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Review

Chronic effect of different types of stretching on ankle dorsiflexion range of motion: Systematic review and meta-analysis

Diulian Muniz Medeiros*, Tamara Fenner Martini

Federal University of Health Sciences of Porto Alegre, Graduate Program of Rehabilitation Sciences, Physical Therapy Department, Porto Alegre, Brazil

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ABSTRACT

The calf muscles are one of the muscle groups that have the most need for adequate flexibility since they are deeply related to normal lower limb function. When the goal is to increase flexibility, the most commonly used technique is stretching. However, it remains unknown which stretching technique and parameters are the most effective to increase flexibility. Hence, the aim of the current review was to investigate the influence of chronic stretching on ankle dorsiflexion range of motion (DFROM) of healthy individuals. The search strategy included MEDLINE, PEDro, Cochrane CENTRAL, LILACS, and manual search from inception to February 2017. Randomized and controlled clinical trials that have analyzed the influence of chronic stretching on DFROM were included. On the other hand, studies with special populations (children, and people with any dysfunction/disease), and articles with no control group were excluded. Twenty studies were included out of 493 identified. The meta-analysis was performed according to the stretching technique used in the study. The results show that static stretching (5.17°; 95% CI: 4.39–5.95; I^2: 0%) and proprioceptive neuromuscular facilitation (4.32°; 95% CI: 1.59–7.04; I^2: 46%) are effective in increasing DFROM. Ballistic stretching did not show positive results to increase DFROM (3.77°; 95% CI: −0.03 to 7.56; I^2: 46%). In conclusion, chronic stretching is an effective way of improving ankle mobility in healthy individuals, especially when it contains a static component.

1. Introduction

Ankle plantar flexors are one of the muscle groups that have the most need for optimal mobility [1]. Proper ankle dorsiflexion range of motion (DFROM) is crucial to allow proper function in both exercises [2] and activities of daily living [3]. Furthermore, adequate DFROM is fundamental since the lack of plantar flexors flexibility seems to be a risk factor for several musculoskeletal dysfunctions such as plantar fasciitis [4], Achilles tendinitis [5], and knee injuries [6,7].

The most common approach used to enhance DFROM is stretching, which is a fundamental part of both rehabilitation and training protocols [8]. Stretching has the capacity of chronically increase flexibility, which in turn seems to increment muscle performance [9], and attenuate symptoms exercise-induced muscle soreness [10]. Generally, there are three main types of stretching: static stretching (SS), proprioceptive neuromuscular facilitation (PNF), and ballistic stretching (BS).

Even though there are a considerable amount of evidence on the topic [11], it remains unclear which stretching technique is the most effective in increasing DFROM. Moreover, there are several flexibility training protocols found in the literature, which makes it difficult to precisely establish a safe and effective protocol to increase flexibility. To the best of the authors' knowledge, there are two prior review studies that analyzed the effects of stretching on DFROM. However, they present limitations that should be mentioned.

The study from Radford et al. [12] analyzed only five studies, which is a small number to provide reliable information. The review from Young et al. [11] analyzed more studies (19 studies), but the meta-analysis contained only 8 studies. Furthermore, the authors do not provide any information regarding either the stretching techniques or the stretching protocols found in the literature. There seems to be a need for a review study that takes these details into account. Hence, the aim of the current systematic review and meta-analysis is to analyze the chronic influence of different types of stretching (SS, PNF, and BS) on DFROM of healthy participants, and verify if different flexibility training protocols produce distinct responses on DFROM.

2. Methods

The current study utilized PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) guidelines for Systematic Reviews and Meta-analysis [13].

* Corresponding author at: Rua Sarmento Leite 245, Centro Histórico, 90050170 Porto Alegre, Rio Grande do Sul, Brazil.
E-mail addresses: diulian@ufcspa.edu.br (D.M. Medeiros), tamarafm@ufcspa.edu.br (T.F. Martini).

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Table 1
Characteristics of the studies included in the review.

