Heliyon 9 (2023) e18795

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Dynamic and static stretching on hamstring flexibility and stiffness: A systematic review and meta-analysis

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ARTICLE INFO

Keywords:
Muscle stretching exercises
Hamstring
Range of motion
Mechanical properties

ABSTRACT

Introduction: Hamstring injuries are one of the most common types of damage in sports. Insufficient flexibility and high stiffness are important reasons for it. Stretching is often used in warm-up activities before exercises to increase flexibility, among which dynamic stretching (DS) and static stretching (SS) are the most widely used. The effects of these two stretching techniques on the flexibility or stiffness of the hamstring still need to be clarified.
Objective: This study aimed to compare the short-term, medium-term, and long-term effects of DS and SS on improving hamstring flexibility and stiffness via a meta-analysis of RCTs.
Methods: RCTs were identified from PubMed, Cochrane Library, Web of Science, and PEDro from inception to July 28, 2022. The methodological quality was evaluated using the PEDro scale. The mean difference and 95% confidence interval of the outcome variables before and after stretching were calculated and the extracted data were quantitatively processed using a random or fixed effects model.
Results: A total of 27 RCTs and 606 participants were included. In terms of improving the ROM of the hamstring, there was no significant difference in the acute (MD, −0.70, 95% CI, −1.54 to 0.14; $Z = 1.63$, $P > 0.05$) and sub-acute effects (MD, 1.71, 95% CI, −2.80 to 6.22; $Z = 0.74$, $P > 0.05$) between a single bout of SS and DS, while the acute (MD, −5.13, 95% CI, −7.65 to −2.61; $Z = 3.99$, $P < 0.05$) and sub-acute effects (MD, −5.30, 95% CI, −6.33 to −4.27; $Z = 10.04$, $P < 0.05$) of multiple bouts of SS was superior to DS; There was no significant difference in the medium-term effect between the two stretching techniques (MD, 3.48, 95% CI, −2.57 to 9.53; $Z = 1.13$, $P > 0.05$), but the long-term effect of SS was better than DS (MD, - 10.40, 95% CI, −10.97 to −9.83; $Z = 35.57$, $P < 0.05$). Regarding the length of the hamstring, the acute (MD, −0.41, 95% CI, −1.09 to 0.26; $Z = 1.20$, $P > 0.05$) and sub-acute effects (MD, −0.73, 95% CI, −1.69 to 0.22; $Z = 1.51$, $P > 0.05$) of a single bout of DS and SS were similar. Two studies have compared the effects on hamstring stiffness, with one showing similar effects, and the other showed that DS was superior to SS. One study showed no difference in the magnitude of change in improving passive torque. No studies explored the effect of DS and SS on hamstring myofascial length. Only one study demonstrated no significant difference in hamstring thickness.
Conclusions: A single bout of DS and SS have similar short-term effects in improving hamstring ROM and length, while multiple bouts of SS can significantly improve hamstring ROM compared to DS. DS and SS showed similar effects on hamstring myofascial length.

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https://doi.org/10.1016/j.heliyon.2023.e18795
Received 27 April 2023; Received in revised form 26 July 2023; Accepted 27 July 2023
Available online 29 July 2023

1. Introduction

Flexibility refers to the joint's range of motion (ROM) and represents the ability to move the joint through a full ROM without restriction and pain [1], which is essential to physical fitness and dramatically impacts sports performance [2–4]. Gender, age, physical fitness, joint type, tendon, ligament, and muscle extensibility affect flexibility [2,4,5]. Muscle stiffness is quantified by the ratio of change in the force of the muscle to its length [6]. As muscle stiffness increases or flexibility decreases, the elasticity of the muscle decreases, meaning that when force is applied to the muscle, it is difficult for the muscle to be lengthened, resulting in insufficient or limited ROM [7–9]. Proper flexibility and stiffness allow muscles to adapt better to stress, prevent muscle pain, and improve athletic performance. Conversely, a lack of muscle flexibility can lead to limited joint movement and strength imbalance, affecting daily life and athletic performance, and even increasing the risk of sports injuries [10,11].

Hamstring injuries are one of the most common types of damage in sports and have a high risk of recurrence [12]. A study by the Union of European Football Associations showed that the proportion of hamstring injuries in European men's professional football increased from 12% to 24% of all injuries between 2001 and 2022 [13]. Studies have shown that the cause of hamstring injuries is usually weak strength or poor flexibility [12,14]. Therefore, adequate warm-up exercises are possibly important to prevent or reduce hamstring injury.

Stretching is one of the most common pre-workout warm-up activities and is also applied in the relaxation phase after exercise [7, 15]. During stretching, the applied force induces acute elongation of soft tissue, leading to increased muscle flexibility and joint ROM [9,16,17]. Currently, several stretching techniques are proposed, including static stretching (SS), dynamic stretching (DS), ballistic stretching (BS), and Proprioceptive Neuromuscular Facilitation (PNF), among which SS and DS are the most widely used stretching techniques [10,18].

SS is considered an easy and safe stretching technique and can be performed passively or actively [4]. During this procedure, the muscle is extended either passively or actively to the end of the ROM in a controlled manner or when the subject feels a stretch or tolerable pain and remains in this position for a specific time [19,20]. Its mechanisms mainly involve reduced muscle–tendon unit (MTU) stiffness, increased tolerance to stretch, and decreased reflex activity [10,17,20,21]. However, many studies have found that repeated and continuous SS possibly reduce muscle and sports performance, such as jump height, sprint speed, muscle strength, agility, balance, and reaction time [3,8,19,22,23]. Mechanical and neural factors can explain it. Mechanically, SS increases the length and compliance of the MTU, resulting in a decrease in peak torque and muscle contraction speed [24,25]. Neurologically, SS may reduce nerve impulses and optimal muscle activation [26,27].

DS refers to the controlled movement of the limb within active ROM, which is usually slow, rhythmic, or repetitive [7,8,11]. Recent studies have recommended DS as an alternative to SS because it improves muscle strength and performance while increasing ROM [11], due to a higher "Post-Activation Potentiation" (PAP) and increased muscle temperature, thus reducing the viscous resistance of muscles [17,28]. Contrary to SS, many studies have indicated that DS can improve sports performance of sprinting, jumping, and muscle strength [17,29,30] on account of decreased MTU stiffness, motor unit activation or increased reflex sensitivity, and decreased inhibition of antagonistic muscles [3,17].

Given the importance of the hamstring in sports activities and the high incidence of injury in sports, the correct and effective selection of the right way of stretching is important. Due to the conflicting and controversial research results on the effects of DS and SS on muscle flexibility, therefore, it is essential to conduct a meta-analysis to compare the effects between DS and SS on the flexibility of the hamstring and to throw light on sports enthusiasts, especially professional athletes sports enthusiasts.

2. Methods

This study was conducted based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statements and was registered in PROSPERO (Registration Number: CRD42022353525).

2.1. *Eligibility criteria*

Published RCTs with parallel or crossover designs that compared DS with SS on hamstring flexibility or stiffness were included. The participants included in eligible studies should be over 18 years old, and the intervention methods implemented should consist of both DS and SS. Studies described as DS (including BS, PNF, etc.) but not meeting the definition of DS were excluded. Many studies have shown that the increase or improvement of joint ROM is mainly attributable to the decrease of MTU stiffness or the rise in stretch tolerance [20]. Therefore, the outcome variables mainly include the macro-ROM and length changes and the micro indicators of stiffness, thickness, and passive torque (PT) in the hamstring.

2.2. *Primary outcomes*

- ROM of the hamstring was measured by a goniometer or digital inclinometer.
- Hamstring length was measured by specific tests including but not limited to "Sit and Reach (SR)" and "Finger Ground Distance (FGD)."

3. Secondary outcomes

- Hamstring stiffness was measured by Supersonic Shear Imaging Technique.
- Hamstring PT was measured by the isokinetic dynamometer.
- Hamstring fascicle length was measured by ultrasound.
- Hamstring thickness was measured by ultrasound.

The effects were divided into short-term, medium-term, and long-term effects according to the time they were evaluated after the intervention.

- Short-term effect: it was divided into acute effect and sub-acute effect; Acute effect was measured immediately within 5 min after the intervention. The sub-acute effect was measured within 5–60 min after the intervention.
- Medium-term effect: the outcome was measured within 60 min to 3 days after the intervention.
- Long-term effect: the outcome was measured more than three days after the intervention.

