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Review article

Acute Effects of Dynamic and Ballistic Stretching on Flexibility: A Systematic Review and Meta-analysis

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Abstract

Dynamic stretching (DS) uses a controlled movement through the range of motion (ROM) of the active joint(s) by contracting the agonist muscles without being held in an end position. In contrast, ballistic stretching (BS) typically uses uncontrolled movements of a higher velocity with bouncing actions. However, BS is often considered to be a form of DS. When considered together, DS and BS reportedly increase flexibility, evidenced by single- and multiple-joint ROM improvements and other measurements. However, a meta-analysis with subgroup analyses revealing the acute effects of DS and BS on flexibility in detail, independently of other stretching methods, has yet to be conducted. The purpose of this meta-analysis was to investigate the acute effects of DS and BS on flexibility in healthy participants. The PubMed, Web of Science, and Scopus databases were searched for eligible papers published before September 9, 2024; 17 papers were included in the meta-analysis. The main meta-analysis was performed with a random-effect model, and subgroup analyses were performed to examine the effects of age (young vs. middle-aged and older), sex (male vs. mixed sex), stretching methods (DS vs. BS), stretched muscles (hamstrings vs. plantar flexors vs. multiple muscles), and flexibility outcomes (single-joint ROM vs. straight-leg raise test vs. sit-and-reach test). A small increase in flexibility was found following DS and BS (considered together) (effect size = 0.372, Z = 3.936, 95% confidence interval = 0.187–0.557, $p < 0.001$, $I^2 = 27\%$). Subgroup analyses revealed no significant differences between age ($p = 0.24$), sex ($p = 0.76$), stretching method ($p = 0.83$), stretched muscle ($p = 0.20$), or flexibility outcome ($p = 0.34$) groups. Our results suggest that DS and BS effectively provide acute, small-magnitude improvements in flexibility that are not significantly affected by individual characteristics, stretching methods, stretched muscles, or flexibility outcomes.

Key words: Warm-up exercise; ballistic stretching; range of motion; sit-and-reach test; healthy participants.

Introduction

Various stretching methods, such as static stretching (SS), dynamic stretching (DS), ballistic stretching (BS), and proprioceptive neuromuscular facilitation stretching (PNFS), are widely used by athletes and the general population for promoting flexibility and overall health (Konrad et al., 2017; Mahieu et al., 2007; Matsuo et al., 2019;2023; Spernoga et al., 2001; Zmijewski et al., 2020). Low flexibility is associated with a greater risk of muscle injury in athletes (Witvrouw et al., 2003), metabolic syndrome in community-dwelling older adults (Chang et al., 2015), and the risk of falls in older people (Menz et al., 2006). Therefore, stretching is mainly performed to increase flexibility—the intrinsic property of body tissues, particularly muscles and connective tissues, that determines the achievable range of motion (ROM) without injury (Knudson, 2008)—evidenced by improved single- and multiple-joint ROM and other measurements. Indeed, a recent meta-analysis review (Behm et al., 2023a) reported that a single bout of stretching is considered effective in providing acute, small-magnitude increases in ROM.

Among the various stretching methods, SS is the most well-known. SS involves lengthening a muscle until either a stretch sensation or the point of discomfort is reached, and then holding the muscle in a lengthened position for a prescribed period of time (Behm et al., 2023a; Behm et al., 2016; Behm and Chaouachi, 2011). Previous meta-analysis reviews have reported that SS has positive acute and chronic effects on flexibility (Arntz et al., 2023; Ingram et al., 2025). However, many recent review articles have also shown that prolonged SS (> 60 s per muscle group) without a proper dynamic warm-up can have detrimental acute effects on muscular performance measurements (Behm et al., 2016; 2021). In contrast to SS, many previous studies have shown that DS has beneficial acute effects on muscular performance measurements (Behm et al., 2016; Behm and Chaouachi, 2011; Little and Williams, 2006; Perrier et al., 2011; Yamaguchi and Ishii, 2005). Indeed, Behm et al. (2016) conducted a systematic review and reported mean performance impairments of 3.7% immediately after SS and an increase in performance of 1.3% after DS. Moreover, another meta-analysis review, which investigated the influence of stretching the hip flexor muscles, reported small impairments in muscular performance after SS and an increase after DS when removing the joint

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position sense parameter (Konrad et al., 2021). Therefore, DS methods are recommended as a component of warm-up exercises over SS.

DS uses a controlled movement through the ROM of the active joint(s) by contracting agonist muscles, which allows the antagonist muscle group to elongate without being held in an end position (Behm et al., 2023a; Behm et al., 2023b; Fletcher, 2010; Opplert and Babault, 2018). BS is often considered a form of DS (Behm and Chaouachi, 2011; Opplert and Babault, 2018), but it differs from DS in that it typically uses a higher velocity and uncontrolled movements with bouncing actions at the end of the ROM (Bacurau et al., 2009; Behm et al., 2023a; Nelson and Kokkonen, 2001). Numerous studies have reported that when pooled together, DS and BS have positive acute effects on flexibility (Bacurau et al., 2009; Behm et al., 2023b; Konrad et al., 2017; Matsuo et al., 2019;2023; Mizuno and Umemura, 2016; Nelson and Kokkonen, 2001). Therefore, DS and BS are considered effective stretching methods for improving flexibility. Indeed, Opplert and Babault (2018) performed a systematic review and reported substantial evidence pointing out the positive effects of DS and BS on ROM and subsequent performance. Moreover, Behm et al. (2023a) performed a meta-analysis to investigate the acute effects of various stretching methods (SS, DS/BS, and PNFS) and reported that subgroup analysis revealed the positive effects of DS/BS on ROM. However, a meta-analysis with subgroup analyses to reveal the acute effects of DS and BS on flexibility in detail, independently of the other stretching methods (SS and PNFS) is yet to be conducted. Consequently, there is a need to summarize all the available evidence for these stretching techniques.