Study (year)	Groups (n)	Mean age ± SD	Stretching technique and protocol	Type of ROM assessment	Other variables evaluated	Ankle dorsiflexion ROM results
Akagi and Takahashi (2014)	Young men SS (19) CG (19)[a]	23.7 ± 2.3	SS 3 × 120 s 5 x week/6 weeks	Dynamometer PROM Hip and knee fully extended (prone)	Muscle thickness Muscle hardness MTU stiffness Joint torque	SS > CG
Abdel-Aziem and Mohammad (2011)	Not specified SS (25) CG (25)	SS: 22.3 ± 2.3 CG: 21.9 ± 4.1	SS 5 × 30 s – twice a day 5 x week/6 weeks	Universal goniometer AROM with hip and knee fully extended (prone)	Isokinetic dynamometer eccentric and concentric peak torques at 30 and 120°/s	SS > CG
Blazevich et al. (2014)	Healthy men SS (12) CG (10)	18.6 ± 0.9	SS 4 × 30s Daily/3 weeks	Dynamometer PROM seated Hip at 75° knee fully extended	EMG US images Muscle stiffness RFD	SS > CG
Christiansen (2008)	Healthy elderly SS (19) CG (18)	SS: 72.5 ± 4.7 CG: 71.6 ± 5	SS 3 × 45 s twice daily/8 weeks	Universal goniometer PROM with knee fully extended (supine)	Kinematic/kinetic analysis	SS > CG
Gajdosik et al. (2005)	Older women SS (10) CG (9)	65–89	SS 10 × 15s 3 x week/8 weeks	Dynamometer PROM with hip and knee fully extended	Functional tests Passive torque MVC	SS > CG
Gajdosik et al. (2007)	Unconditioned women SS (6) CG (4)	18–31	SS 10 × 15 s 5 x week/6 weeks	Dynamometer PROM with hip and knee fully extended	EMG Passive torque	SS > CG
Guissard and Duchateau (2004)	Healthy subjects SS (12)[a] CG (12)	21–35	SS 5 × 30 s – 4 stretching exercises 5 x week/6 weeks	Dynamometer PROM with hip and knee fully extended (prone)	EMG Passive torque	SS > CG
Johanson et al. (2009)	Healthy participants SS (8) CG (8)	SS: 29 ± 10.8 CG: 25.9 ± 5.5	SS 5 × 30 s – twice a day Daily/3 weeks	Goniometer PROM with hip and knee fully extended (prone)	EMG during gait	SS > CG
Konrad and Tilp (2014a)	Police cadets SS (20) CG (18)	22.9 ± 2.7	SS 4 × 30 s 5 x week/6 weeks	Electronic goniometer AROM Upright	EMG US images Passive torque	SS > CG
Konrad and Tilp (2014b)	Police cadets BS (21) CG (18)	22.6 ± 2.5	BS 4 × 30 s 5 x week/6 weeks	Electronic goniometer AROM Upright	EMG US images Passive torque	BS > CG
Konrad et al. (2015)	Police cadets PNF (20) CG (18)	23.6 ± 2.5	PNF 4 × 30 s 5 x week/6 weeks	Electronic goniometer AROM Upright	EMG US images Passive torque	PNF > CG
Knight et al. (2001)	SS (19) CG (18)	27.2 ± 7.27	SS 4 × 20s 3 x week/6 weeks	Universal goniometer AROM and PROM with 30° knee flexion	No other variables	SS > CG
Mahieu et al. (2006)	Recreationally athletes SS (33)	SS: 22.0 ± 1.1 BS: 21.9 ± 1.0	SS and BS 5 × 20 s	Universal goniometer AROM	US images Passive torque	SS = BS = CG

(continued on next page)

Table 1 (*continued*)

Study (year)	Groups (n)	Mean age ± SD	Stretching technique and protocol	Type of ROM assessment	Other variables evaluated	Ankle dorsiflexion ROM results
	BS (33) CG (30)	CG: 23.3 ± 9.1	Daily/6 weeks	Weight-bearing position		
Mahieu et al. (2009)	Recreationally athletes PNF (33) CG (29)	PNF: 22 ± 2.2 CG: 22.7 ± 1.9	PNF 5 × 30 s Daily/6 weeks	Universal goniometer AROM Weight-bearing position	US images Passive torque	PNF > CG
Nakamura et al. (2011)	Healthy males SS (9) CG (9)	SS: 21.1 ± 2.3 CG: 21.8 ± 0.8	SS 2 × 60 s Daily/4 weeks	Dynamometer PROM with hip and knee fully extended (prone)	US images Passive torque	SS > CG
Nakamura et al. (2016)	Healthy male SS (12) CG (12)	23.8 ± 2.3	SS 4 × 60 s 3 x week/4 weeks	Dynamometer PROM with hip and knee fully extended (prone)	EMG US images Passive torque	SS > CG
Nelson et al. (2012)	Undergrad students SS (13) CG (12)	23.2 ± 3.2	4 × 30s 3 x week/10 weeks	Angle finder Weight-bearing position	10RM test	SS > CG
Peres et al. (2002)	Healthy college students SS (11) CG (8)	22.5 ± 2.0	10 min 5 x week/3 weeks	Inclinometer PROM with hip and knee fully extended (prone)	No other variables	SS > CG
Rees et al. (2007)	Healthy active women PNF (10) CG (10)	19.7 ± 1.6	4–6 sets of 6–10 maximal contraction 3 x week/4 weeks	Goniometer Position not clear	Isometric PT RFD	PNF > CG
Youdas et al. (2003)	Active participants SS (22) CG (22)	24.9 ± 3.8	SS 1 × 30–120 s 5 x week/6 weeks	Universal goniometer AROM with hip and knee fully extended (prone)	No other variables	SS = CG

SS = static stretching; PNF = proprioceptive neuromuscular facilitation; CG = control group; PROM = passive range of motion; AROM = active range of motion; EMG = electromyography; US = ultrasonography; MTU = muscle-tendon unit; MVC = maximal voluntary contraction; RFD = rate of force development; RM = repetition maximum.

