REVIEW

Nr 2023;13 (1):61-75

Foam Rolling is not Superior to dynamic Stretching in Augmenting Muscle Strength and Physical Performance Markers: A Systematic Review and Meta-Analysis

Neha Dutta[1], Shalini Sharma[2], Dimple Khurana[1], Shikha Malik[1], Saurabh Sharma[1], Raj Kumar Sharma[3]

[1] *Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia, A Central University, New Delhi, India*
[2] *Department of Physiotherapy, Plena Healthcare Geri Care Home, Melbourne, Victoria, Australia*
[3] *Dean, Santosh University, Ghaziabad, Uttar Pradesh, India*

CORRESPONDING AUTHOR:
Saurabh Sharma
Centre for Physiotherapy and Rehabilitation Sciences
Jamia Millia Islamia
A Central University
Jamia Nagar
New Delhi, India
E-mail: ssharma@jmi.ac.in

DOI:
10.32098/mltj.01.2023.07

LEVEL OF EVIDENCE: 1

SUMMARY

Background. Dynamic stretching (DS) and foam rolling (FR) are frequently being used as warm-up to improve bio-motor ability. The review aimed to compare the acute effects (immediate and five minutes post-intervention) of DS and FR on flexibility, jump height, and muscular strength in the athletic and physically active population.
Methods. Electronic databases (Medline/PubMed, Web of Science, Scopus, Google Scholar, Cochrane Library, PEDro, and Hooked on evidence databases) were searched to obtain relevant studies. The methodological quality of the studies was assessed with the Physiotherapy evidence database (PEDro) scale. Meta-analysis was performed using the Rev Man 5.3 software to pool outcomes using the random-effects model, standardized mean difference (SMD) and 95% confidence interval (CI), and significance level set to $p < 0.05$.
Results. 406 papers were found and eight were included (n = 174).There was no significant mean difference between FR and DS on flexibility (immediate) (SMD: 0.15 (95%CI 0.23-0.52); p = 0.45), flexibility (five-minute) (SMD: 0.11 (95%CI -0.26-0.48); p = 0.55), jump height (immediate) (SMD: 0.20 (95%CI 0.12-0.53); p = 0.22), leg extensor strength (immediate) (SMD: 0.28 (95%CI 0.34-0.89); p = 0.37) and leg flexor strength (immediate) (SMD: 0.69 (95%CI 0.52-1.91); p = 0.26). The dosimetry from the qualitative summarization of studies suggests 2 sets (60 seconds each) of each FR and DS were performed on each muscle of the lower quadrant.
Conclusions. FR and DS exert similar magnitude of effect on flexibility, jump height, and muscular strength. The findings could help clinicians plan mode of warm-up for athletes.
Study registration. The study was registered in PROSPERO vide n. CRD42021225107.

KEY WORDS

Flexibility; jump height; myofascial release; strength; stretching.

INTRODUCTION

Before engaging in any sports activities, warm-up training is of paramount importance as it prepares the body for vigorous activities, enhances performance, and contributes to steering clear of injury (1). An appropriately planned warm-up can have a greater impact on sports performance, increase the pace of force-generating quantity of muscle cells (2-5), increase metabolic activity (6) and achieve explosive power and coordination to increase flexibility (7). A greater risk of muscle injury can be a result of lower levels of flexibility (8, 9). Flexibility is an essential part of adequate musculoskeletal characteristics (10) and is defined as the potential to voluntarily move a joint through its full range of motion (ROM) (11). Flexibility is an important component for both prevention and the rehabilitation of musculoskeletal injuries (10) and is necessary for safe and effective sports participation. Jumping force is considered one of the primary characteristics and it greatly influences performance in sports that requires jumping (12). Vertical jumping is a complicated human movement that desires intense motor integration between upper and lower body segments (13). A person's maximum jump height, which is a measure of leg muscle power, can give important normative information about a person's functional capacity and performance in numerous sports (14). Jumping performance ability is controlled by a person's capacity to use the elastic and neural profits of the stretch-shortening cycle (15). The ability to exert force on an external entity or resistance is known as muscular strength (16, 17). Better jumping, sprinting and sport-specific success are all linked to muscular strength. However muscular strength is crucial for athletic performance and injury prevention (18).