3.1. Search strategies

Studies with language limited to English were identified through computer-aided literature retrieval on Medline (via PubMed),

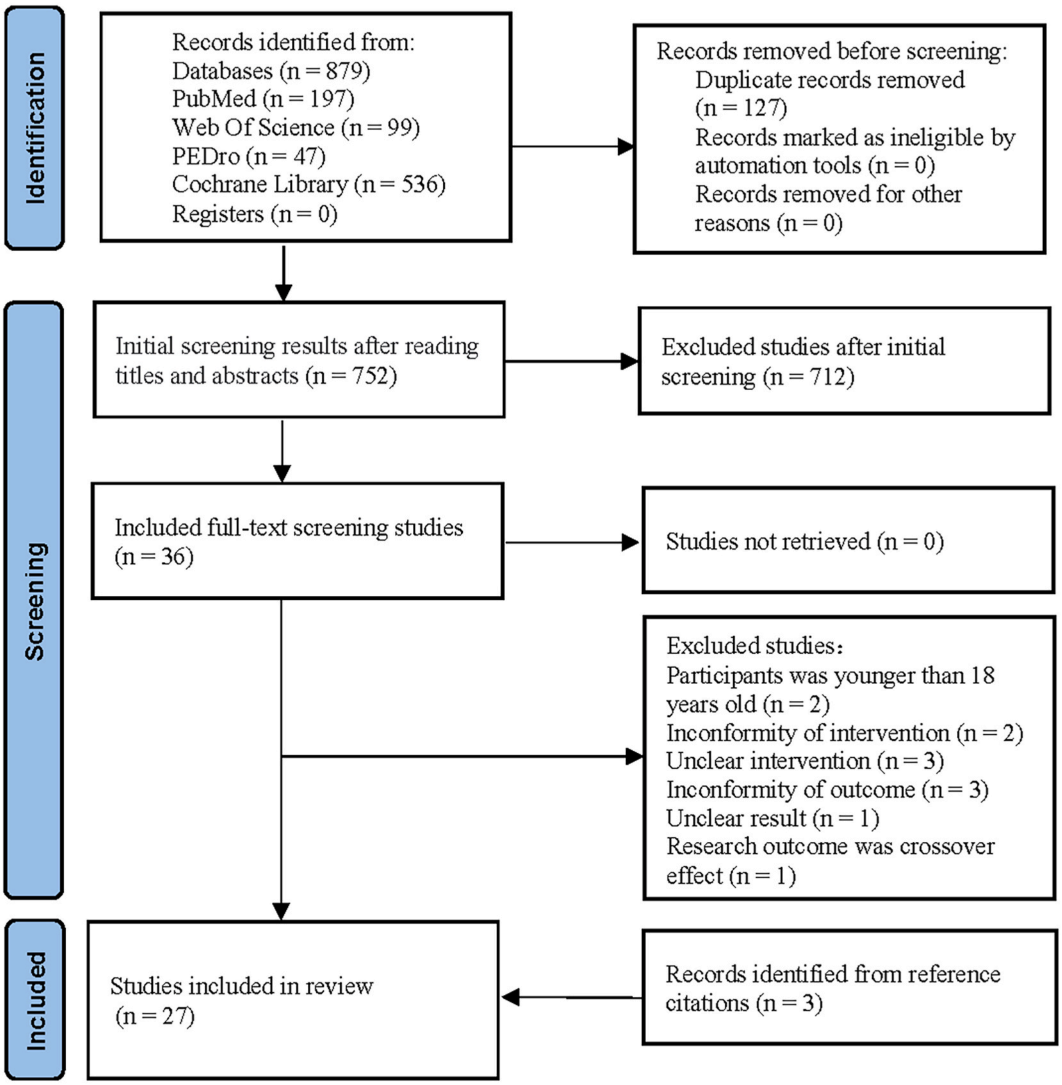

Fig. 1. Flow diagram for the systematic search.

Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and Physiotherapy Evidence Database (PEDro) from inception to July 28, 2022. We manually retrieved references from relevant reviews or clinical trials, the grey literature database on OpenGrey (www.opengrey.eu), and the clinical trial registration platform (www.clinicaltrials.gov). Detailed search strategies on CENTRAL were shown in Appendix 1. Other database search strategies were the same as this framework.

3.2. Study selection and data extraction

Two independent authors (CP, and LLW) conducted the screening and selection of studies. Studies were excluded if the titles and abstracts did not meet the pre-set standards. The consensus was achieved by discussion when divergence existed. Then, the full text of the studies was screened. Reasons for the exclusion of the literature from the full-text screening were recorded in the screening form. Two reviewers (CP, LLW) independently extracted trial details, including the first author, publication date, type of design, participants' data (physical activities, sample size, and age), stretching parameters, and measurement tools of hamstring flexibility or stiffness, follow-ups, from eligible studies. The authors were contacted via email if the required data were unavailable.

3.3. Assessment of methodological quality

PEDro scale was performed by two independent researchers (CP, LLW) to evaluate the methodological quality of each eligible RCT (9–10: excellent, 6–8: good, 4–5: fair, and ≤4: poor) [31], which consisted of 11 aspects (1: eligibility criteria were specified, 2: subjects were randomly allocated to groups, 3: allocation was concealed, 4: the groups were similar at baseline regarding the most important prognostic indicators, 5: there was blinding of all subjects, 6: there was blinding of all therapists, 7: there was blinding of all assessors, 8: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups, 9: all subjects for whom outcome measures were available received the treatment or control condition as allocated, 10: the results of between-group statistical comparisons are reported for at least one key outcome, 11: the study provides both point measures and measures of variability for at least one key outcome). Each item was evaluated as 'yes' or 'no' according to whether it met the criteria, and "Item 1″ was not considered in calculating the total score.

3.4. Statistics and data synthesis

Extracted data were processed by Review Manager Software (version 5.40) with a random or fixed effects model. We calculated mean differences (MD) with a 95% confidence interval (CI) for continuous outcome variables (ROM, distance of SR and FGD, muscle stiffness, thickness, PT, and fascicle length). I^2 and Q tests were used to calculate heterogeneity between studies. I^2 greater than 50% or $P < 0.1$ was considered to have greater heterogeneity. Then, subgroup analysis was performed comparing the results from the number of intervention sessions or effect duration aimed at the source of heterogeneity.

4. Results

4.1. Literature search

A total of 879 citations were retrieved (Fig. 1). After removing duplicate citations, 752 citations remained. Based on the information in the title and abstract, 35 citations were left for full-text screening. After the full-text screening, the age of the subjects in the two studies was below 18 years old [32,33], so those two studies were excluded. Two studies were excluded because they did not conform to the established definition of intervention [34,35]. In two studies, the intervention methods were not clearly defined and were excluded [36,37]. The outcomes of 3 studies did not meet the inclusion criteria and were excluded [38–40]. One study had unclear outcome indicators, so it was excluded [41]. One study, exploring the interaction effect of DS and SS, was excluded [42]. In addition, during the full-text screening process, we obtained three potentially eligible papers from Refs. [3,43,44]. Finally, 27 articles, meeting the eligibility criteria, were included for further analysis [1–4,8,14,16,21,24,29,43–59].

4.2. Study characteristics

4.2.1. Study design

The 27 studies [1–4,8,14,16,21,24,29,43–59] were all RCTs (Ten [2,14,43,44,47–49,53,58,59] were parallel design, and the remaining seventeen [1,3,4,8,16,21,24,29,45,46,50–52,54–57] were crossover design). In parallel design trials, the sample size ranged from 16 to 64 with 309 participants. In crossover design trials, the sample size ranged from 9 to 36, with 297 participants (Table 1).

4.2.2. Participants

The primary study population was young people, with an average age range from 18 to 27.8 years old [1–4,8,14,16,21,24,29,43,44,47–50,52–59]. One study compared the effects of stretching on young adults (mean age, 22 years) versus middle-aged adults (mean age, 46.3 years) [51]. The subjects of one study were older people, with an average age of 63.2 years old [45]. One study's participants included people of all ages, ranging from 24 to 56 years old [46]. The subjects of 9 studies were amateur or professional athletes, including wrestlers, football, fighting, rowing, handball players, and dancers [3,4,8,14,29,49,52,54,55]. The subjects of 9 studies [1,

Table 1
Characteristics of included studies.