[a] Studies that used the contralateral leg as control group.

2.1. Data sources and searches

The authors searched the following electronic databases (from inception to February 2017): MEDLINE (accessed by PubMed), Physiotherapy Evidence Database (PEDro), The Cochrane Central Register of Controlled Trials (Cochrane CENTRAL), and *Centro Latino-Americano e do Caribe de Informação em Ciências da Saúde* (LILACS). In addition, the references of published studies were explored. The search comprised the following terms: "Flexibility", "Range of Motion", "Joint Range of Motion", "Joint Flexibility", "Muscle Stretching Exercises", "Proprioceptive Neuromuscular Facilitation (PNF) Stretching", "PNF stretching", "Passive Stretching", "Static Stretching", "Muscle Stretching Exercises" combined with a high sensitivity combination of words used in the search for randomized clinical trials [14]. The authors included publications in English, Spanish, and Portuguese. For the combination of the keywords, the Boolean terms "AND" and "OR" were utilized. The complete search strategy used for the MEDLINE database is shown in Table 1.

2.2. Eligibility criteria

The authors included randomized clinical trials (RCT) and controlled clinical trials (CCT), and studies that evaluated the effects of stretching (SS, PNF, and/or BS) on ankle DFROM. The following exclusion criteria were used: (1) samples comprised of people with any disease/dysfunction; (2) non-application of muscle stretching; (3) no ROM assessment; (4) samples with mean age under 18 years old; (5) repeated measures design studies; (6) studies with no control group.

2.3. Studies selection and data extraction

Two investigators independently evaluated titles and abstracts of all articles identified by the search strategy. All abstracts that did not provide sufficient information regarding the inclusion and exclusion criteria were selected for full-text evaluation. In the second phase, the same reviewers independently evaluated the full-text articles and made their selection in accordance with the eligibility criteria. Disagreements between reviewers were solved by consensus or through a third person review. Using standardized forms, the same two reviewers independently conducted data extraction with regard to the methodological characteristics of the studies, number of participants, age, stretching technique and protocol, ROM assessment protocol, and results. Disagreements were also solved by consensus. The main outcome extracted was DFROM.

2.4. Quality assessment

Study quality assessment included adequate sequence generation, allocation concealment, blinding of outcome assessors, description of losses and exclusions, and intention-to-treat analysis. Use of intention-to-treat analysis was considered as a confirmation on study assessment that the number of participants randomized and the number analyzed were identical, except for patients lost to follow-up or who withdrew consent for study participation. Studies without a clear description of these characteristics were considered as unclear or not reporting the latter. The same two reviewers independently performed the quality assessment.

2.5. Data synthesis and analysis

Pooled-effect estimates were obtained by post-intervention values [15]. Calculations were performed using a random-effects method. *P* value ≤ 0.05 and confidence interval of 95% (95%CI) were considered statistically significant. Statistical heterogeneity of the treatment effects among studies was assessed using Cochran's Q test and the inconsistency I^2 test, in which values above 25% and 50% were considered indicative of moderate and high heterogeneity, respectively [16]. All analyses were conducted using Review Manager version 5.3. The analyses were performed taking the types of stretching (SS, PNF, and BS) into account. Furthermore, within the analysis of SS, the studies regarding the training volume performed were separated. In the studies that a smaller reported value for ankle ROM indicated greater dorsiflexion, the means from 90° was subtracted prior to analysis to allow comparisons with other presented results. For the studies that reported only standard error (SE), the standard deviation (SD) was estimated by multiplying the SE by the square root of the sample size (n). The heterogeneity between studies was explored by re-running the meta-analyses removing one paper at a time to check whether some individual study explained heterogeneity.

3. Results

3.1. Description of studies

The search strategy yielded 493 articles, of which 29 studies were considered as potentially relevant and retrieved for detailed analysis. In the full-text analysis, 9 studies were excluded. Hence, 20 studies met the eligibility criteria and were included in the systematic review (n = 659), and all of them presented suitable data for meta-analysis. Fig. 1 shows the flow diagram of the studies included in this review, and Table 2 summarizes the studies' characteristics and their conclusions.

3.2. Risk of bias

Of the studies included in this systematic review, 40% presented an adequate sequence generation, 35% reported allocation concealment; 25% had blinded assessment of outcomes, 30% described losses to follow-up and exclusions, and 25% of the studies used the intention-to-treat principle for statistical analyses (Fig. 2).