Before sports performance, among different types of stretching exercises, dynamic stretching (DS) is proposed for tissue health and performance boosting (19-21). DS allows entire body movements and requires actively extending a joint across its ROM without holding the movement at its endpoint (19, 22). DS provides the sport-specific warm-up, enhances muscle temperature, decreases muscle stiffness (23), improves nerve conduction, and increases metabolic rates associated with the phosphagen and glycolytic energy system (24). Studies have demonstrated that DS is successful in improving lower limb flexibility, maximal muscle strength, and vertical jump height without detrimental effects on performance (19, 25, 26).

Foam rolling (FR) has grown in popularity among the general population (27) and in recent years FR has been included in training programs (28). FR is a self-myofascial release technique where a solid foam cylinder is rolled backward and forward over the muscle and fascia (27). At the time of rolling, direct and sweep pressure is applied to the soft tissue, which results in fascial mobilization and increased ROM. FR creates friction, breaks fascial adhesions remove mechanical restrictions from the myofascial tissue, and restores lower limb flexibility (29-32). Furthermore, the FR technique aims to improve mobility and ROM, without detrimental effects on neuromuscular force development (33). Because of the likely potential physiological mechanism, it is accepted that FR helps both athletes and the physically active population in enhancing sports performance as well as recovery from exhausting physical activities (34). The benefit of the FR protocol is that it increases lower limb flexibility without related decreases in explosive strength, sprint time, or jump height (33).

Some research studies have been conducted to identify the most prudent warm-up protocol during the pre-exercise protocol (27, 28, 30). This will assist the athletes, coaches, and other sports professionals in including the pre-exercise protocol that benefits the most athlete's performance. Wilke *et al*. (35) conducted a systematic review on the acute effect of FR on ROM healthy adults and found FR as an effective method to induce acute improvement in lower limb flexibility. Opplert and Babault (36) published a review article on the acute effects of DS on muscle flexibility and performance and represent DS as a more effective modality than static stretching to be applied before explosive and high-speed activities.

The present study differentiates itself from other trials in terms of its objective (present study included studies that compared the acute effects (immediate and 5 minutes post-intervention) of DS and FR to enhance muscle strength and physical performance marker) and its outcomes measures (lower quadrant flexibility, jump height and muscular strength of quadriceps and hamstring muscle).

Nevertheless, the evidence to show the impact outcome effect of FR and DS on lower quadrant flexibility, jump height, and muscular strength (Quadricep and Hamstring) is limited and inconclusive. Contrasting results, inadequate RCTs, and inconsistencies associated with attributes used in studies across the board could be some of the reasons. These reasons make it essential to investigate the effect of FR & DS on physical performance. Over and above, limited systematic review and meta-analysis could be found which may have assessed the literature and deliberated the effect of FR and DS on lower quadrant flexibility, jump height, and muscular strength (Quadricep and Hamstring).

Therefore, this systematic review and meta-analysis aimed to investigate the acute effects (immediate and five minutes post-intervention) of FR and DS on lower quadrant flexibility, jump height, and muscular strength (Quadricep and Hamstring) in the athletic and physically active population. This information regarding the effect of FR and DS on sports-specific bio-motor abilities in athletic/physically active populations will provide an understanding of how to manipulate the sports performance level by using FR and DS as adjunct warm-up aids.

METHODS

The present systematic review and meta-analysis were performed following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guide-

lines. The component of the structured PICO format was mentioned as follows:
P (Population): Athlete & Physically active
I (Intervention): FR (Immediate and five minutes post-intervention)
C (Comparison): DS (Immediate and five minutes post-intervention)
O (Outcomes): Lower quadrant flexibility (Quadricep femoris, Hamstring, Gluteus maximus, and Gastrocnemius), Jump height (CMJ), and Muscular strength (Hamstring and Quadricep femoris).

