic stretching has been found for SS 0.01% and for DS 0.02% [66]; for SS 0.16% and for DS 0.14% [67]; and for SS 0.09% and for DS 0.10% [68]. Our findings consider that both stretching methods in the warm-up obtain improvements in ROM. In accordance with the present results, previous studies have reflected the positive effect of SS on increasing ROM [65,69] and the positive effect of DS [50,70]. The increase in ROM after SS may be due to the exposure to stretching of the muscle tissue in a fixed position [57]. There is an increase in tendon elasticity and, therefore, a decrease in passive torque and an increase in ROM [61]. Similarly, the increase in ROM after DS may be due to the increase in angular displacement produced during this type of stretching [68,71].

Some of the limitations of this systematic review and meta-analysis are as follows: The results may be influenced by the heterogeneity of the warm-up protocols that included dynamic stretching. There were differences in the exercises, sets, repetitions, and musculature involved. On the other hand, the heterogeneity of the sample should also be highlighted. Despite having met the established inclusion criteria (men and women over 18 years of age without pathologies or health problems), the level of physical condition was not homogeneous, which may have conditioned the effect of the different types of stretching. It is recommended that future research should standardize the methods of dynamic stretching in the warm-up, as well as consider the level of training of the participants.

5. Conclusions

The results of the meta-analysis confirm the recommendation to include dynamic stretching as opposed to static stretching in the warm-up. Dynamic stretches included in the warm-up are attributed to greater positive effects on lower-limb performance and range of motion. Including dynamic stretching in the warm-up routine will provide a greater preparation for explosive and a large range of motion activities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14093872/s1, Table S1. Effects of moderating variables.

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