3.3. Effects of interventions

The quantitative analysis of DFROM was carried out by grouping the articles that have applied the same stretching technique (SS, PNF, and BS).

3.4. Effects of SS on ankle DFROM

Fifteen studies [17–30] (n = 232) evaluated the influence of SS on ankle DFROM. The analysis showed that SS is effective in increasing flexibility when compared to a control group (5.17°; 95% CI: 4.39–5.95; I^2: 0%) (Fig. 3). The studies were divided in three subgroups according to the total flexibility training volume performed (< 3000 s; > 3000 s < 5000 s; and > 5000 s), the analyses showed an average increase in DFROM of 5.41°, 4.99°, and 5.31°, respectively.

3.5. Effects of PNF on ankle DFROM

Three studies [31–33] (n = 138) evaluated the influence of PNF stretching on ankle DFROM. The analysis showed that PNF is effective in increasing flexibility when compared to a control group (4.32°; 95% CI: 1.59–7.04; I^2: 32%) (Fig. 4).

3.6. Effects of BS on ankle DFROM

Only two studies [34,35] (n = 89) evaluated the influence of BS stretching on ankle DFROM. The analysis showed that BS is ineffective in increasing flexibility when compared to a control group (3.77°; 95% CI: −0.03 to 7.56; I^2: 46%) (Fig. 5).

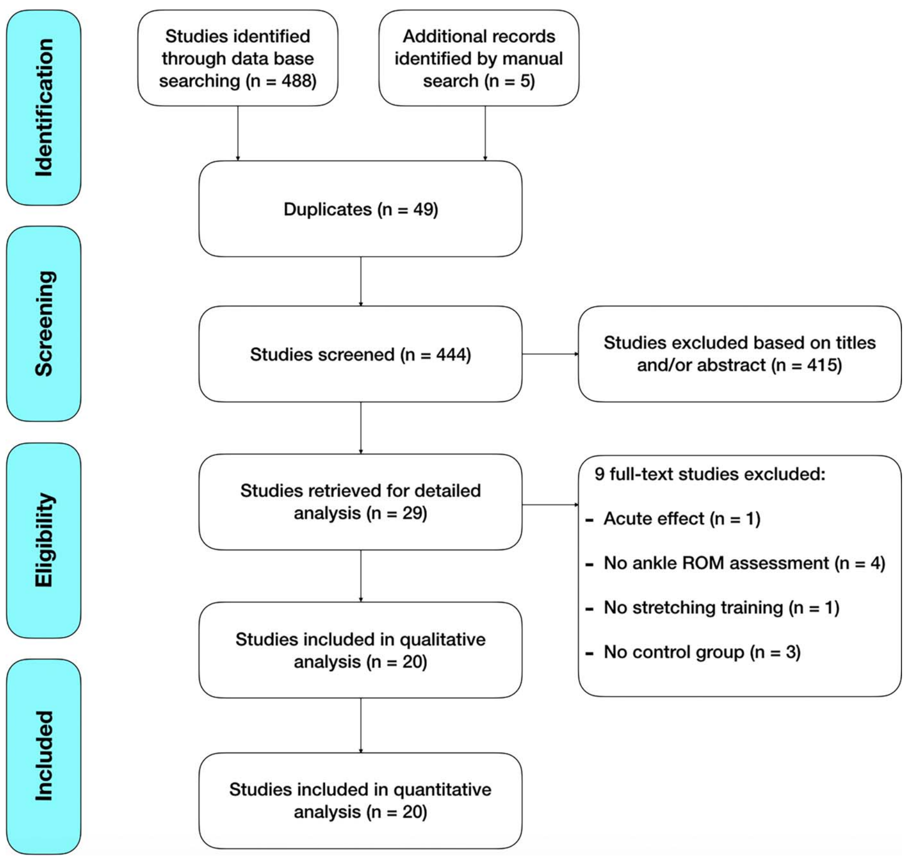


Fig. 1. Flowchart of the included studies.

4. Discussion

4.1. Summary of evidence

The evidence presented in this review showed that flexibility training using SS or PNF stretching is effective to enhance ankle DFROM, regardless the total flexibility training volume applied. On the other hand, BS does not seem to increase ankle DFROM.

4.2. Effects of SS on ankle DFROM

Static stretching involves reaching a certain ROM and holding the muscle (group) lengthened for a predetermined period of time [36]. Static stretching was the most common stretching technique among the included studies (15 out of 20), and it was effective in increasing flexibility, which is line with previous investigations [37]. This technique does not necessarily require assistance from another individual, and it is easily performed. Therefore, its application is highly recommended when the goal is to maintain a continuous flexibility training routine.