Search strategy

Studies that were published in the English language and the studies that inspected the impact of DS and FR on lower quadrant flexibility, jump height and muscular strength (Quadriceps femoris and Hamstring) were included in this study. Literature was searched till November 2021 independently by the four authors through electronic database searches using Medline/PubMed, Web of Science (WoS), Google Scholar, Cochrane library, Pedro, Hooked on evidence, and Scopus databases using several keywords: ("Dynamic stretching", "Foam rolling", "Flexibility", "Range of motion", "Self-myofascial release", "Self-massage", "Myofascial Foam Rolling", "Dynamic Exercise", "Jump Height", "Vertical jump", "Muscular Strength") and connected by Boolean operator logic ("AND" and "OR") as shown in (**figure 1**). Additionally, we restricted our search to studies involving the human population and studies which were published in English. The study selection flow chart is shown in (**figure 2**).

Study selection criteria

All four authors (ND, DK, SM and SS) assessed the screening of the eligible studies to be included in this systematic review. The evaluation of the articles was primarily based on the title followed by the abstract. Lastly, if preliminary screening couldn't decide the eligibility, then the full text of the article was reviewed based on inclusion and exclusion criteria. Study inclusion and exclusion criteria (**table I**) are as follows:
Inclusion criteria (studies were included if they met the following eligibility criteria):
1. Randomized Control Trial studies.
2. Studies that included athletes and the physically active population (age: 18-40 years).
3. Studies in which FR and DS were compared.
4. Studies that examined the effects of at least one outcome measure related to lower limb flexibility, jump height, and muscular strength of quadriceps femoris and hamstring (immediately and five minutes post-intervention).
5. Studies investigating the human population only.
6. Studies that were published from 2017-2021.
Exclusion criteria (studies were excluded if):
1) Studies that included intervention on lower limb musculoskeletal injury.
2) Non-RCT trials, case reports, meta-analyses, systematic reviews, or review articles.
3) Studies that were not published in the English language.

1. Dynamic stretching AND Foam rolling AND Flexibility
2. Dynamic stretching AND Foam rolling AND Range of motion
3. Dynamic stretching AND Self-myofascial release AND Flexibility
4. Dynamic stretching AND Self-massage AND Flexibility
5. Dynamic stretching AND Myofascial Foam Rolling AND Flexibility
6. Dynamic Exercise AND Foam rolling AND Flexibility
7. Dynamic stretching AND Foam rolling AND Jump Height
8. Dynamic stretching AND Foam rolling AND Vertical Jump
11. Dynamic stretching AND Foam rolling AND Muscle strength
12. "Dynamic stretching AND Foam rolling" Flexibility
13. "Dynamic stretching AND Foam rolling" Range of motion
14. "Dynamic stretching AND Self-myofascial release" Flexibility
16. "Dynamic stretching AND Self-myofascial release" Vertical Jump
17. "Dynamic stretching AND Self-myofascial release" Muscle strength
18. Dynamic stretching* AND Self-myofascial release* Flexibility
20. Dynamic stretching* AND Self-myofascial release* Vertical Jump
21. Dynamic stretching* AND Self-myofascial release* Muscle strength

Figure 1. Search strategies using different keywords.