Study ID	Study Design	Participants	SS protocols	DS protocols	Outcomes	Follow-up Period	Main Results, P value
Webright, W. G. 1997	RCT parallel	n (SS) = 15 (6 M 9 F) n (DS) = 11 (6 M 5 F) Healthy subjects with limited right hamstring flexibility (minimum of 15° loss of active knee extension) Age (SS) = 21.2 (3.65) Age (DS) = 21.8 (3.16)	Modified hurdler's position on the floor, flexed from the hip until a stretch sensation was felt in the posterior thigh, knee, and/or calf, avoiding cervical flexion, sustained for 30 s, twice daily, 6 weeks.	Sitting slumped on a sturdy object with feet do not reach the floor. Keep the right foot maximally dorsiflexed. Then, the knee was extended to end range for 1 s. Then lowered the leg and relaxed the foot in plantar flexion. Repeated 30 times, twice daily, 6 weeks.	Knee flexion ROM with the femur maintained in 90° of hip flexion	Immediately after the stretch	No significant difference in pre-test to post-test measures of knee ROM between the SS and DS groups. $P > 0.05$
Bandy, W. D. 1998	RCT parallel	n (SS), n (DS) = 19 Subjects with hamstring inflexibility (30° loss of active knee extension) Age (SS) = 24.63 (2.38) Age (DS) = 25.53 (4.86)	Standing, left foot planted on the floor, stretch the hamstring by raising right leg with the knee fully extended. Then flexed forward from the hip, maintaining the spine in a neutral position, sustained for 30 s, five times a week for 6 weeks.	Lying supine and holding the hip in 90° of flexion, actively extended the leg (5 s), and held the leg at the end of knee extension for 5 s, and slowly lowered the leg (5 s), repeat 6 times, 5 sessions a week for 6 weeks.	Knee extension ROM with the femur maintained in 90° of hip flexion	Immediately after the stretch	Both SS and DS could increase hamstring flexibility, but a 30-s SS was more effective than DS, for enhancing flexibility. $P < 0.05$
Herman, S. L. 2008	RCT parallel	n (SS) = 10 M n (DS) = 10 M Collegiate wrestlers Age (SS) = 19.5 (0.3) Age (DS) = 20.3 (0.3)	Step forward with the left leg and reach toward the left foot by bending the waist (Trunk remains straight). Both knees are slightly bent, and the arms are straight on either side of the forward leg. Repeat on the opposite side. Each SS was held for 30 s and performed only once, lasted 15 min, 5 times a week for 4 weeks.	Reach high overhead. Squat and reach between the legs, allowing the back to flex, but keeping the heels down. Return to the starting position. Perform at a slow cadence. Perform 1 repetition of each exercise, lasted approximately 15 min, 5 times a week for 4 weeks.	SR	Immediately after the stretch	Those two stretching methods showed similar effects in improving flexibility of the hamstrings. $P > 0.05$
O'Sullivan, K. 2009	RCT crossover	n (SS), n (DS) = injured (16 M, 2 F), uninjured (16 M, 2 F) Previously hamstring injured and uninjured university students Age (SS), Age (DS) = injured 21 (2), uninjured 21 (1)	The participant placed their leg on an elevated surface with their knee extended and their ankle plantarflexed, then lean forward from the hip, with their spine in neutral until a stretch was felt in the posterior thigh. This position was held for 30 s and repeated 3 times.	Each participant was instructed to swing the leg to be stretched forward into hip flexion whilst keeping their knee extended and their ankle plantarflexed and then swing back into slight hip extension, lasted for 30 s, and repeated 3 times.	Passive Knee Extension ROM with the femur maintained in 90° of hip flexion	Immediately after the stretch and after a 15-min rest	ROM after SS was greater than after DS ($p < 0.001$). After 15 min, there was a significant decrease in ROM for static stretching. ($p < 0.001$)
Amiri-Khorasani, M. 2011	RCT crossover	n (SS), n (DS) = 18 M Professional adult soccer players with no history of major lower limb injury Age (SS), Age (DS) = 19.22 (1.83)	Stretching hamstrings for 15s on each leg until approached the end of the ROM but within the pain threshold.	Stretching hamstrings for 30s at a rate of approximately 1 stretch cycle per second or unilaterally for 15s.	ROM of the hip in the follow-through kicking phase	After a 2-min rest after the stretch	There was a significant difference after DS compared with SS during the follow-through phase. ($p < 0.01$)
Behm, D. G. 2011	RCT crossover	n (SS), n (DS) = 10 M (young) and 7 M (middle-aged) Subjects participating in recreational or fitness activities 2–4 times per week Age (SS), Age (DS) = 22	In a standing position, flexing their hip, and placing their heel with an extended leg on a 50 cm high platform, then reaching forward with their arms towards the extended leg; 4 repetitions and held at the point of discomfort for 30s each.	Walking lunges: lunging motions with hip flexion and knee flexion of the front leg); 4 repetitions in total for 30 s each and achieving the highest ROM possible for all DS.	SR	Immediately after the stretch and after a 10-min rest	There were no significant differences between the SS and DS immediately after the stretch ($P > 0.05$), but SS was greater than DS after 10 min ($P < 0.05$).

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Table 1 (*continued*)

Study ID	Study Design	Participants	SS protocols	DS protocols	Outcomes	Follow-up Period	Main Results, P value
		(1.4) (young), 46.3 (6.5) (middle-aged)					
Perrier, E. T. 2011	RCT crossover	n (SS), n (DS) = 21 M Recreationally active university students Age (SS), Age (DS) = 24.4 (4.5)	Supine with both legs fully extended, raising one leg, using the hands to support both above and below the knee. Only a small amount of knee flexion was allowed. 2 repetitions of 30 s each for each lower extremity.	Step into single leg Romanian dead lift; Walking diagonal lunges; High knee pulls (knee to chest, on toe); Straight leg strides (back and forth-no walk-rest 20 s between reps); Each exercise was performed twice.	SR	Immediately after the stretch	There was no difference in flexibility between SS and DS. $P > 0.05$
Silveira, G. 2011	RCT crossover	n (SS), n (DS) = 12 (5 F 7 M) University students with a variety of sporting backgrounds and free of any bony or soft tissue injury Age (SS), Age (DS) = 24.8 (6.8)	In a supine position, lying on an exercise treatment bench with a Velcro sling passing around the ankle to flex the hip and stretch the hamstrings. The stretch was held for 15 s to the terminal range of discomfort or tightness felt in the back of the thigh. 75 s for each stretch.	The dominant leg was flexed at the hip in a forward kicking action, 5 sets of 7 or 8 forward leg swings or kicks, total 225 s; Dominant leg swung across the midline of the body towards the opposite shoulder to stretch the hamstring.	Active SLR	Immediately after the stretch	No difference in flexibility between SS and DS was investigated. $P > 0.05$
Samson, M. 2012	RCT crossover	n (SS), n (DS) = 19 (10 F 9 M) University students and staff involved in recreational or competitive sports Age (SS), Age (DS) = 22.2 (3.3) (F), 27.8 (8.4) (M)	Supine, hip flexion to maximum ROM with legs partially abducted and knees slightly flexed. Each stretch was repeated for 3 sets of 30s and held at the point of mild discomfort.	All stretches were performed dynamically to full ROM at a moderate speed of approximately 1 Hz (approximately 30 repetitions per set)	SR	Immediately after the stretch	The SS condition increased sit and reach ROM more than the dynamic condition. ($p < 0.05$)
Morrin, N. 2013	RCT crossover	n (SS), n (DS) = 10 F Dancers Age (SS), Age (DS) = 27 (5)	Sit upright on the floor, flex one knee and slide the heel until it touches the inner side of the opposite thigh. Keep the extended leg straight and bend at the hips and lower torso onto the extended thigh. Each stretch was completed twice, and each repetition was held for 30s.	With hands on hips, walk around the room while extending alternate legs forward in a parallel grand battement fashion. Each stretch was completed twice, and each repetition was held for 30s.	Active SLR	Immediately after the stretch	SS displayed significantly greater changes than DS. ($p < 0.05$)
Chen. 2015	RCT parallel	n (SS), n (DS) = 12 M Students with limited passive straight-leg elevation (hip flexion ROM of less than 80°) Age = 20.6 (2.4)	Lunge position, rotating the trunk and using the hand to reach gently to the opposite toes of the dominant leg with the knee extended to stretch the hamstrings to the point of discomfort without pain, maintained for 15 s, followed by 15s of rest, total 6 sets.	Raise the arms horizontal to the floor, then actively swing the dominant leg forward with hip flexion and knee extension to allow the toes to approach the hands. 15 rhythmic repeated movements per set for 6 sets, with 15s of rest between sets.	Passive SLR; Myotonometer for hamstrings stiffness	Immediately after the stretch	There was no significant difference in ROM between SS and DS. ($P > 0.05$) Hamstrings stiffness decreased significantly more in DS than in SS. ($P < 0.05$)
C Kurt. 2015	RCT crossover	n (SS), n (DS) = 24 M Well-trained combat athletes Age (SS), Age (DS) = 22.7 (3.3)	Sit on the ground. Legs are straight out in front. Bend forward and keep the back straight. Each limb for 20s and rested for 20s between exercises.	Kick leg up then out straight as high as possible. Try to touch the toe with the contralateral hand. Then, perform it with the other leg. Each exercise lasted for 15s, two sets with 30s inter-set and inter-exercise rest intervals.	FGD	At the 15th second and the 2nd, 4th, 6th, 8th, 10th and 15th minute after the stretch.	There was no difference in flexibility between SS and DS at the 15th second and the 2nd, 4th, 6th, 8th, 10th and 15th minute after the stretch. $P > 0.05$
Chaouachi, A. 2015	RCT crossover	n (SS), n (DS) = 14 M Healthy highly trained	Unilateral supine, hip flexion straight leg with eight repetitions of 30s each to the point of discomfort, with 20s	Eight sets of 30s of unilateral hip flexion kicking actions through a full ROM, with 20s rest between sets,	Hip flexion ROM with knee extended	After 1-min and 10-min rest of stretch	There were no significant between the two interventions

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Table 1 (*continued*)