An interesting detail regarding the analysis of the influence of SS on DFROM was that a higher total training volume (> 5000 s) does not seem to provide better results than shorter training routines (< 3000 s). This is relevant once it might help to treat a pathological condition (e.g. plantar fasciitis) or decrease injury risk [6] soon after the beginning of the flexibility training. It is important to mention that the use of SS immediately prior to activities that demand maximal force production has been discouraged [38]. However, the use of SS in separate moments, as part of the training routine, has shown to be beneficial to muscle performance [39].

Usually, the theories used to explain the increase in muscle length following SS training are addition of sarcomeres in series [40], viscoelastic adaptations [41,42], and increase in stretch tolerance [43]. The addition of sarcomeres in series is a factor that may contribute to the increased flexibility after chronic stretching. Studies involving animals [44], tendon transfer [45], and mathematical models [40] have been performed in an attempt to elucidate the sarcomerogenesis process. Furthermore, ultrasonography has been performed in an attempt

Table 2
Complete search strategies for MEDLINE.

#1	"Range of Motion, Articular" [Mesh] OR "Joint Range of Motion" OR "Joint Flexibility" OR "Flexibility, Joint" OR "Range of Motion" OR "Passive Range of Motion" OR "muscle length" "stiffness" OR "Extensibility"
#2	"Muscle Stretching Exercises"[Mesh] OR "Exercise, Muscle Stretching" OR "Exercises, Muscle Stretching" OR "Muscle Stretching Exercise" OR "Dynamic Stretching" OR "Stretching, Dynamic" OR "Isometric Stretching" OR "Stretching, Isometric" OR "Active Stretching" "Stretching, Active" OR "Static-Active Stretching" OR "Static Active Stretching" OR "Stretching, Static-Active" OR "Static Stretching" OR "Stretching, Static" OR "Passive Stretching" OR "Stretching, Passive" OR "Relaxed Stretching" OR "Stretching, Relaxed" OR "Static-Passive Stretching" OR "Static Passive Stretching" OR "Stretching, Static-Passive" OR "Ballistic Stretching" OR "Stretching, Ballistic" OR "Proprioceptive Neuromuscular Facilitation (PNF) Stretching"
#3	(randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized controlled trials[mh] OR random allocation[mh] OR double-blind method[mh] OR single-blind method[mh] OR clinical trial[pt] OR clinical trials[mh] OR ("clinical trial"[tw]) OR ((singl*[tw] OR doubl*[tw] OR trebl*[tw] OR tripl*[tw]) AND (mask*[tw] OR blind*[tw])) OR ("latin square"[tw]) OR placebos[mh] OR placebo*[tw] OR random*[tw] OR research design[mh:noexp] OR follow-up studies[mh] OR prospective studies [mh] OR cross-over
#4	#1 AND #2 AND #3