Therefore, the purpose of this study was to systemically review papers and analyze the acute effects of DS and BS on flexibility in healthy participants, including evaluating potential moderating variables that may influence the effects of DS and BS (e.g., age, sex, stretching methods, stretched muscles, and flexibility outcomes). These data may guide the development of recommendations concerning the appropriate stretching methods to increase flexibility.

Methods

This review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for systematic reviews with a meta-analysis (Page et al., 2021). Our systematic review and meta-analysis was not pre-registered in a database.

Search strategy

The scientific literature was searched on the PubMed, Web of Science, and Scopus databases. The search was conducted on September 9, 2024, and papers published before that date were considered for inclusion in this study. The search code for all three databases was ([Flexib*] OR [Range of motion]) AND (Stretch*) AND ([Muscle] OR [Tendon]) AND ([acute effects] OR [training effects] OR [effects]).

Study selection

All study selection procedures were performed by seven independent reviewers (SM, KT, MN, TF, KO, GN, and TM). First, the titles and abstracts of all papers were reviewed to assess suitability. Those not consistent with the purpose of the study were excluded with reference to the inclusion and exclusion criteria (below). Following the initial screening process, the full-text articles were assessed. This process was performed by two researchers, with any disagreements resolved by a third researcher.

Inclusion and exclusion criteria

Articles investigating the acute effects of DS and BS on flexibility were included if they fulfilled the following selection criteria: (1) it was a randomized controlled trial; (2) it included measurements of acute pre- and post-stretching flexibility parameters such as single- or multiple-joint ROM for the stretched muscle(s) or joint(s); (3) it was published in a peer-reviewed journal in English before September 9, 2024; and (4) the study participants were healthy individuals. DS was defined as a controlled movement through the ROM of the active joint(s) by contracting agonist muscles, which allows the antagonist muscle group to elongate without being held in an end position (Behm et al., 2023a; Behm et al., 2023b; Fletcher, 2010; Opplert and Babault, 2018). BS was defined as high velocity and uncontrolled movements with bouncing actions at the end of the ROM (Bacurau et al., 2009; Behm et al., 2023a; Nelson and Kokkonen, 2001). We excluded studies that dealt with training (chronic, long-term) effects of stretching, investigated any combined interventions (e.g., DS with resistance training), lacked a control group, or had another treatment as a control group (e.g., static stretching). Moreover, we excluded review papers, case reports, special communications, letters to the editor, invited commentaries, conference papers, and theses.

Extraction of the data

The following data were extracted from the included papers: (1) characteristics of the paper (authors, year of publication, and sample size); (2) characteristics of participants (sex and age); (3) characteristics of stretching (stretching methods [DS or BS], stretched muscles, volume [sets, duration/repetitions], amplitude/intensity, velocity/frequency); and (4) flexibility measurements. For flexibility measurements, the pre- and post-intervention values plus standard deviations of the stretching and control groups were extracted. If flexibility was measured more than once after stretching to confirm the prolonged effects, the value measured at the closest time point after stretching was adopted. When the required data were not described in a paper, the corresponding authors were contacted via e-mail or similar channels (e.g., ResearchGate) to provide information. The studies were excluded if there was no response from the corresponding authors.

Statistical analysis and data synthesis

The statistical analysis was performed in accordance with previous studies (Behm et al., 2023a; Konrad et al., 2024; Takeuchi et al., 2023). The meta-analysis was performed using IBM SPSS version 29.0 (IBM Corp., Armonk, NY, USA). By applying a random-effect meta-analysis, the effect size (Cohen's d) in terms of the standardized mean difference was assessed. If more than one effect size was reported in a study, the mean of all measurements within the study was used for the meta-analysis and defined as combined (Behm et al., 2023a; Borenstein et al., 2010; Konrad et al., 2024; Takeuchi et al., 2023). Based on previous meta-analytic studies (Behm et al., 2023a; Konrad et al., 2024; Takeuchi et al., 2023), subgroup analyses were performed when there were ≥ 3 studies included in each subgroup. Consequently, subgroup analyses for age (young vs. middle-aged and older), sex (male vs. mixed sex), stretching methods (DS vs. BS), stretched muscles (hamstrings vs. plantar flexors vs. multiple muscles), and flexibility outcome (single-joint ROM vs. straight-leg raise test vs. sit-and-reach test) were conducted. Q-statistics were applied to determine the differences between the effect sizes of the subgroups (Behm et al., 2023a; Konrad et al., 2024; Takeuchi et al., 2023). The effect of a standardized mean difference of < 0.2 was considered trivial, 0.2–0.6 was considered small, 0.6–1.2 was considered moderate, 1.2–2.0 was considered large, 2.0–4.0 was considered very large, and > 4.0 was considered extremely large (Hopkins et al., 2009). I^2 statistics were calculated to assess the heterogeneity among the included studies, and thresholds of 25%, 50%, and 75% were defined as having a low, moderate, and high level of heterogeneity, respectively (Behm et al., 2023a; Higgins et al., 2003; Konrad et al., 2024; Takeuchi et al., 2023). An alpha level of 0.05 was defined for the statistical significance of all the tests.