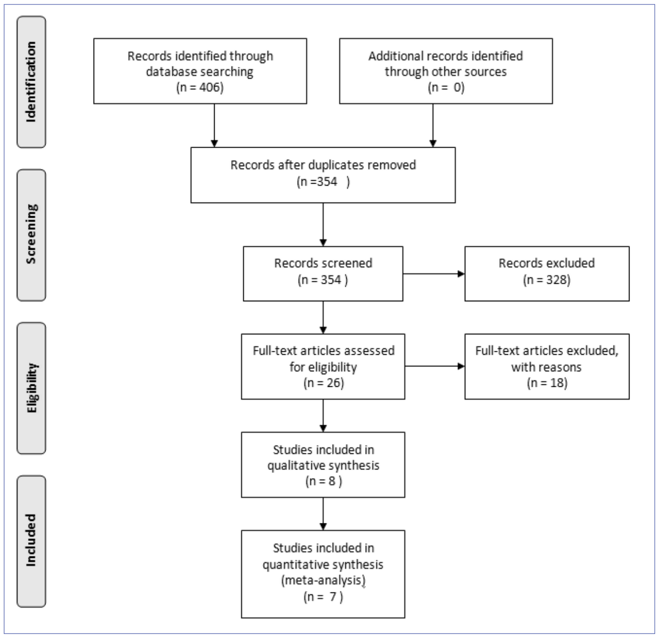

Figure 2. PRISMA flow chart.
Schematic breakdown of literature search results.

Methodological quality assessment

The quality of the included studies was assessed with the Physiotherapy evidence database scale (PEDro) which has been revealed to represent high reliability and validity for this purpose (37). Three authors (ND, DK & SM)

Table I. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Athlete & Physically active participants (18-40 years)	Lower limb musculoskeletal injury studies
Studies in which FR and DS were compared	Studies that receive only DS or only FR
Studies that examined the effects of at least one outcome measure related to lower limb flexibility, jump height, and muscular strength (immediately and five-minute post-intervention)	Studies that don't examined the effects on lower limb flexibility, jump height, and muscular strength (immediately and five minute post-intervention)
Studies investigating the human population only	Case reports, meta-analyses, systematic reviews or review article
Studies that were published from 2017-2021.	Non- English literature

DS: dynamic stretching; FR: foam rolling.

independently scored the studies, and disagreements were resolved through discussion with the fourth author (SS). The methodological quality of included studies was assessed based on 11 criteria: eligibility criteria, randomized allocation, concealed allocation, comparable at baseline, blinding of the subject, blinding of a therapist, blinding of assessors, adequate follow-up, intention to treat analysis, comparable between groups and point estimates and variability. A point was awarded, when the criterion of each category is met, excluding criterion number 1. Criterion number 1 is not used for the calculation of the total score of the scale. Therefore, the 0-10 total score was determined by counting the number of criteria satisfied by each study. Study quality was rated as poor (PEDro score ≤ 3), fair (PEDro score 4-5), or high (PEDro score > 5) (38) (**table II**). Furthermore, this scale acquires adequate reliability (intra-class correlation coefficient of 0.68) (39).

Data extraction

For the meta-analysis, we used the Review Manager software (version 5.3) of the Cochrane Collaboration to perform the quantitative analysis. Three authors (ND, DK, SM)

Table II. PEDro Scoring for Assessment of Methodological Quality.

PEDro scale	Behra & Jacobson, 2017	Kopec *et al.*, 2017	Lopez *et al.*, 2021	Pisirici *et al.*, 2020	Siebert *et al.*, 2020	Smith *et al.*, 2018	Somers *et al.*, 2019	Su *et al.*, 2017
1. Eligibility criteria	+	+	+	+	+	+	+	+
2. Randomized allocation	+	+	+	+	+	+	+	+
3. Concealed allocation	-	-	-	+	-	-	+	-
4. Comparable at baseline	+	+	+	+	+	+	+	+
5. Blinding of subject	-	-	-	-	-	-	+	-
6. Blinding of therapist	-	-	-	-	-	-	-	-
7. Blinding of assessors	-	-	-	+	-	-	+	-
8. Adequate follow-up	+	+	+	+	+	+	+	+
9. Intention- to-treat analysis	-	-	-	-	-	-	-	-
10. Comparison between groups	+	+	+	+	+	+	+	+
11. Point estimates and variability	+	+	+	+	+	+	+	+
Total Score	**5**	**5**	**5**	**7**	**5**	**5**	**8**	**5**