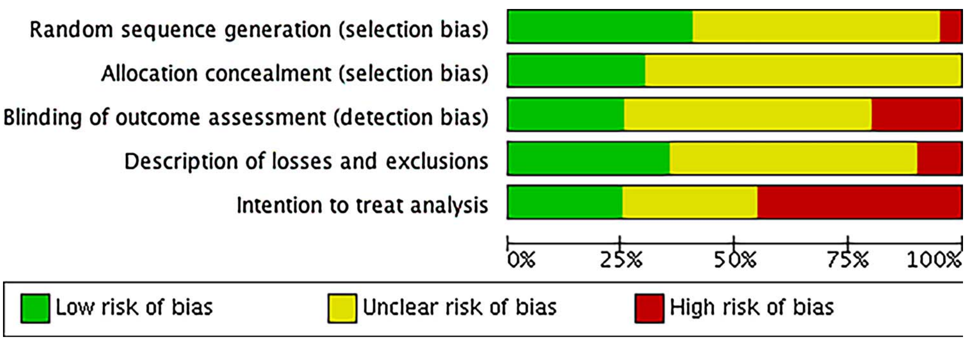
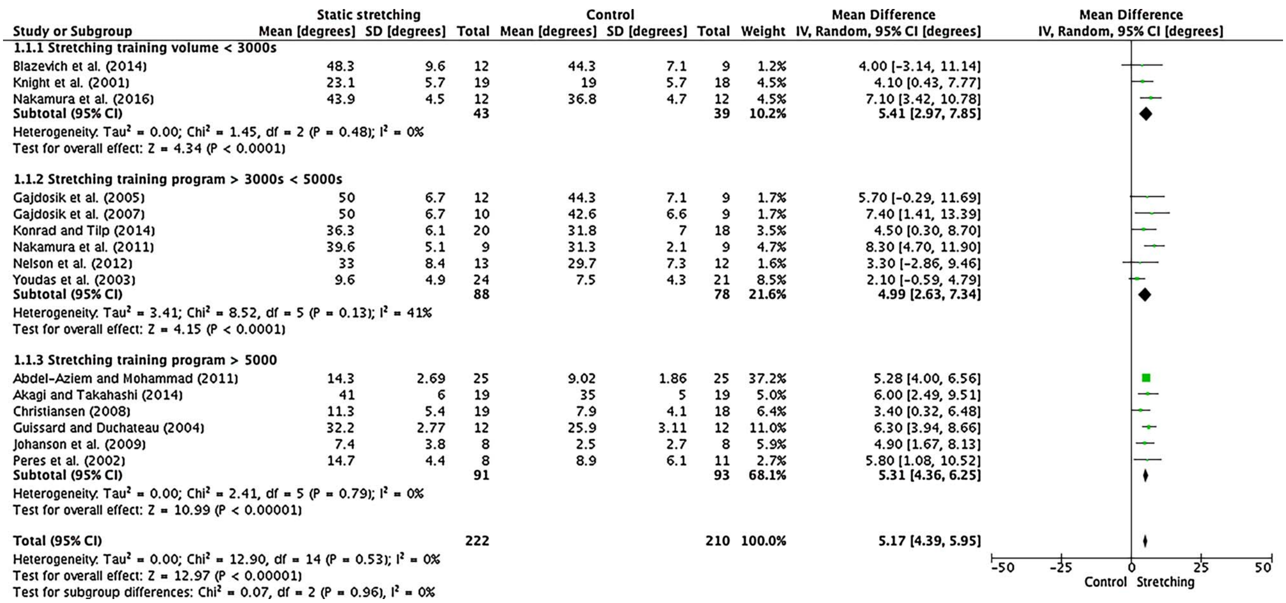
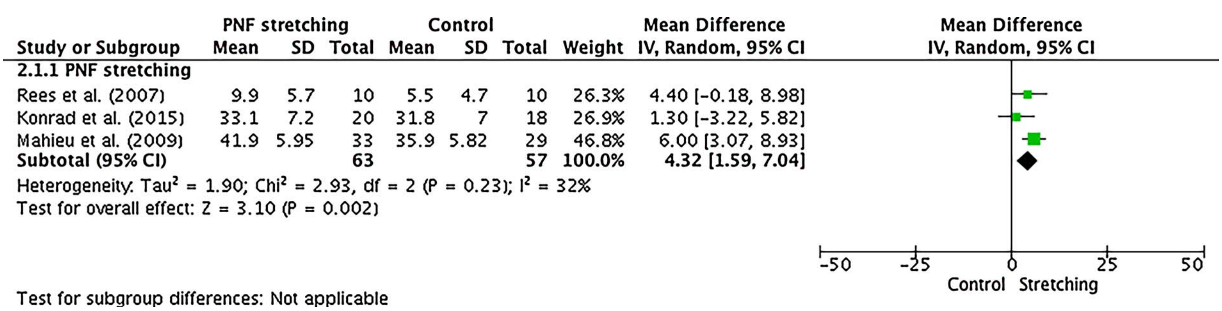


Fig. 2. Risk of bias graph: review authors' judgments about each risk of bias item presented as percentages across all included studies.