Study ID	Study Design	Participants	SS protocols	DS protocols	Outcomes	Follow-up Period	Main Results, P value
		rowers Age (SS), Age (DS) = 18 (2)	rest between repetitions. The same researcher helped in achieving the desired ROM for each subject.	approximately 1s for hip flexion and 1s for the return to the starting point (hip extension).			of SS and DS. $P > 0.05$
Su, Hsuan 2016	RCT crossover	n (SS), n (DS) = 20 (5 M 15 F) College students Age (SS), Age (DS) = 21.43 (1.48)	In a supine position, keep left leg on the floor and right knee extended, slowly raise right leg toward the chest using hands or a towel. Hold the position for 30s, then change to the left leg. Hold the position for 30s, then change to the left leg.	Standing, kick one leg forward with knee extended. Step forward and kick the other leg forward with knee extended. Repeat each movement for 1 min. Both movements were performed 3 times for a total of 6 min.	SR	After 5 min rest of stretch	Statistically insignificant difference was found in hamstrings flexibility. ($P > 0.05$)
Matsuo, S. 2019	RCT crossover	n (SS), n (DS) = 16 M Healthy young men Age (SS), Age (DS) = 22.2 (1.2)	Standing and placing the right heel (with an extended leg) on a platform (50 cm high), then reached forward with their arms toward the extended leg. Ten 30s sets of SS were performed with a 20s rest period between each set.	Standing upright beside parallel bars and held a parallel bar with his left hand with knee extended and swung their right leg up to the anterior aspect of their body. Each exercise was performed 5 times slowly to practice, and then 10 times as quickly as possible without bouncing. Ten 30-s sets of DS (15 repetitions of the DS movement in each set) were performed with a 20s rest period between each set.	ROM; PT at the onset of pain. Passive Stiffness	Immediately after the stretch	The effects of stretching do not appear to differ between the two stretching methods. ($P > 0.05$)
Zhou, Wen-Sheng 2019	RCT crossover	n (SS), n (DS) = 11 Elderly people absence of conditions possibly affecting hip joint flexion or extension Age (SS), Age (DS) = 63.2 (7.13)	Adopting a forward flexion position while sitting in a chair, and to stretch the hamstrings by adopting a forward lunge position. Each set included six 30-s long repetitions, with 30s of rest between repetitions.	Standing with left foot while holding onto the back of a chair. Each set containing fifty repetitions performed to the rhythm of a metronome, and with 30 s of rest between sets. In total, 3 sets were performed, and the DS trial covered 130s (43.6 s × 3 sets).	Measurement of ROM of passive hip flexion	Immediately after and at 60 min after completing the stretch	Hip flexion ROM at 0 min showed no significant difference between DS and SS. However, DS had a better sustained effect than that provided by SS at 60 min, $p < 0.05$).
Fakhro, M. A. 2020	RCT parallel	n (SS), n (DS) = 32 M Football players Age (SS), Age (DS) = 24.7 (4.1)	In a supine position, the tested limb was in full knee extension and the foot, in a relaxed position, and moved up passively by the assessor to a point of slight pain or discomfort at the posterior aspect of the thigh, held for 30s and performed 3 times for a total of 1 min and 30s, 15 min after a match or training.	Participants swung their tested leg actively into hip flexion while keeping their knee fully extended and their ankle fully plantar flexed until a stretch was felt in the posterior thigh. This was repeated over 30s at the end of the participant's warm-up phase.	Passive SLR	15 min after the first intervention and after four weeks	SS was showed to be superior to the DS in short (15min) and long-term hamstring extensibility (4 weeks). ($P < 0.05$)
Ferreira-Junior, Joao B. 2021	RCT parallel	n (SS) = 14 n (DS) = 13 College students engaged in moderate physical activity Age (SS) = 21.1 (2.1) Age (DS) = 21.3 (1.7)	Stood with one leg stretched on a bench while the other leg supported their body mass. Then, lean forward at the waist with the arms reaching for the toes with both knees extended; Seated and maintained one leg stretched while the other one was fully extended. Then, subjects lean forward and held the stretch position by actively contracting the muscles in opposition to the muscle being	Stood upright, swung upward by flexing the hip and while maintaining the leg in the extended position. Standing upright, hip was flexed until the thigh of the stretched leg was parallel to the ground. Then, the subject extended their leg. 15 repetitions through a challenging ROM to the same threshold of mild discomfort. There was a 15s rest period between each set and each stretching	Biceps femoris muscle thickness	One week after the last training session	There was no significant differences in muscle thickness (SS 6.0 (3.5) mm; DS (6.7 (4.1) mm) across groups. ($p > 0.05$)

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Table 1 (*continued*)

Study ID	Study Design	Participants	SS protocols	DS protocols	Outcomes	Follow-up Period	Main Results, P value
			stretched for 20s to the threshold of mild discomfort. 15s rest period between each set and each stretching exercise. The total time was approximately 80 s, 2 days per week for 8 weeks.	exercise. The total time was approximately 80s, 2 days per week for 8 weeks.			
Lee, Jin Hyuck 2021	RCT parallel	n (SS) = 25 (11 M 14 F) n (DS) = 21 (8 M 13 F) Patients with patellofemoral pain and had <141° of knee extension angle during the hamstring flexibility test Age (SS) = 27.2 (7) Age (DS) = 25.1 (9.2)	Sitting or standing, the affected leg was maintained in a straightened position with ankle dorsiflexion. The foot was grasped using the ipsilateral hand or a towel, with the contralateral hand keeping the affected knee straight, with a slight trunk forward flexion. Repeated for 3 sets, with a holding time of 15s, twice a day and 12-week follow-up.	Supine, the affected leg was maintained at 90° flexion of the hip and knee. The distal thigh was grasped by a towel; then, active knee extension through contraction of the quadriceps. Standing, repeated hip flexion with the knee extended, 3 sets, 15 repetitions with a 1-s holding time, twice a day and 12-week follow-up.	Knee extension ROM with the femur maintained in 90° of hip flexion	After the 12-week follow-up	There were no differences in hamstring flexibility between the two groups. $P > 0.05$
Siebert, T. 2022	RCT crossover	n (SS), n (DS) = 14 M Male sport students with diverse sport experience Age (SS), Age (DS) = 23.7 (1.3)	Flexed the hip slowly until a pain score of 8. If this threshold was reached, SS was performed for 30s. In case of reduced pain, the hip angle was further increased. After 30s, the leg was released followed by the resting period, repeated 3 sets, 30s rest between each stretching.	Be like the protocol of SS. The subject gave feedback to the assessor how far the hip could be flexed. Within 30s, the assessor flexed the hip slightly rhythmically about 10–12 times, repeated 3 sets, 30s rest between each stretching.	ROM of hip flexion	5 min after the intervention	No significant difference was observed between SS and DS in terms of hamstring flexibility. ($p > 0.943$)
Gunaydin, G. 2020	RCT parallel	n (SS), n (DS) = 14 Healthy individuals Age (SS) = 24.07 (3.20) Age (DS) = 22.57 (2.06)	Supine on the bed and one leg was fixed to the bed with a belt. Hold the ends of the exercise band wrapped around the foot with two hands. Then raise the leg as high and straight as he/she could, and stretch for 15s, 6 weeks, 3 days a week and 10 repetitions per day.	Supine, hold the exercise band wrapping around the sole of the foot with two hands. Then, raise the leg as high and straight as possible and contract the quadriceps for 2s and then relaxed, 6 weeks, 3 days a week and 10 repetitions per day.	Passive knee extension ROM with the femur maintained in 90° of hip flexion	Three days after the last stretching (6 weeks)	The flexibility increase in the DS was higher than the SS group. $P < 0.001$
Vasileiou 2013	RCT crossover	n (SS), n (DS) = 22 M Healthy, amateur soccer players Age (SS), Age (DS) = 21.9 (3.2)	Stretching one leg forward with the toes pointing up while bending the opposing leg. Reaching to touch forward knee with head. Twice each and for 10s each.	Moving each leg front to back with knee extended. 10 repetitions for each leg and repeated two times.	ROM of hip flexion	Immediately after the stretch	No differences found between trials (SS or DS). $P > 0.05$
Zmijewski, P. 2020	RCT crossover	n (SS), n (DS) = 13 F Healthy female handball players Age (SS), Age (DS) = 22.1 (3.2)	Sitting, extend a single leg and flex the other leg until the foot was in contact with the thigh. Flexed forward from the waist, keeping the back flat. Each stretch was held to the point of slight discomfort (not pain) for 20s per muscle group followed by a 10s passive rest period in a neutral position. Each stretch was repeated three times for each limb in alternating order.	12 sets of leg swings (in 3 successive sets) including a set of 20s anterior or posterior leg swings in a standing position, followed by a 10s passive rest interval in a neutral position. Each set of stretches (around 14–18 swings in one set/muscle group) was repeated three times for each limb in alternating order.	SR	Immediately after the stretch	Athletes demonstrated a similar increase in ROM for the DS and SS protocols. $P > 0.05$

(*continued on next page*)

Table 1 (*continued*)

Study ID	Study Design	Participants	SS protocols	DS protocols	Outcomes	Follow-up Period	Main Results, P value
Amber Magner 2012	RCT crossover	n (SS), n (DS) = 9 (5 M 4 F) Recreationally trained subjects and participated in a variety of sport backgrounds Age (SS), Age (DS) = 24 - 56	Standing Stretches: feet together, bend over at the waist keeping back straight; Sitting Stretches: double leg hamstring stretch: seated keep back of knees on ground and bend at the waist forward reaching to touch toes; Single leg hamstring: bend right leg to the inside of left leg, leaving left leg straight in front, bend at waist forward to touch toes. Repeat procedure with left leg bent and right forward. Static stretches were held for 12s, and the same stretch was duplicated on the opposite limb being stretched, lasting 10 min.	Jog, Back pedal, Jog down, Skipping, High knees, Butt kicks, High knees down, Skipping, Carioca, walking sumo squats, Defensive slides, Frankenstein walks, Heel walks/toe walks, Wall assisted leg throws-facing wall, Wall assisted leg throws-side to wall, Frankenstein-keeping legs straight swing one at a time high up in front with your hands stretched out and chest high, lasting 10 min.	SR	Immediately after the stretch	No differences found between trials (SS or DS). $P > 0.05$
Philip Ford 2007	RCT parallel	n (SS), n (DS) = 8 Physically active individuals Age = 22.1 (3.04)	In a seated position, the treatment leg was fully extended at the knee with the left hip externally rotated and flexed, then flexed the trunk toward the right leg, to the point of mild discomfort without pain in the posterior aspect of the knee and thigh. This position was repeated 5 times for 30s with a 10s rest period between each stretch.	In a seated position, each subject grabs the side of the treatment table with the trunk in slight flexion and to actively extend the right knee, to the point of mild discomfort without pain, repeated 10 times and held in that position for a period of 10s with a relaxation period of 10s.	Active Knee Extension ROM	Immediately, 3-min, 7-min, 12-min, 18-min, 25-min, after the stretch	SS was showed to be superior to the DS, 3-min, 7-min, 12-min, 18-min, 25-min, after the stretch ($P < 0.05$), but not immediately after the stretch. ($P > 0.05$)
Jesus López 2013	RCT parallel	n (SS) = 11 (4 M 11 F) n (DS) = 9 (5 M 4 F) Healthy, active students Age = 21.79 (2.45)	A series of 10 repetitions of the following cycle: passive elongation of the hamstring muscle group to maximum ROM, holding the position for 10s; then relaxation of the muscles in the initial position for 5s, while trying to increase the ROM in each repetition, a total stretching time of 100s per session and per leg making a total working time of 6 min, 2 sessions per week for 9 weeks.	Four series of 12 repetitions of the following cycle: initial active stretching (by contraction of the flexor muscles of the hip), the motion being assisted by gently stretching the hamstring passively until the maximum ROM was reached, holding the position for 2s, then returning to the initial position, with a total stretching time of 96s per session and per leg and a total working time of 8 min, 2 sessions per week for 9 weeks.	Active and passive SLR	Immediately after the stretch	There were no significant post-test differences between DS and SS. ($P > 0.05$)
Cem Kurt 2016	RCT crossover	n (SS), n (DS) = 20 Professional football players Age (SS), Age (DS) = 25.3 (4.3)	Standing hamstring stretch. 5 min of SS (6 different unilateral SS exercises [1 × 20s hold for each extremity, 10 s interval between exercises] and one bilateral exercise [2 × 20s hold])	Walking hamstring kicks, walking lunges, lateral walking lunges, power high knee, dynamic hip flexor, leg swing towards the opposite side and explosive hip flexion mobility. 5 min of DS [7 different DS exercises (2 × 20s, with 10s between exercises)].	FGD	Immediately after the stretch	The difference between SS and DS was insignificant. $P > 0.05$