A total score out of 10 is determined from the number of criteria that are satisfied, except that scale item 1 is not used to generate the total score. + Indicates score 1; - Indicates score 0.

independently explored and pulled out the data from each study included for the review and then disagreements were resolved through discussion with the fourth author (SS). We contacted the corresponding author if any data was not clear in the included study. We have selected the Lower quadrant flexibility, Vertical jump height, and Muscular strength of the hamstring and quadriceps femoris as the primary outcome measures. Lower quadrant flexibility is measured through Sit and reach test (SRT) in (cm), Modified Thomas test (MTT) in degree, Passive hip flexion test (SLRT) in degree, and Forward lunge technique in cm. The SRT has a test-retest reliability of above 0.90 (40) and was used to assess low back and hamstring flexibility (27, 41). MTT is used to assess the flexibility of quadriceps muscle (42) and the intraclass correlation coefficient (ICC) of ROM measurements was 0.87 for MTT (43). MTT was assessed using an inclinometer (43). SLRT was assessed using an inclinometer and the ICC of ROM measurements was 0.87 for SLRT (44). A weight-bearing lunge technique was used to assess ankle dorsiflexion (DF) ROM and the ICC of ROM measurements was 0.97-0.99 (44). Countermovement jumps (CMJs) were performed on an infrared jump system according to standard methodology (45). The ICC for this test was 0.90 (46). Isokinetic knee extensor and flexor muscle strength were assessed using the isokinetic dynamometer (28, 41). The peak torque in N.m was recorded (28, 41, 47). The isokinetic quadriceps and hamstrings muscle strength measured at 60°/second using the Biodex System has high ICC values ranging from r = 0.88 to r = 0.97 (48). During extraction, the data for different studies were filtered based on a comparison among various variables, including participant characteristics (including sample size and age), intervention characteristics, measurement method, design of the study (author's name and year of publication), and the conclusion drawn. Pre-intervention Mean ± Standard deviation (SD) and Post-intervention Mean ± SD of all outcome measures for DS and FR intervention were also extracted.

Operational group definitions

DS is used as a part of the warm-up phase (28), as DS mimics the entire body movement pattern performed during exercise and involves actively moving a joint through its ROM without holding the movement at its end range (19, 22). DS protocol consisted of exercises (straight leg march, forward lunge with opposite arm reach, forward lunge with elbow to instep, lateral lunge, trunk rotations, and multidirectional skipping exercises) which target gluteus maximus, quadriceps, hamstring, and gastrocnemius muscles (27, 28, 30, 41, 49-52). Each movement was performed continuously for 2 sets each set for 60 sec (50) with 10 sec of rest between each set (30). Participants were instructed that the velocity of movement had to be slowly increased from 50 to 90% of their maximal velocity for each exercise (53). DS exercise group included studies that used DS protocol and have the potential to provide the sport-specific warm-up, decrease muscle stiffness and increase joint ROM (27, 28, 41, 49). We excluded studies utilizing any other form of stretching interventions (such as static stretching or ballistic stretching). Studies that used only the FR group as a comparator were included.

FR is a kind of self-myofascial release technique in which a dense foam cylinder is used to roll backward and forward over the muscle and fascia to release adhesion on the surface of the deep fascia (27). FR was performed with a grid foam roller device of medium density. FR was applied to the gluteus maximus, quadriceps, hamstring, and gastrocnemius muscles (27, 28, 30, 41, 49-52) for 2 sets each set for 60 sec (50) with 30 sec of rest (27) between each set. Participants were instructed to apply pressure to the foam roller with as much body weight as possible. FR was conducted at a rate of 30 rolls per minute using a metronome to keep pace (27). FR group included studies that used FR protocol to remove mechanical restrictions from the myofascial tissue and increase the flexibility of lower quadrant muscles (27, 28, 41, 49). Studies that used only the DS group as a comparator were included.