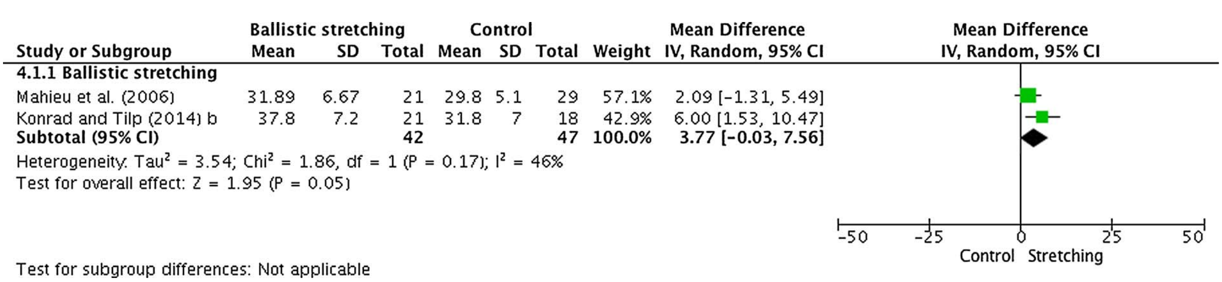
Study or Subgroup	Static stretching Mean [degrees]	SD [degrees]	Total	Control Mean [degrees]	SD [degrees]	Total	Weight	Mean Difference IV, Random, 95% CI [degrees]
1.1.1 Stretching training volume < 3000s								
Blazevich et al. (2014)	48.3	9.6	12	44.3	7.1	9	1.2%	4.00 [−3.14, 11.14]
Knight et al. (2001)	23.1	5.7	19	19	5.7	18	4.5%	4.10 [0.43, 7.77]
Nakamura et al. (2016)	43.9	4.5	12	36.8	4.7	12	4.5%	7.10 [3.42, 10.78]
Subtotal (95% CI)			**43**			**39**	**10.2%**	**5.41 [2.97, 7.85]**
Heterogeneity. Tau² = 0.00; Chi² = 1.45, df = 2 (P = 0.48); I² = 0%								
Test for overall effect: Z = 4.34 (P < 0.0001)								
1.1.2 Stretching training program > 3000s < 5000s								
Gajdosik et al. (2005)	50	6.7	12	44.3	7.1	9	1.7%	5.70 [−0.29, 11.69]
Gajdosik et al. (2007)	50	6.7	10	42.6	6.6	9	1.7%	7.40 [1.41, 13.39]
Konrad and Tilp (2014)	36.3	6.1	20	31.8	7	18	3.5%	4.50 [0.30, 8.70]
Nakamura et al. (2011)	39.6	5.1	9	31.3	2.1	9	4.7%	8.30 [4.70, 11.90]
Nelson et al. (2012)	33	8.4	13	29.7	7.3	12	1.6%	3.30 [−2.86, 9.46]
Youdas et al. (2003)	9.6	4.9	24	7.5	4.3	21	8.5%	2.10 [−0.59, 4.79]
Subtotal (95% CI)			**88**			**78**	**21.6%**	**4.99 [2.63, 7.34]**
Heterogeneity. Tau² = 3.41; Chi² = 8.52, df = 5 (P = 0.13); I² = 41%								
Test for overall effect: Z = 4.15 (P < 0.0001)								
1.1.3 Stretching training program > 5000								
Abdel-Aziem and Mohammad (2011)	14.3	2.69	25	9.02	1.86	25	37.2%	5.28 [4.00, 6.56]
Akagi and Takahashi (2014)	41	6	19	35	5	19	5.0%	6.00 [2.49, 9.51]
Christiansen (2008)	11.3	5.4	19	7.9	4.1	18	6.4%	3.40 [0.32, 6.48]
Guissard and Duchateau (2004)	32.2	2.77	12	25.9	3.11	12	11.0%	6.30 [3.94, 8.66]
Johanson et al. (2009)	7.4	3.8	8	2.5	2.7	8	5.9%	4.90 [1.67, 8.13]
Peres et al. (2002)	14.7	4.4	8	8.9	6.1	11	2.7%	5.80 [1.08, 10.52]
Subtotal (95% CI)			**91**			**93**	**68.1%**	**5.31 [4.36, 6.25]**
Heterogeneity. Tau² = 0.00; Chi² = 2.41, df = 5 (P = 0.79); I² = 0%								
Test for overall effect: Z = 10.99 (P < 0.00001)								
Total (95% CI)			**222**			**210**	**100.0%**	**5.17 [4.39, 5.95]**
Heterogeneity. Tau² = 0.00; Chi² = 12.90, df = 14 (P = 0.53); I² = 0%								
Test for overall effect: Z = 12.97 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.07, df = 2 (P = 0.96), I² = 0%								

Fig. 3. Analysis for the studies that performed static stretching (SS).



Study or Subgroup	PNF stretching Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
2.1.1 PNF stretching								
Rees et al. (2007)	9.9	5.7	10	5.5	4.7	10	26.3%	4.40 [−0.18, 8.98]
Konrad et al. (2015)	33.1	7.2	20	31.8	7	18	26.9%	1.30 [−3.22, 5.82]
Mahieu et al. (2009)	41.9	5.95	33	35.9	5.82	29	46.8%	6.00 [3.07, 8.93]
Subtotal (95% CI)			**63**			**57**	**100.0%**	**4.32 [1.59, 7.04]**
Heterogeneity. Tau² = 1.90; Chi² = 2.93, df = 2 (P = 0.23); I² = 32%								
Test for overall effect: Z = 3.10 (P = 0.002)								
Test for subgroup differences: Not applicable								

Fig. 4. Analysis for the studies that performed proprioceptive neuromuscular facilitation (PNF).