Risk of bias assessment and methodological quality

The methodological quality of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (Konrad et al., 2024; Konrad et al., 2022; Takeuchi et al., 2023). The PEDro scale consists of 11 methodological criteria, and two independent assessors scored each item with 0 or 1 point. Higher scores on the PEDro scale indicate a better methodological quality. When there were differences in scores between assessors, the mismatched scores were resolved between the assessors. Moreover, Egger's regression intercept test statistics and visual inspection of the funnel plot were applied to detect possible publication bias.

Results

Search outcomes

In total, 2777 papers were identified from searching the databases, and six papers were identified from a personal library (Figure 1). After removing duplicates, 2228 papers were screened, and 24 papers were identified as eligible for this systematic review and meta-analysis. However, six papers were excluded because we could not obtain the flexibility data from the authors (Behara and Jacobson, 2017; Chen et al., 2015; de Cunha et al., 2021; Morrin and Redding, 2013; Oliveira et al., 2023; Smith et al., 2018).

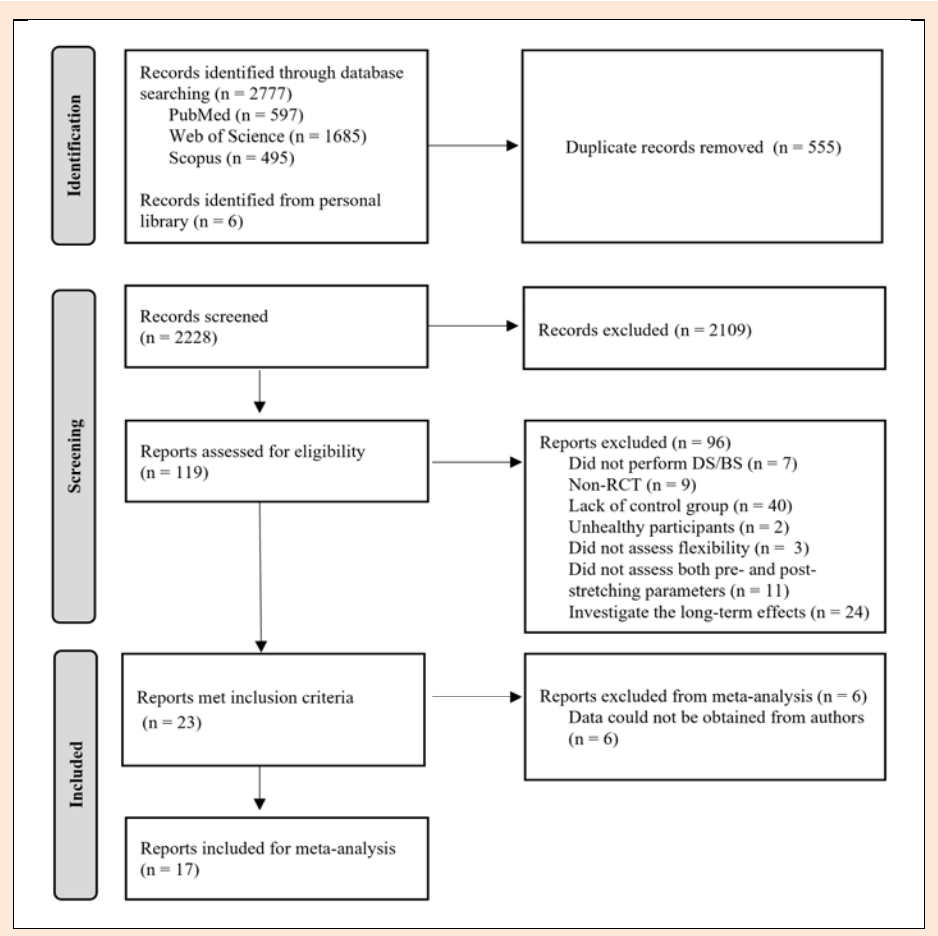

Figure 1. PRISMA flowchart. DS: dynamic stretching, BS: ballistic stretching, RCT: randomized controlled trial.

Overall, 35 effect sizes from 17 papers were included in this systematic review and meta-analysis (Barbosa et al., 2018; Behm et al., 2011; Chen et al., 2018; Hernández-Trujillo et al., 2024; Inoue and Nagano, 2023; Jung et al., 2023; Kaneda et al., 2020; Konrad et al., 2017; Mizuno, 2017; Mizuno and Umemura, 2016; Muanjai and Namsawang, 2023; Murphy et al., 2010; Nelson and Kokkonen, 2001; Oliveira et al., 2018; Paradisis et al., 2014; Ryan et al., 2014; Wiemann and Hahn, 1997). Table 1 presents the characteristics and outcomes of the 17 included studies.