SR = Sit and Reach test. SLR = Straight Leg Raise test. FGD = Finger Ground Distance. ROM = Range of Motion. PT = Passive Torque. SS = Static Stretching. DS = Dynamic Stretching. M = Male. F = Female.

16,21,24,43,44,46,51,58] were healthy people with different levels of physical activity and one study [57] was healthy men without sports backgrounds. Two studies [50,59] had a history of injury, and three [47,48,53] had limited ROM. The subjects of 11 studies [4,8,14,16,24,49,51,53–55,57] were male, and two [29,52] were female.

4.3. Interventions and comparisons

The techniques of SS were similar in most studies. Most of the methods implemented were to flex the trunk from the hip in a sitting or standing position with the knee in an extended position [29,43,45,47,48,50–52,54,57–59]. In some studies, the hip was flexed in the supine or lateral position, and the knee was maintained in an extended position [1,2,14,16,21,24,55,56]. Different studies had different standards for the end position of stretching. Eight studies required the subjects to remain still when they felt mild discomfort or tolerated pain or stretching [1,14,21,47,50,51,55,58]. Four studies required the subject to feel discomfort but no pain [29,43,52,53]. One study [16] required subjects to move to the end of ROM within the pain threshold, but one study [44] stretched the hamstring until they had a pain score of 8 points. One piece of literature required subjects to increase their ROM with each stretch continuously. The holding time duration was 10–30s, mostly 30s, and the number of repetitions ranged from 2 to 10.

The methods of DS varied in this review. Most of the papers used forward and backward leg swings with the knee extended or kicking while stepping forward in a standing, supine, or lateral lying position [1–3,8,14,16,21,29,45,50,52–59]. Four studies [47,48,58,59] kept the hip and knee around 90° flexion simultaneously in a sitting or standing position and then repeated knee extension and flexion. Three studies [3,24,51] implemented the DS through lunging, and one study [43] repeatedly bent the trunk with the knee extended in a sitting position to stretch the hamstring dynamically. Regarding the end feeling of stretching, three studies [47,51,55] were performed on the endpoint of the maximum ROM. In comparison, three studies [21,43,52] were committed to the full ROM without pain or when there was mild tension or slight discomfort, and two studies [14,58] required movement to the stretching position. Two articles [43,59] required subjects to hold for 1s and 10s at the end position of maximum ROM, respectively, while the other two studies [2,44] required holding for 2s. The DS manner was slow in some studies but fast in others. One piece of literature [57] required subjects to stretch slowly five times and then quickly ten times, while three pieces [45,53,55] stretched rhythmically with a metronome.

4.4. Outcome measurements

Among the 27 articles, the SR test was performed in 7 [21,24,29,46,49,51,56], and the FGD test was conducted in 2 studies [3,54]. Four articles [2,48,50,59] measured the knee extension angle in 90° hip flexion, while one study [47] measured the knee flexion angle in the same position. Nine articles [1,8,14,16,44,45,52,53,55] measured the hip flexion angle in a supine or standing position with active or passive straight leg raising. One literature [4] measured the hip angle at different stages of kicking, two [53,57] measured passive stiffness, one [57] measured PT at the onset of pain using an isokinetic dynamometer, and one [58] estimated biceps femoris thickness using ultrasound. Twenty-four articles [1,3,4,8,16,21,24,29,43–57,59] examined the acute effects of stretching. Seven studies [8,14,43,45,50,51,54,55] examined sub-acute effects. One study [2] examined medium effects, and two studies [14,58] examined long-term results.

4.5. Methodological quality

The methodological quality of the included articles was assessed by the PEDro scale, with scores ranging from 2 to 8 points, and most of the studies were above 7 points. Eleven studies [2–4,24,43,47–49,53,55,58] did not mention or implement allocation concealment, and 21 [2–4,8,16,21,24,29,43–47,49–56] did not blind participants, therapists, or assessors. Six studies [1,45,49,53,58,59] did not conduct intention-to-treat analysis, five [45,49,53,58,59] reported incomplete results, and three [4,24,55] did not perform the random allocation. One study [49] did not report point estimation and variability measurements (Table 2).

4.6. Primary outcomes

4.6.1. Short-term (acute phase) effects on hamstring ROM

Fifteen studies [1,4,8,16,43–45,47,48,50,52,53,55,57,59] explored the acute effect of DS and SS on hamstring ROM and were divided into two subgroups according to the number of intervention sessions. Subgroup one, the impact of a single bout of stretching, contained nine crossover RCTs [1,4,8,16,45,50,52,55,57] and two parallel RCTs [43,53]. Of the nine studies [1,4,16,43,45,50,52,55,57] with available primary data, eight studies [1,4,16,43,45,50,55,57] investigated that there was no significant difference between DS and SS on hamstring ROM. Still, one study [52] demonstrated that SS improved hamstring ROM better than DS. The pooled results of 9 studies [1,4,16,43,45,50,52,55,57] showed no significant difference between DS and SS on hamstring ROM after a single bout of stretching (MD, −0.70, 95% CI, −1.54 to 0.14; $Z = 1.63$, $P > 0.05$) (Fig. 2). The inter-study heterogeneity was higher ($I^2 = 61\%$). Two studies [8,53] were not included in this meta-analysis because the data could not be extracted in the full text, and there was no response after contacting the authors. In the study by Chen et al. [53] and Vasileiou et al. [8], there was no statistically significant difference in hamstring ROM between the two groups after one bout of DS and SS.

Subgroup two explored the effect of multiple stretching sessions (stretching cycles of 6–12 weeks), including four parallel RCTs [44,47,48,59]. Three [44,47,59] demonstrated no significant difference between DS and SS in improving hamstring ROM—only the study by Bandy. W. D et al. [48] showed that SS improved hamstring ROM better than DS after six weeks cycle. The results were consistent

Table 2
Methodological Quality of included studies.

Study ID	1	2	3	4	5	6	7	8	9	10	11	total
Webright, W. G. 1997	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Bandy, W. D. 1998	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Herman, S. L. 2008	Yes	Yes	No	Yes	No	No	No	No	No	No	No	2
O`Sullivan, K. 2009	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Amiri-Khorasani, M. 2011	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	5
Behm, D. G. 2011	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Perrier, E. T. 2011	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	5
Silveira, G. 2011	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Samson, M. 2012	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Morrin, N. 2013	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Chen. 2015	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
C Kurt. 2015	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Chaouachi, A. 2015	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	5
Su, Hsuan 2016	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Matsuo, S. 2019	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8
Zhou, Wen Sheng 2019	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	5
Fakhro, M. A. 2020	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8
Ferreira-Junior, Joao B. 2021	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	5
Lee, Jin Hyuck 2021	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	6
Siebert, T. 2022	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Gunaydin, G. 2020	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6
Vasileiou 2013	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Zmijewski, P. 2020	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Amber Magner 2012	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Philip Ford 2007	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	5
Jesus López 2013	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	7
Cem Kurt 2016	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	6

1: eligibility criteria were specified. 2: subjects were randomly allocated to groups. 3: allocation was concealed. 4: the groups were similar at baseline regarding the most important prognostic indicators. 5: there was blinding of all subjects. 6: there was blinding of all therapists. 7: there was blinding of all assessors. 8: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups. 9: all subjects for whom outcome measures were available received the treatment or control condition as allocated. 10: the results of between-group statistical comparisons are reported for at least one key outcome. 11: the study provides both point measures and measures of variability for at least one key outcome.