Study or Subgroup	Ballistic stretching Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
4.1.1 Ballistic stretching								
Mahieu et al. (2006)	31.89	6.67	21	29.8	5.1	29	57.1%	2.09 [−1.31, 5.49]
Konrad and Tilp (2014) b	37.8	7.2	21	31.8	7	18	42.9%	6.00 [1.53, 10.47]
Subtotal (95% CI)			**42**			**47**	**100.0%**	**3.77 [−0.03, 7.56]**
Heterogeneity. Tau² = 3.54; Chi² = 1.86, df = 1 (P = 0.17); I² = 46%								
Test for overall effect: Z = 1.95 (P = 0.05)								
Test for subgroup differences: Not applicable								

Fig. 5. Analysis for the studies that performed ballistic stretching.

to identify structural changes within the muscle [21]. Static stretching seems to increase fascicle length, especially when it is performed with high intensity (constant torque approach) [46], which is particularly important to potentiate dynamics activities by increasing muscular contraction velocity [47]. Nevertheless, there is still insufficient information regarding the stretching intensity and volume necessary to induce an adaptation within the muscle cell.

Another mechanism used to explain increased flexibility following SS is viscoelastic adaptations within the muscle-tendon unit (MTU) [48]. The viscoelastic variable most evaluated among the studies in this field is passive stiffness, which is the change in passive tension per unit change in length of the muscle [49]. Decreased passive stiffness seems to contribute to flexibility improvements after chronic stretching [26]. However, sometimes neither structural changes nor viscoelastic adaptations are observed following regular stretching. There is a considerable amount of evidence [20,31,43] stating that regular stretching only modifies the perception of the discomfort associated with stretch [50].

4.3. Effects of PNF on ankle DFROM

Three studies evaluated the influence of PNF stretching on DFROM. The analysis showed that PNF was effective in increasing flexibility. The main argument against the use of PNF stretching is that it usually needs assistance from another person, which would difficult its regular application. However, two of the included studies [31,32] employed protocols that the participants were able to perform the stretching by themselves. Therefore, PNF stretching seems to be a good option to be added in a stretching training protocol.

This stretching technique uses SS and isometric contractions of the target muscle in a cyclical pattern [51]. There are two main types of PNF stretching: contract-relax (CR) and contract-relax agonist contract (CRAC). It is believed that CR stretching sparks an inhibitory activity of the Golgi tendon organ (GTO), which leads to a muscular relaxation known as autogenic inhibition [52]. The CRAC is identical to CR stretching, but it includes a subsequent contraction of the agonist muscle. This contributes to relaxing the muscle being stretched through a spinal reflex known as reciprocal inhibition [51], which may maximize the increase in ROM. It is important to mention that all three studies included in the analysis performed CRAC stretching, which makes our results more reliable.

The mechanisms involved in flexibility improvements after PNF training are identical as those seen in SS, but the benefits may be enhanced by the neural responses aforementioned [51]. Nevertheless, this hypothesis has been refuted [53]. It is still uncertain whether the isometric contractions induce neural responses or just act as a distraction that enables the participant to tolerate a higher stretching intensity [54].

4.4. Effects of BS on ankle DFROM

Ballistic stretching is a type of dynamic stretching that involves the execution of fast bouncing movements used to achieve a greater ROM [55]. Only two studies evaluated the influence of BS on DFROM. The analysis showed that BS does not increase flexibility. Even though BS does not seem to provide flexibility improvements, this technique may be particularly important in warm-up routines [56,57]. It is well documented that both SS [58] and PNF [59] may decrease performance when employed prior to activity, and this may be because of neural inhibition [60]. On the other hand, BS has shown positive results in performance when applied before exercise [56,57].

4.5. Study strengths and limitations

To the best of the authors' knowledge, the current study is the first meta-analysis to analyze the role of different types of stretching (SS, PNF, and BS) on DFROM. Moreover, a strategy for a sensitive and comprehensive search to assure the location of all studies in this field was held. Making a parallel of this investigation with the review by Young et al. [11], it seems that the current results are more conclusive based on two main reasons: (1) this meta-analysis included 20 whilst theirs contained only eight studies; and (2) only studies that evaluated chronic effects of stretching were included in the current study, the fact that they have mixed acute and chronic effects studies weakens their conclusions. The irregular distribution of studies in the meta-analysis restricts this study's conclusions, and this must be pointed as a relevant limitation. Indeed, an analysis containing two studies will not have the same impact of an analysis containing 15 studies. The low to moderate methodological quality of the included studies must be highlighted as a limitation. Less than half of the studies failed to explain the generation of the random sequence. Only five studies blinded the outcome assessors. None of the included studies presented all the items in the risk of bias analysis.

5. Conclusion

Ankle stretching is a common technique used as part of the treatment of several ankle/foot conditions (e.g. plantar fasciitis, Achilles tendinopathy). The current review demonstrated that chronic stretching is effective to increase DFROM. Static stretching was the most common approach among the included studies, probably because it is easily performed and it usually shows satisfactory results. However, PNF stretching (especially self-stretching protocols) should not be disregard in a flexibility training routine. Future systematic reviews could verify the influence of other strategies (e.g. eccentric training) on DFROM to establish which alternative is the most adequate to increase ankle mobility.

Conflict of interest

The authors declare that they have no conflict of interest.

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