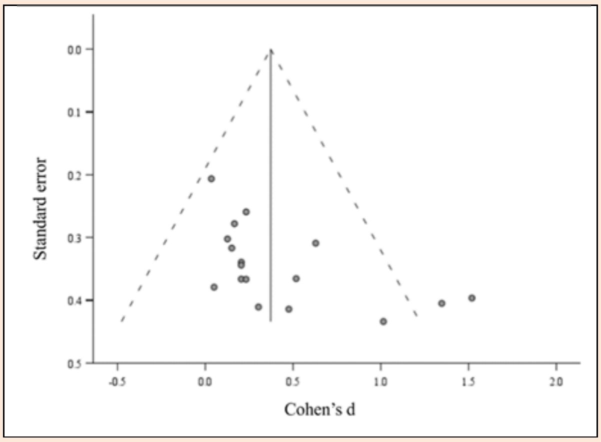

Figure 2. Funnel plot analysis.

Risk of bias assessment and methodological quality

Figure 2 shows a funnel plot of the 17 papers included in the meta-analysis. A visual inspection of the funnel plot and Egger's regression intercept test indicated a significant reporting bias ($p = 0.013$). The methodological quality of each paper, as assessed by the PEDro scale, is summarized in Table 2. The agreement of the PEDro scale between assessors was 97.9% (183 of 187 points). The mean and standard deviation of the PEDro scale was 6.53 ± 0.72 (ranging between 6 and 8 points), which indicated a low risk of bias (Konrad et al., 2022; Maher et al., 2003; Moran et al., 2021).

Acute effects

The meta-analysis revealed that DS and BS (considered together) had significant acute effects on flexibility (effect size = 0.372, Z = 3.936, 95% CI = 0.187–0.557, $p < 0.001$, $I^2 = 27\%$; Figure 3). Considered separately in subgroup analyses, both DS (effect size = 0.419, $p = 0.002$) and BS (effect size = 0.461, $p < 0.001$) had similar effect sizes (Table 3). However, subgroup analysis revealed that there were no significant differences in age (young vs. middle-aged and older; $p = 0.24$), sex (male vs. mixed sex; $p = 0.76$), stretching methods (DS vs. BS; $p = 0.83$), stretched muscles (hamstrings vs. plantar flexors vs. multiple muscles; $p = 0.20$), or flexibility outcome (single-joint ROM vs. straight-leg raise test vs. sit-and-reach test; $p = 0.34$; Table 3) groups.

Discussion

Our meta-analysis examined the acute effects of DS and BS on flexibility, independently of other stretching methods such as SS and PNFS. DS and BS have significant acute effects on flexibility, evidenced by single- or multiple-joint ROM and other measurements, with a small effect size (effect size = 0.372, $p < 0.001$) compared with control conditions. Additionally, the subgroup analysis indicated no significant differences between DS and BS ($p = 0.83$), the muscles stretched ($p = 0.20$), and flexibility outcome ($p = 0.34$). Therefore, these results suggest that DS and BS can improve flexibility acutely regardless of the stretching method (DS or BS), stretched muscle, and flexibility outcome. These results are in accordance with a recent meta-analysis article that reported the acute effects of various stretching methods (SS, DS/BS, and PNFS), in which subgroup analyses also revealed that there were no significant differences in stretching methods and muscles tested (i.e., sit-and-reach test, isolated hamstrings, and triceps surae ROM tests) (Behm et al., 2023a).

The overall effect size in this study (effect size = 0.372) was smaller than that in a previous meta-analysis investigating the effects of various stretching methods (SS, DS/BS, and PNFS) (effect size = 0.555) (Behm et al., 2023a). However, that study's subgroup analysis effect size for DS/BS (effect size = 0.447) was similar to the present study's overall effect size and subgroup analysis effect sizes for DS (effect size = 0.419) and BS (effect size = 0.461). In the previous investigation, DS and BS used a controlled or uncontrolled movements respectively, to elongate the target muscle without holding it in a static end position (Behm et al., 2023a). Therefore, it is possible that the substantial stretching loads of DS and BS are smaller than those of SS, which is performed by holding the muscle in a lengthened position for a prescribed period of time, because DS and BS consist of a stretched phase and a slack phase. Indeed, a recent meta-analysis review, which investigated the effects of SS and DS on the ROM of the hamstrings, reported that there was no significant difference in the acute (within 5 min after the intervention) and subacute (within 5–60 min after the intervention) effects between a single bout of SS or DS, but the acute and subacute effects of multiple bouts of SS were superior to DS (Cai et al., 2023). Previous studies have suggested that increased ROM immediately after SS and DS is attributable to changes in the pain threshold or stretch tolerance and decreased passive stiffness (Matsuo et al., 2019;2023). Similarly, to SS and DS, Konrad et al. (2017) reported that ROM increased and muscle–tendon stiffness decreased significantly after BS. In contrast, other previous studies have reported that DS did not change passive stiffness and suggested that increased flexibility after DS may be primarily caused by enhanced stretch tolerance (Mizuno, 2017; Mizuno and Umemura, 2016). Moreover, Behm et al. (2023b) reviewed conflicting reports on the acute and chronic effects of DS in which DS can result in a decrease, no change, or even an increase in muscle and/or muscle–tendon unit stiffness. Therefore, consistent results have not been observed, especially regarding changes in passive stiffness after DS.