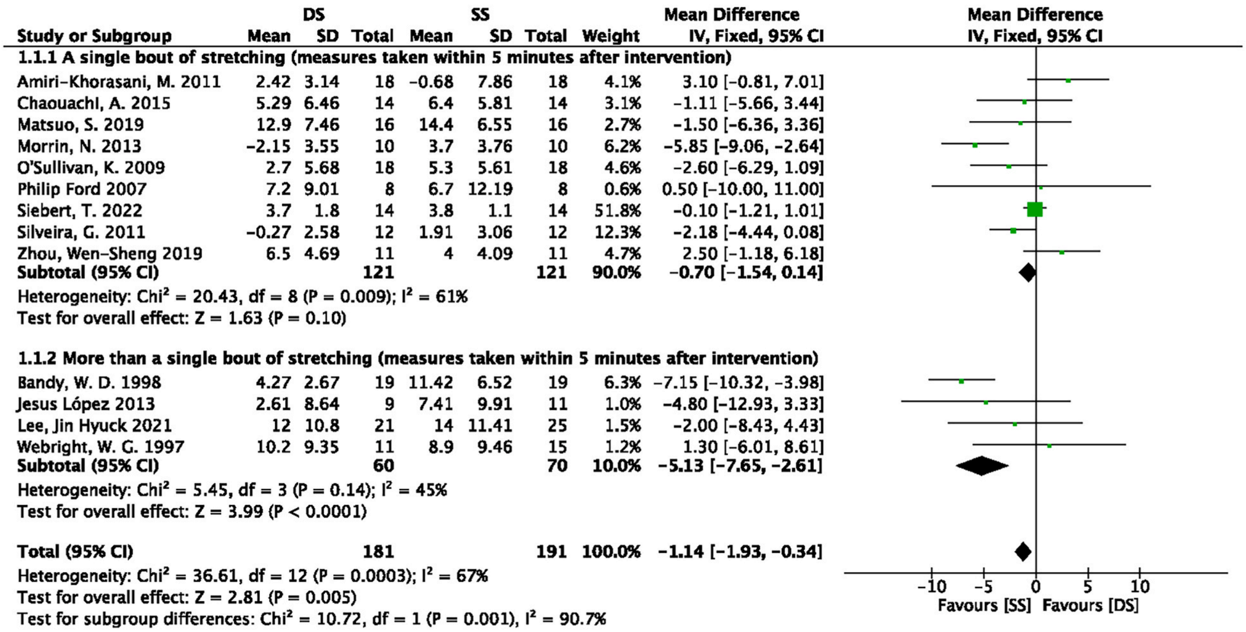

Fig. 2. Short-term (acute phase) effects on hamstring ROM.

with the meta-analysis (MD, −5.13, 95% CI, −7.65 to −2.61, Z = 3.99; P < 0.05). The heterogeneity among the studies was small (I^2 = 45%) (Fig. 2).

4.6.2. Short-term (sub-acute phase) effects on hamstring ROM

Four studies [43,45,50,55] explored the sub-acute effect of a single bout of DS and SS on hamstring ROM, three [43,50,55] of which showed no significant difference between DS and SS. Only Zhou, Wen-Sheng et al. [45] demonstrated that DS has a better-sustained impact than SS 60 min after the intervention, in which the study population was all elderly, with an average age of 63.2 years, and most of them had varying degrees of limitation of the hip. The four studies' [43,45,50,55] pooled results showed no significant difference between the two stretch techniques on hamstring ROM after a single bout of stretch (MD, 1.71, 95% CI, −2.80 to 6.22; Z = 0.74, P > 0.05) (Fig. 3). The inter-study heterogeneity was higher (I^2 = 71%). However, Fakhro, M. A. et al. [14] explored different results after four weeks of intervention, showing that SS improved more in hamstring ROM (MD, −5.30, 95% CI, −6.33 to −4.27; Z = 10.04, P < 0.05).

4.6.3. Medium-term effects on hamstring ROM

In this meta-analysis, no crossover RCT explored the medium-term effects of DS and SS on hamstring ROM. Only one parallel RCT [2] with a 6-week follow-up found that the two stretch methods had a similar impact in improving hamstring flexibility after multiple stretch sessions (MD, 3.48, 95% CI, −2.57 to 9.53; Z = 1.13, P > 0.05).

4.6.4. Long-term effects on hamstring ROM

Only one study by Fakhro, M.A, and colleagues [14] found that after four weeks of DS and SS, SS resulted in a more remarkable long-term improvement in hamstring ROM than DS, and this effect was sustained for four weeks (MD, −10.40, 95% CI, −10.97 to −9.83; Z = 35.57, P < 0.05).

In summary, the meta results showed no significant difference between a single bout of SS and DS in improving the acute and sub-acute effects of hamstring ROM. However, after multiple intervention sessions (more than six weeks in this review), SS had more significant acute and sub-acute effects on improving hamstring ROM compared to DS. Still, there was no significant difference in the medium-term effects compared with DS. Regarding long-term effects, only one study showed that SS significantly improved hamstring ROM compared with DS four weeks after the intervention (Results are shown in Table 3).

4.6.5. Short-term (acute phase) effects on hamstring length

Eight studies [3,21,24,29,46,51,54,56] explored the acute effects of DS and SS on hamstring length, all with a single stretch session. Given that raw data were available for only six studies [3,24,46,51,54,56], only these six studies were included in the meta-analysis. The pooled results showed no significant difference in the acute effect of DS and SS on hamstring length after a single bout of stretch

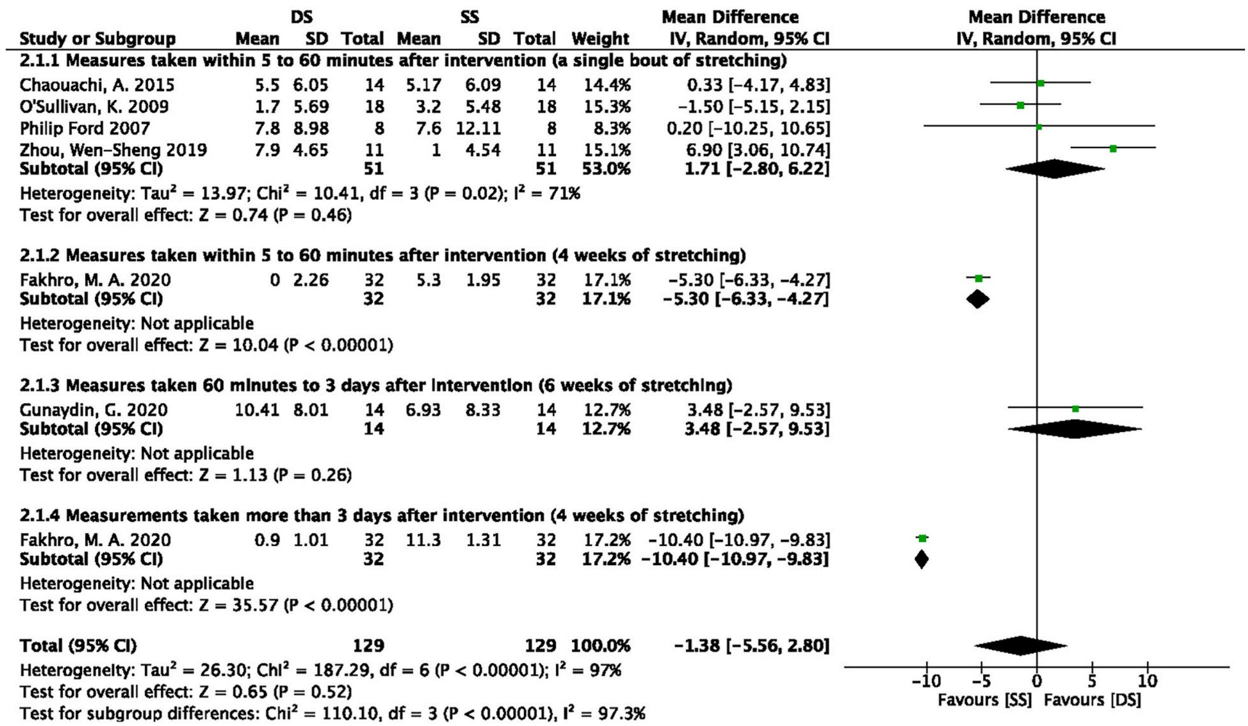

Fig. 3. Sub-acute phase, medium-term, long-term effects on hamstring ROM.

Table 3
Summary of results comparing DS with SS on ROM and Length of Hamstring.

Stretch sessions Effects of stretch	A single bout of stretch		Multiple bouts of stretch	
	ROM	Length	ROM	Length
Short-term (acute phase) 95%CI	DS = SS (-1.54, 0.14)	DS = SS (-1.09, 0.26)	SS > DS (- 7.65, - 2.61)	DS = SS Not available
Short-term (sub-acute phase) 95%CI	DS = SS (-2.80, 6.22)	DS = SS (-1.69, 0.22)	SS > DS (- 6.33, - 4.27)	Not available
Medium-term 95%CI	Not available	Not available	SS = DS (- 2.57, 9.53)	Not available
Long-term 95%CI	Not available	Not available	SS > DS (- 10.97, - 9.83)	Not available

ROM = Range of Motion. DS = Dynamic Stretching. SS = Static Stretching.