Table 1. **Characteristics of the included studies.**

Study	Participants	Characteristics	Stretching method	Muscles stretched	Amplitude/ intensity	Volume (sets, duration/repitions)	Velocity/ frequency	Flexibility outcome
Barbosa et al. (2018)	Healthy, physically active males	Total: $n = 45$, DS: $n = 15$ (21.47 ± 3.0 years), CG: $n = 15$ (21.27 ± 2.8 years)	DS	Hamstrings	Mild discomfort	30 reps × 3 sets	Established "beep" rate	Knee extension ROM
Behm et al. (2011)	Young and middle-aged males	Total: $n = 18$, Young: $n = 10$ (22 ± 1.4 years), Middle-aged: $n = 8$ (46.3 ± 6.5 years)	DS	Quadriceps, Hamstrings, Plantar flexors	The highest ROM possible for all DS	8 reps (30 s) × 3 stretches	Not reported	Hip extension ROM, Sit-and-reach test
Chen et al. (2018)	Healthy young males	Total: $n = 36$ (22.0 ± 1.5 years), DS (CKC): $n = 12$, DS (OKC): $n = 12$, CG: $n = 12$	DS (CKC), DS (OKC)	Hamstrings	ROM (less than the point of discomfort)	DS (CKC): 8 reps (15 s) × 6 sets, DS (OKC): 15 s × 6 sets	DS (CKC): 1:1 s, DS (OKC): Not reported	Straight-leg raise test
Hernández-Trujillo et al. (2024)	Healthy, recreationally active males and females	Total: $n = 60$ (46.4 ± 5.5 years, 30 males and 30 females), BS: $n = 20$ (10 males and 10 females), CG: $n = 20$ (10 males and 10 females)	BS	Quadriceps, Hamstrings, Hip extensors, Hip flexors, Hip adductors, Hip abductors	ROM	20 s × 3 sets × 6 stretches	Following the metronome rhythm (40 bpm)	Hip flexion ROM, Knee flexion ROM
Inoue and Nagano (2023)	Healthy adult males	Total: $n = 12$ (21.2 ± 0.6 years)	DS, BS	Hamstrings	70%–90% of the maximum value of the POD	2 min × 4 sets	Not reported	Straight-leg raise test
Jung et al. (2023)	Healthy young males and females	Total: $n = 44$ (36 males and 8 females) DS: $n = 11$ (26.27 ± 1.68 years, 9 males and 2 females), BS: $n = 11$ (26.73 ± 2.15 years, 9 males and 2 females), CG: $n = 11$ (27.45 ± 3.17 years, 9 males and 2 females)	DS, BS	Plantar flexors	DS: Not reported, BS: 2–5° at the end ROM	45 s × 4 sets	DS: Once per second, BS: Twice per second	Ankle DF ROM
Kaneda et al. (2020)	Healthy young males	Total: $n = 17$ (23.2 ± 1.1 years)	DS	Hamstrings	ROM	15 reps (30 s) × 4 sets	Once every 2 s	Straight-leg raise test, Passive knee extension test
Konrad et al. (2017)	Healthy young males and females	Total: $n = 122$ (79 males and 43 females), BS: $n = 24$ (22.6 ± 2.8 years, 16 males and 8 females), CG: $n = 24$ (23.8 ± 3.5 years, 11 males and 13 females)	BS	Planter flexors	The last 5° of the individuals' ROM	30 s × 4 sets	At a frequency of 1 Hz	Ankle DF ROM

DS: dynamic stretching, BS: ballistic stretching, CKC: closed kinetic chain, OKC: open kinetic chain, CG: control group, ROM: range of motion, POD: point of discomfort, DF: dorsiflexion. Values are expressed as the mean ± standard deviation.

Table 1. Continue…

Study	Participants	Characteristics	Stretching method	Muscles stretched	Amplitude/ intensity	Volume (sets, duration/repititions)	Velocity/ frequency	Flexibility outcome
Mizuno (2017)	Healthy young males and females	Total: *n* = 15 (8 males and 7 females, 23 ± 2 years)	DS (1 set), DS (4 sets), DS (7 sets)	Plantar flexors	ROM	15 reps (30 s) × 1 set, 15 reps (30 s) × 4 sets, 15 reps (30 s) × 7 sets	Once every 2 s	Ankle DF ROM
Mizuno and Uemura (2016)	Healthy young males and females	Total: *n* = 12 (8 males and 4 females, 23 ± 1 years)	DS	Plantar flexors	ROM	15 reps (30 s) × 4 sets	Once every 2 s	Ankle DF ROM
Muanjai and Namsawang (2023)	Healthy young and older adult females	Total: *n* = 30, Young: *n* = 15 (20.9 ± 0.7 years), Older: *n* = 15 (66.6 ± 4.2 years)	DS	Hamstrings	The point of maximum dis-comfort without pain	8 reps × 6 sets	Stretch the hamstring muscles for 1 s and 1 s down back to the starting position	Straight-leg raise test, Sit-and-reach test
Murphy et al. (2010)	Healthy, physically active males	Total: *n* = 42, DS: *n* = 13 (20 ± 2 years), CG: *n* = 15 (21 ± 2 years)	DS	Pectoralis major, Deltoids, Latissimus dorsi, Hamstrings, Quadriceps, Gluteus maximus, Hip flexors, Calves	Until subjects felt slight discomfort, but not to a range of motion that produced pain	10 reps (20 s) × 12 stretches	Once every 2 s	Hip flexion ROM, Knee flexion ROM, Sit-and-reach test
Nelson and Kok-konen (2001)	College students	Total: *n* = 22 (males: 23.3 ± 2.7 years, females: 21.6 ± 3.0 years, 11 males and 11 females)	BS	Quadriceps, Hamstrings, Gluteals, Hip Adductors, Plantar flexors	2–5° at the end of the ROM	15 s × 3 sets unassisted × 5 stretches, 15 s × 3 sets assisted × 5 stretches	Once per second	Sit-and-reach test
Oliveira et al. (2018)	Trained young male soccer players	Total: *n* = 12 (17.67 ± 0.87 years)	BS	Quadriceps, Hamstrings, Hip extensors, Planter flexors	The maximum POD	30 s × 3 sets × 4 stretches	1:1 s	Sit-and-reach test
Paradisis et al. (2014)	Active adolescent boys and girls	Total: *n* = 47 (14.6 ± 1.7 years, 17 males and 30 females)	DS	Quadriceps, Hamstrings, Hip extensors, Plantar flexors	Not reported	20 reps (40 s) × 4 stretches	Once every 2 s	Sit-and-reach test
Ryan et al. (2014)	Healthy males	Total: *n* = 26 (22.2 ± 1.3 years)	DS, DS (twice the volume)	Quadriceps, Hamstrings, Hip extensors, Hip flexors, Hip adductors, Hip abductors, Plantar flexors	ROM	DS: 4 reps × 8 stretches, 6 reps × 3 stretches, DS (twice the volume): 8 reps × 8 stretches, 12 reps × 3 stretches	In a controlled manner through a ROM	Sit-and-reach test
Wiemann and Hahn (1997)	Healthy males	Total: *n* = 69 (aged 20 to 34), BS: *n* = 16, CG: *n* =15	BS	Hamstrings	Not reported	15 s × 3 sets × 3 stretches	Rhythmically	Hip flexion ROM

DS: dynamic stretching, BS: ballistic stretching, CKC: closed kinetic chain, OKC: open kinetic chain, CG: control group, ROM: range of motion, POD: point of discomfort, DF: dorsiflexion. Values are expressed as the mean ± standard deviation.

Table 2. PEDro scale.

Study	Random allocation	Concealed allocation	Groups similar at baseline	Assessor blinding	Participant blinding	Therapist blinding	Less than 15% dropouts	Intention-to-treat analysis	Between-group statistical comparisons	Point estimates and variability	Eligibility criteria specified *	Total
Barbosa et al. (2018)	1	1	1	1	0	0	1	1	1	1	1	8
Behm et al. (2011)	1	0	1	0	0	0	1	1	1	1	0	6
Chen et al. (2018)	1	0	1	0	0	0	1	1	1	1	1	6
Hernández-Trujillo et al. (2024)	1	0	1	0	0	0	1	1	1	1	1	6
Inoue and Nagano (2023)	1	0	1	0	0	0	1	1	1	1	1	6
Jung et al. (2023)	1	1	1	1	0	0	1	1	1	1	1	8
Kaneda et al. (2020)	1	1	1	0	0	0	1	1	1	1	1	7
Konrad et al. (2017)	1	1	1	0	0	0	1	1	1	1	0	7
Mizuno (2017)	1	0	1	0	0	0	1	1	1	1	0	6
Mizuno and Uemura (2016)	1	0	1	0	0	0	1	1	1	1	0	6
Muanjai and Namsawang (2023)	1	0	1	1	0	0	1	1	1	1	1	7
Murphy et al. (2010)	1	0	1	0	0	0	1	1	1	1	1	6
Nelson and Kokkonen (2001)	1	0	1	0	0	0	1	1	1	1	0	6
Oliveira et al. (2018)	1	1	1	0	0	0	1	1	1	1	1	7
Paradisis et al. (2014)	1	0	1	0	0	0	1	1	1	1	0	6
Ryan et al. (2014)	1	0	1	0	0	0	1	1	1	1	0	6
Wiemann and Hahn (1997)	1	1	1	0	0	0	1	1	1	1	0	7

PEDro, Physiotherapy evidence database; 1, one point scored; 0, no points scored; * Criterion of random allocation was not counted in the total score.

Several studies have examined the optimal conditions for DS. Takeuchi et al. (2022) reported that ROM did not change after DS at low speed and normal amplitude, but it was increased after DS at low speed and wide amplitude, at fast speed and normal amplitude, and at fast speed and wide amplitude. Oba et al. (2025) reported that the shear wave velocity (an index of muscle stiffness) significantly decreased after four sets of 30-s DS, while no significant changes were observed after one set of 30-s DS. Moreover, Mizuno (2017) reported that ROM was significantly increased after four and seven sets of DS, while no significant changes were observed after one set of DS. Therefore, it is possible that DS with greater loads, determined by the stretching amplitude/intensity, volume (sets, duration/repetitions), and velocity/frequency, may lead to greater changes in flexibility. However, compared with SS, it is difficult to quantify the applied load of DS between studies because there are various conditions described among papers, some of which have not been reported. Therefore, subgroup analysis of the DS or BS conditions was not performed in this study. Further studies are required to investigate the optimal conditions for DS and BS to improve flexibility.