(MD, −0.41, 95% CI, −1.09 to 0.26; Z = 1.20, P > 0.05) (Fig. 4). The inter-study heterogeneity was small ($I^2 = 0\%$). In two studies [21, 29], raw data were unavailable after screening the full text and remained unavailable after contacting the authors. In one study [29], SS and DS were found to have similar efficacy in improving hamstring flexibility, consistent with the meta-analysis results. However, a study conducted by Samson M et al. [21] showed a different effect, which found that SS improved the SR distance more than DS. In addition, a 4-week follow-up study conducted by Herman, S. L et al. [49] found that the two stretching methods presented similar effects in improving hamstring length.

4.6.6. *Short-term (sub-acute phase) effects on hamstring length*

Two studies [51,54] explored the sub-acute effects of a single session of DS and SS on hamstring length. The pooled data showed no significant difference between DS and SS on hamstring length after a single bout of stretch (MD, −0.73, 95% CI, −1.69 to 0.22; Z = 1.51, P > 0.05). The inter-study heterogeneity was higher ($I^2 = 71\%$).

In summary, no studies have investigated DS and SS's medium and long-term effects on hamstring length. According to the available meta-analysis, a single bout of DS and SS demonstrated similar efficacy in improving the acute and sub-acute outcomes of hamstring length. Because there is only one long-term follow-up study with multiple intervention sessions, it is unable to analyze whether various bouts of DS and SS show similar effects in increasing hamstring length.

4.7. *Secondary outcomes*

The secondary outcomes of this study mainly included stiffness, myofascial length, fiber thickness, and PT during stretching of the hamstring. There were few studies related to this outcome after the literature search, so the results of these studies could not be quantitatively integrated by meta-analysis.

One study conducted by Matsuo, S. et al. [57] found that a single bout of SS and DS significantly decreased immediate PT and passive stiffness of the hamstring, but there was no difference in the magnitude of change between the two stretching methods. However, Chen et al. [53] concluded that hamstring stiffness decreased significantly in the DS group after a single stretch cycle compared with the SS group. The PEDro score of the study by Matsuo, S. et al. [57] was 8 points, which was of high quality, while the study by Chen et al. [53] was of low quality, with only 4 points. Therefore, the integration of the results of the above two studies could not prove that DS and SS were different in improving PT and stiffness of the hamstring.

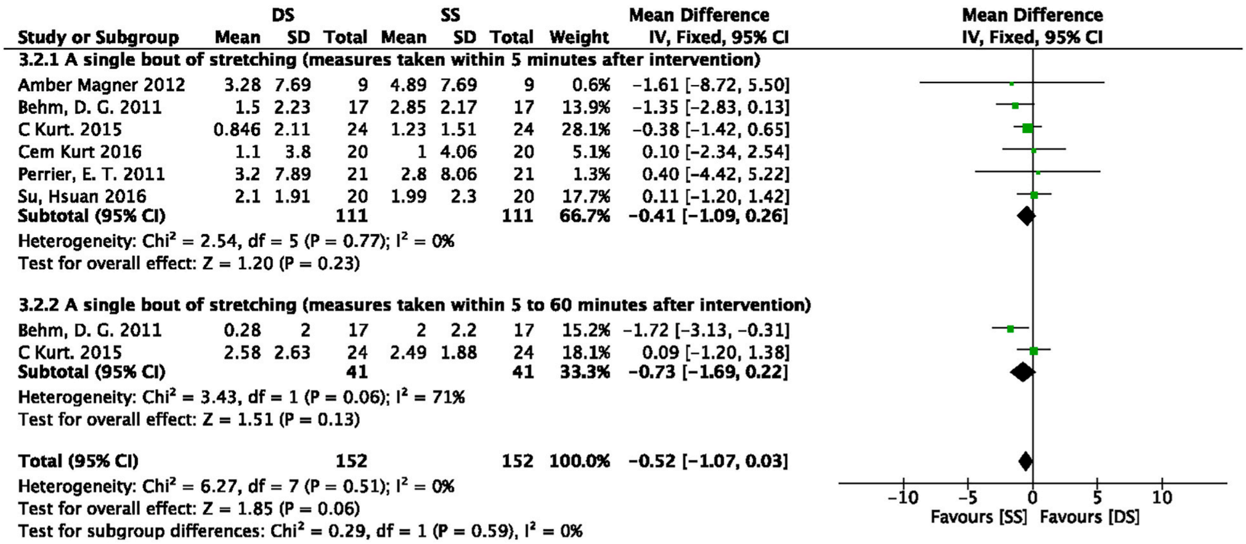

Fig. 4. Short-term effects on hamstring length.

In addition, we also found that no studies are exploring the effect of DS and SS on hamstring myofascial length, and only one study by Ferreia-Junior and colleagues [58] that investigated the impact of DS and SS on hamstring thickness was found, demonstrating that DS and SS could improve hamstring thickness compared with the control group one week after the intervention. Still, there was no statistically significant difference between the DS and SS. Given that the PEDro score was only 5, it could not be considered that there was a difference in improving the hamstring muscle thickness between the two stretching methods.

5. Discussion

5.1. Effects of DS and SS on hamstring ROM

This study showed that DS and SS in a single bout of the stretch did not differ significantly in improving the acute and sub-acute effects of hamstring ROM. Still, SS was substantially more effective than DS in multiple cycles of stretch (over four weeks). In terms of medium-term results, only one study demonstrated no significant difference in enhancing hamstring ROM between DS and SS after multiple stretch sessions. Regarding long-term effects, only one study investigated that SS significantly improved hamstring ROM compared with DS after numerous cycles of stretch.

In addition, the heterogeneity between studies [1,4,8,16,43,45,50,52,53,55,57] on the acute and sub-acute effects of a single stretch cycle was relatively significant ($I^2 = 61\%$, 71%, respectively), which possibly was because the subjects in these studies were both young and elderly, and age factor exerted a particular influence. The heterogeneity between the studies [14,44,47,48,59] on the acute and sub-acute effects of multiple stretching cycles was small ($I^2 = 45\%$). Most studies [47,48,59] on the acute effects of multiple stretch sessions had involved subjects with limited ROM of the hamstrings, which may be one of the factors influencing different results of single versus multiple stretch cycles. There was only one study on the medium-term and long-term effects, and all were based on various stretching periods. Therefore, the credibility of the results is not high and needs further study.

Some studies have shown that the increase in ROM after DS and SS intervention was due to the increase in PT and the decrease in passive stiffness at the onset of pain [56,57], while others [20,55] have shown that the increase in acute flexibility was mainly due to the increase in tensile tolerance or the change in mechanical properties (the decrease in muscle stiffness). However, the study by Zhou, Wen-Sheng et al. [45] showed that after 60 min of intervention, DS had a better-sustained effect than SS, which potentially was because its subjects were older people with a certain degree of limited ROM. In addition, the method of DS utilized inertia to swing the leg, possibly making the hip flexion angle larger than that in other studies. This review explored that the acute and sub-acute effects of SS in improving hamstring ROM were significantly better than those of DS with multiple stretch sessions. Jesus et al. [44] suggested that this may be due to the inhibition of motor neuron α in the Golgi tendon organ during longer SS, resulting in a relaxation effect. However, DS usually does not include the stretch posture process, and the maintenance time is short, so there is little relaxation effect. In addition, in the process of SS, the decrease in the amplitude of the H-reflex indicated a reduction in the activity of the involuntary spinal reflex, which was also beneficial for promoting muscle extensibility.

In this review, only one study conducted by Gunaydin and colleagues [2] explored the medium-term effects of SS and DS on hamstring ROM, and the results showed that there was no significant difference in the improvement of hamstring ROM between DS and SS after multiple bouts of stretch. The PEDro score of this study was 6, but as there was only one study, the reliability of the results was not high, and further research is needed. Previous studies investigated that SS was more effective in reducing PT, while DS was more effective in reducing muscle stiffness. However, the SS in this study only lasted for 15s, while Lee and Jin Hyuck et al. [59] evidenced that the stretch duration was an essential factor affecting muscle stiffness. Normally, 30-the 60s of SS was more effective in improving hamstring flexibility than 15s of SS. Therefore, the finding of no difference between the two methods was potentially due to SS's short duration.

Regarding long-term effects, only one study by Fakhro et al. [13] demonstrated that four weeks of SS significantly improved hamstring flexibility more than DS, possibly due to increased muscle length after long-term stretch. In contrast, the short-term stretch was only an increase in muscle tolerance.

Although the results of this study found that SS showed superior or similar effects in improving hamstring ROM than DS, considering different stretch sessions and efficacy, some studies preferred the application of DS, especially in the pre-workout warm-up activities [10,17,20]. Amiri-Khorasani et al. [4] suggested that the DS warm-up protocol increased hip dynamic ROM more than SS because DS increased the antagonist muscle strength compared to SS, and produced greater angular displacement of the joint in a rehearsal manner to subsequent exercises. Related mechanisms were also proposed in the study of Behm et al. [20]; that is, DS could increase core temperature, nerve conduction velocity, and central driving force. In addition, many studies have shown that prolonged SS potentially leads to performance degradation and adversely affects motor performance. The study by Behm et al. [20] and Jules Opplert et al. [17] found that longer stretches, significantly more than the 60s, possibly impair the performance, such as a decrease in muscle strength, vertical jump height, and sprint running speed. The mechanisms may be related to reduced maximum power output due to auto-inhibition, and partial muscle damage [8]. In addition, some studies have compared the three stretching methods of SS, DS, and BS. Some believed that BS is a type of DS [10]. Still, others suggested that the two should be distinguished because BS is a rapid and uncontrolled movement, usually involving a fast bounce at the end of joint movement [17]. Up to now, there have been few studies recommending BS when considering its adverse effects, such as not conducive to the improvement of ROM and subsequent exercise performance, which perhaps lead to muscle strain [25,60] because it causes the stretch reflex stimulated of the stretched muscle causing the muscle produced an enormous tension [17].