The present subgroup analysis revealed no significant difference in flexibility after stretching between age groups (young vs. middle-aged and older; $p = 0.24$). Many previous studies have reported that older persons have lower flexibility than younger persons (Behm et al., 2011; Hirata et al., 2020; Medeiros et al., 2013; Wilke et al., 2019). Indeed, Medeiros et al. (2013) reported that there was a clear trend for diminishing flexibility with advancing age. Behm et al. (2011) and Muanjai and Namsawang (2023) reported that the improvements in flexibility following DS did not significantly differ between middle-aged or older persons and younger persons. Together, these results suggest that DS and BS may increase flexibility not only in younger persons but also in older adults with diminished flexibility. However, inconsistent results regarding changes in passive stiffness and stretch tolerance, which affect the change in ROM with aging, have been reported (Gajdosik et al., 2004; Hirata et al., 2020; Nakamura et al., 2017). For example, Gajdosik et al. (2004) reported that older women had reduced ROM and maximum passive resistive force (an index of stretch tolerance), along with greater passive stiffness compared with younger women. Nakamura et al. (2017) reported that older women had less ROM than younger women, but the shear elastic moduli of the medial and lateral gastrocnemius muscles were not significantly different between young and older women. Moreover, Hirata et al. (2020) reported that older men had less ROM and maximum joint torque (an index of stretch tolerance) and slower or equivalent shear wave speeds (an index of muscle stiffness) than younger men. Concerning the effects of SS, recent meta-analysis reviews reported that there are acute effects of SS on passive stiffness in young (Takeuchi et al., 2023) and older persons (Nakamura et al., 2024). Moreover, a previous study reported that SS significantly increased ROM and decreased muscle stiffness in older persons (Nakamura, et al., 2021b). That study also showed that the increase in ROM following SS was attributed not to changes in muscle stiffness but to stretch tolerance. Furthermore, Hirata et al. (2020) suggested that the influence of muscle stiffness on passive ROM weakens with advancing age and that stretch tolerance has a large effect on passive ROM regardless of age. Comparing the effects of SS and DS, Matsuo et al. (2019; 2023) reported that a decrease in passive stiffness and an increase in maximum passive torque (an index of stretch tolerance) were not significantly different between SS and DS in young persons. Therefore, although the effects of DS and BS on passive stiffness and stretch tolerance remain unclear, it is possible that DS and BS increase flexibility regardless of age, while the changes in passive stiffness and stretch tolerance, which contribute to increased ROM, differ with age.

The present subgroup analysis also revealed no significant difference in flexibility improvements after stretching between sex groups (male vs. mixed sex; p = 0.76). This result is consistent with a recent meta-analysis review reporting that the effects of various stretching methods on ROM did not differ between males and females (Behm et al., 2023a). The lack of observable sex differences can be attributed to the assessment of relative changes in flexibility following stretching (changes from pre- to post-stretching). In absolute terms, previous studies indicate that ROM is either greater in females than in males or that it is equivalent (Mier and Shapiro, 2013; Miyamoto et al., 2018; Nakamura et al., 2021a). Previous studies also indicate that passive stiffness or muscle stiffness is either lower in females than in males or that it is equivalent (Miyamoto et al., 2018; Nakamura et al., 2021a; Yu et al., 2022). Furthermore, Miyamoto et al. (2018) reported that in men, ROM was associated with passive muscle stiffness and tolerance to muscle stretch, whereas in women, it was associated with muscle stretch tolerance but not passive muscle stiffness. On the basis of these results, Miyamoto et al. (2018) suggested that muscular factors associated with ROM differed between men and women. Therefore, it was proposed that the factors contributing to the increase in ROM after DS may differ between the sexes, even though the increase itself showed no significant difference. However, to the best of our knowledge, no meta-analysis review investigated the effects of DS or BS on passive stiffness and/or stretch tolerance. Further analysis should be conducted to reveal any sex-based differences in the effects of DS and BS on flexibility in more detail.

We were unable to obtain the data from six papers on acute bouts of DS and BS (Behara and Jacobson, 2017; Chen et al., 2015; de Cunha et al., 2021; Morrin and Redding, 2013; Oliveira et al., 2023; Smith et al., 2018). Four of these papers showed a significant increase in flexibility after DS or BS (Behara and Jacobson, 2017; Chen et al., 2015; de Cunha et al., 2021; Oliveira et al., 2023), and two papers showed no difference between DS and control conditions, or a tendency toward a decrease in flexibility after DS (Morrin

Table 3. Subgroup analyses.

Subgroup	Subgroup categories	Number of studies	Effect size of means (95% CI)	Z-Value	p-Value	Q-statistics
Age	Young	16	0.415 (0.207–0.623)	3.911	< 0.001	
	Middle-aged and older	3	0.131 (−0.295–0.557)	0.602	0.547	
	Overall	19	0.366 (0.187–0.546)	4.008		(Q = 1.38, df (Q) = 1, p = 0.24)
Sex	Male	9	0.426 (0.134–0.719)	2.857	0.004	
	Mixed sex	7	0.361 (0.057–0.664)	2.329	0.020	
	Overall	16	0.391 (0.188–0.594)	3.768	< 0.001*	(Q = 0.09, df (Q) = 1, p = 0.76)
Stretching methods	Dynamic stretching	12	0.419 (0.147–0.690)	3.024	0.002	
	Ballistic stretching	7	0.461 (0.197–0.726)	3.420	< 0.001	
	Overall	19	0.426 (0.236–0.616)	4.395	< 0.001*	(Q = 0.05, df (Q) = 1, p = 0.83)
Stretched muscles	Hamstrings	6	0.569 (0.156–0.981)	2.699	0.007	
	Plantar flexors	4	0.510 (−0.020–1.040)	1.886	0.059	
	Multiple muscles	7	0.190 (−0.031–0.412)	1.686	0.092	
	Overall	17	0.372 (0.187–0.557)	3.936	< 0.001*	(Q = 3.17, df (Q) = 2, p = 0.20)
Flexibility outcome	Single-joint ROM	9	0.326 (0.093–0.559)	2.742	0.006	
	Straight-leg raise test	4	0.698 (0.076–1.320)	2.199	0.028	
	Sit-and-reach test	7	0.221 (0.006–0.435)	2.016	0.044	
	Overall	20	0.336 (0.185–0.486)	4.371	< 0.001*	(Q = 2.14, df (Q) = 2, p = 0.34)

ROM, range of motion; 95% CI, 95% confidence interval; mixed sex, males and females; * Significant difference within a group.

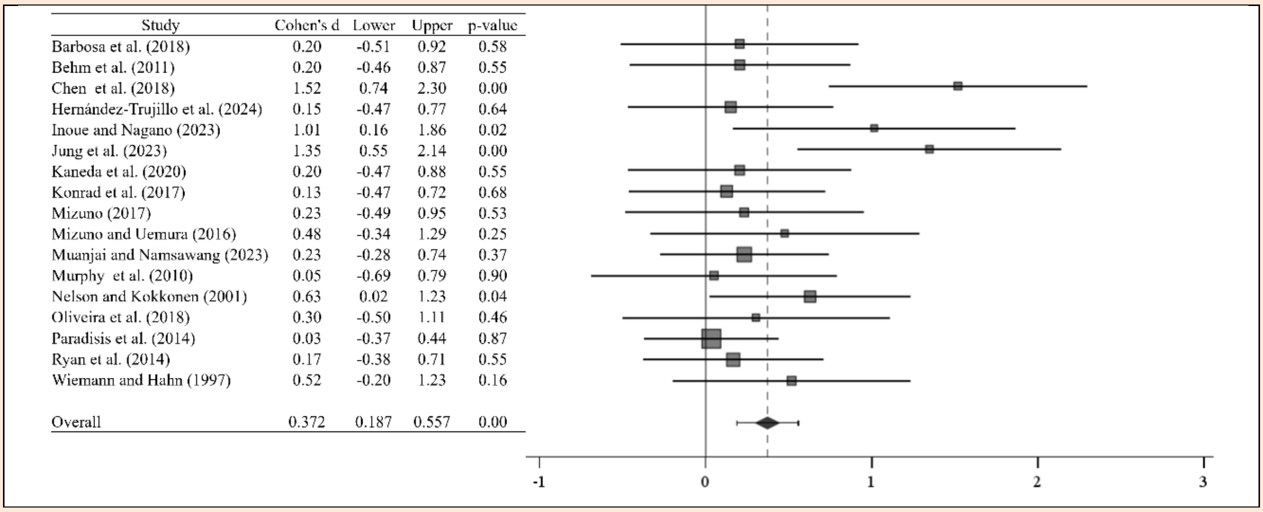

Figure 3. **Forest plot presenting all included studies on flexibility after dynamic or ballistic stretching.**

and Redding, 2013; Smith et al., 2018). Considering the effect sizes in the papers included in this study and the funnel plot analysis (Figures 2 and 3), missing data may not have significantly affected the results of the main meta-analysis of an acute bout of DS or BS.

In the present study, the results revealed a significant publication bias ($p = 0.013$) and low to moderate heterogeneity ($I^2 = 27\%$). The effect sizes in Chen et al. (2018) (effect size = 1.52) and Jung et al. (2023) (effect size = 1.35) were larger than those in the other studies, leading to a potential risk of publication bias and heterogeneity. Even when we excluded these studies, the overall results of the meta-analysis were similar, but the effect sizes became smaller (effect size = 0.251, Z = 3.041, 95% CI = 0.089–0.413, $p = 0.002$, $I^2 = 0\%$), although there was no significant publication bias ($p = 0.152$) or heterogeneity ($I^2 = 0\%$).

There are some limitations in the present study. First, a meta-analysis of the acute effects of DS on muscular performance was not conducted. To the best of our knowledge, no meta-analysis of the acute effects of DS or BS on muscular performance has been conducted. Similar to this study's meta-analysis results on the effects of DS and BS on flexibility, meta-analysis results on muscular performance would be highly valuable, particularly in the sports field. Therefore, further meta-analyses should be conducted to reveal the acute effects of DS and BS on muscular performance. Second, the results of the subgroup analysis revealed that there was no significant difference between age (young vs. middle-aged and older) or sex (male vs. mixed sex) groups. However, there may have been bias in the participant characteristics, as only three papers included in this meta-analysis involved middle-aged or older participants, and only one paper included female participants. Further analysis should be conducted to reveal the influence of participant characteristics in more detail.

Conclusion

This meta-analysis showed that flexibility significantly increases after an acute bout of DS or BS, with a small effect size. Subgroup analyses showed no significant differences based on age, sex, stretching methods, stretched muscles, or flexibility outcomes.

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Key points

- We conducted a meta-analysis to clarify the acute effects of dynamic and ballistic stretching on flexibility in healthy participants.
- Flexibility significantly increases after an acute bout of dynamic or ballistic stretching with a small effect size.
- No significant differences were observed for age, sex, stretching methods, stretched muscles, or flexibility outcomes.

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