5.2. Effects of DS and SS on hamstring length

The meta-analysis of six studies showed that a single bout of DS and SS presented similar efficacy in improving the acute effect on hamstring length. In four [46,51,54,56] of these six studies, the PEDro score was 7 and the remaining two [3,24] was 5 and 6, respectively. The methodological quality of the pooled results was high, and the heterogeneity analysis showed little heterogeneity among the six studies [3,24,46,51,54,56] ($I^2 = 0\%$). In addition, although the original data was not available in the study of Zmijewski P et al. [29], their results evidenced that SS and DS had similar effects on improving the extensibility of the hamstring, consistent with the results of this meta-analysis. However, a study completed by Samson M et al. [21] demonstrated different effects in which it was found that SS improved the distance of SR more than DS, which may be because in Samson M's study [21], in addition to SS and DS interventions, subjects in each group also performed specific aerobic warm-up exercises (such as jumping, jogging, etc.). These warm-up exercises further improved the tolerance and compliance of soft tissues during SS, potentially leading to SS showing better flexibility improvement under the combination of these specific warm-up exercises.

Besides, four [3,24,54,56] of the included participants in these six studies [3,24,46,51,54,56] were young, with an average age between 20 and 30 years, while the other two [46,51] included both young and middle-aged people, but all were under 60 years of age. Previous studies have shown that middle-aged and elderly people are more likely to present loss of ROM and soft tissue extension due to decreased muscle mass and exercise due to increased age and the deterioration of physical function [61]. The study by Zhou Wen-Sheng et al. [45] also explained why stretching effectively improved ROM in older people. Therefore, the stretch results on hamstring length in this meta-analysis are limited to young or middle-aged adults but not older people, especially the elderly over 60 years old.

Regarding the sub-acute effects of a single bout of SS and DS on hamstring length, the meta-analysis results showed no significant difference. The PEDro score of these two studies [51,54] was 7 of high quality, but the inter-study heterogeneity was considerable ($I^2 = 71\%$). In the study of Behm, D. G et al. [51], the total duration of hamstring stretch for a single cycle in the SS protocol was 120s, while in C Kurt's study [54], the period of SS was only 20s. Previous studies have shown that SS increases the length and compliance of the MTU, decreasing peak torque and muscle contraction velocity and inhibiting optimal muscle activation by reducing nerve impulses, resulting in a more sustaining effect [20]. This sustained effect is positively correlated with the duration of SS intervention, possibly explaining why in the study by Behm, D. G et al. [51], there was no statistical difference between the acute effects of DS and SS intervention in improving hamstring length. Still, the SS intervention produced a more significant sustained effect on hamstring extensibility than the DS intervention when measured 10 min after the intervention.

Our study found only one [49] comparing the short-term effects of DS and SS on improving hamstring length with multiple sessions of stretch follow-up up to 4 weeks. The PEDro score was only 2, which was of low methodological quality. Therefore, it is not yet possible to conclude that multiple cycles of DS and SS show similar effects in improving hamstring length. In addition, there are no studies investigating the medium and long-term impact of DS and SS on hamstring length, so the current study cannot provide corresponding recommendations for the medium and long-term results.

5.3. Effects of DS and SS on hamstring PT, stiffness, and thickness

In this review, we found three studies [53,57,58] that explored the effects of DS and SS on PT, stiffness, and thickness of the hamstring Because there are few studies related to those indicators, we conducted a qualitative analysis. During the passive stretch, DS and SS can improve the hamstring's PT, stiffness, and muscle thickness. However, it was impossible to conclude that the effects of the two stretching skills were similar based on the limited number of studies. Different from the study of Matsuo S. et al. [57], Chen et al. [53] showed that DS significantly reduced hamstring stiffness more than SS. Still, their subjects were students with limited hip flexion ROM, and their methodological quality was low (PEDro score was only 4 points). However, the study of Matsuo, S. et al. [57] had a high quality (PEDro score is 8), and the subjects were all healthy people. Hence, the subject factors potentially impacted the results. Matsuo S et al. [57] suggested that the mechanisms by which SS and DS affected PT changes at the onset of pain were similar. Both were due to a reduction in pain or discomfort, accompanied by changes in neurological and psychological factors, but the specific mechanisms are currently unknown. In addition, this study also investigated that SS and DS may affect passive MTU stiffness, with SS mainly reducing muscle stiffness and DS affecting tendon tissue. Regarding muscle thickness, the results demonstrated that both DS and SS improved hamstring muscle thickness with no significant difference between groups. The mechanism possibly was that mechanical load causes structural damage to fibers, blood flow restriction, and metabolite accumulation, which lead to muscle congestion and cell swelling and enhances protein synthesis [62,63].

A review conducted by S. R. Freitas et al. [64], presented that continuous stretching (3–8 weeks) had little effect on the maximum tolerated PT and presented no statistically significant changes in the structural and mechanical properties of the muscle-tendon. It was suggested that the initial stretch (within eight weeks) mainly caused changes in the sensory system. A longer intervention duration (usually more than 8–12 weeks) or greater intensity of stretch stimulation in each period was required to change the MTU. In terms of muscle thickness, Junior et al. [65] explored that SS before resistance training reduced muscle thickness, which was due to the greater load of SS in this study (stretching to a VAS score of 8–10, as compared with Ferreia-Junior, JB et al.'s study [58] of stretching to a score of 5). This also indicated that different stretch intensities perhaps had different effects on muscle thickness. Trindade, T. B. et al. [63] studied the acute effect of SS on biceps femoris thickness before resistance training, and their results also showed that SS increased biceps femoris thickness.

In summary, appropriate hamstring flexibility will make it easier for the muscle to adapt to the stress applied during exercises and allow efficient and effective movement, which can help prevent or reduce athletic injuries or even improve athletic performance [53].

SS is primarily proven to be an effective method for increasing hamstring ROM [66]. However, due to various neural and peripheral mechanisms, especially the reduction of MTU stiffness, multiple studies have shown that this stretching pattern is likely to have acute adverse effects on muscles, mainly manifested as a significant reduction in maximal voluntary contraction, muscle strength, or muscle performance after a single bout of SS [67]. Therefore, SS is not recommended by researchers in many studies to warm up before competition, especially SS with a single stretch duration of more than the 30s, to avoid adverse effects on athletes' performance. On the contrary, DS has been studied by more and more researchers in recent years. After DS, muscle tissue will produce a strong PAP effect and increase muscle temperature, thereby reducing muscle viscosity resistance and effectively increasing ROM. In a recent review [17], Jules Opplert and colleagues summarized the current evidence that DS improved soft tissue flexibility and sports performance and concluded that although the description of the DS intervention was inconsistent in different studies, DS seemed a more appropriate choice than SS as part of a warm-up. In addition, our study's outcome results mainly reflect the hamstring muscle's static flexibility. Still, in actual situations, sports experts or coaches usually pay more attention to dynamic flexibility during exercise or sports competition, which is more critical for preventing injury or improving sports performance. Many studies have confirmed stiff or poor flexibility muscles improved after DS and SS intervention. However, whether this improvement or increased elongation can be manifested in actual exercise was rarely reported. In a study by Amiri Khorasani, M. et al. [4], who explored the effects of DS and SS on dynamic ROM around the hip during kicking movements in professional soccer players, the results showed that the active hip ROM during kicking could be improved after carrying out DS, which may positively affect the angular velocity of the athlete's lower limbs during kicking. In contrast, SS fails to achieve a similar effect, so DS appears more valuable and superior to SS for dynamic movements.

6. Limitations

First, the schemes and intensities of DS in the studies included in this meta-analysis were diverse. This also led to uncertainty when choosing which DS protocol was more effective in pre-workout or warm-up exercises. Therefore, it is crucial to determine an ideal DS regimen for different types of exercise in future studies. Second, both young, middle-aged, and older adults were included in this study. Future studies with large samples should further explore the differences in improving hamstring flexibility between DS and SS in different populations. In addition, most of the population included in this meta-analysis were sports enthusiasts or athletes, so future research can explore whether there are differences between professional athletes and general people after DS and SS intervention. Third, the target muscle group in this study was only the hamstring muscle. Future studies can be reviewed according to different muscle groups to obtain more comprehensive results to better provide a guide for warm-up exercise. Finally, we only retrieved few studies using objective assessment methods like ultrasound, so we were unable to conduct quantitative analysis on it. We also hope that the objective assessment methods which can reflect the flexibility intuitively will be used in more studies in the future.

7. Conclusions

Both dynamic and static stretching can improve hamstring flexibility. A single bout of DS and SS had similar short-term effects on improving hamstring ROM and length. However, multiple sessions of SS significantly improved hamstring ROM compared to DS. As for improving passive torque, stiffness, and muscle thickness, it was impossible to conclude that there were differences between the two stretching techniques based on current evidence. For sports enthusiasts and professional athletes, DS is more recommended as a warm-up for a single stretch cycle before exercise training.

Ethical approval

None declared.

Fundings

Shenzhen Science and Technology Program (No. GJHZ20190823115412789); Shenzhen Science and Technology Program (No. JCYJ20210324134401004); Baoan district medical and health research Program (No. BA202200754203×027202211220130).

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

Additional information

Supplementary content related to this article has been publish online at [URL].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e18795.

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