Data analysis

A meta-analysis was performed to compare changes in the effect size between two intervention (DS and FR) groups. All analysis was conducted using statistical software Review Manager (RevMan) (version 5.3) of the Cochrane Collaboration. The mean and intraclass correlation coefficient (SD) for each intervention were used to calculate the standardized mean difference (SMD) for DS and FR intervention group. SMD was calculated along with the 95% confidence interval and significance level set to $p < 0.05$. We used the following formula for obtaining the SD (54):

SD = [(square root of the number of participants) × (difference of upper and lower limit of 95% CI)] / 3.92

The effect size of the outcome variables was interpreted by the SMD values with a value of 0.2 signifying a small effect size, 0.5 depicting a medium effect size, and 0.8 reflecting a high effect size (55). Heterogeneity was established by the chi-square test and the I2 statistic. The I2 value of 0 to 40% indicate low, 30% to 60% moderate, 50% to 90% substantial, and 75% to 100% considerable heterogeneity (54). The results of both intervention groups (DS and FR) included in this meta-analysis were depicted in forest plots.

Risk of bias assessment

We used the Cochrane risk of bias tool to assess threats to bias for 5 domains: randomization process, deviation from the intended intervention, missing outcomes, and selection of the reported result (**figure 3**). Studies were justified to be of low risk of bias if all domains are judged to be at low risk of bias, high risk of bias if at least one domain is judged to be at high risk of bias or if some concern for multiple domains and moderate risk of bias if at least one domain is judged to be at some concern.

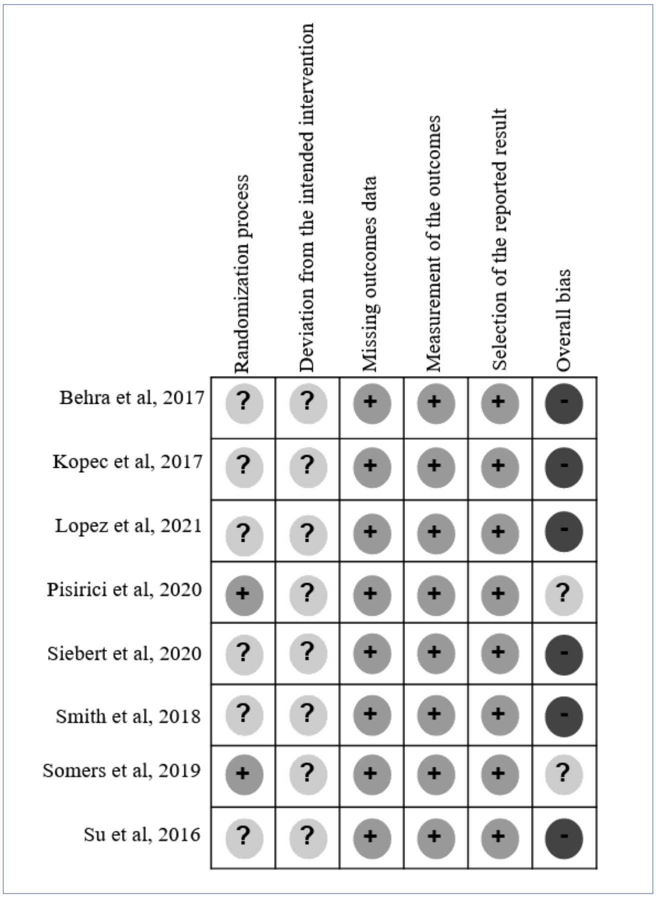

Figure 3. Risk of bias summary review authors' judgements about each risk of bias item for each included study (Rev Man 5.3).
+ indicate low risk of bias; - indicate high risk of bias; ? indicate some concern.

RESULTS

Literature search results

With the use of the search strategy from the electronic database search engines, a total of 406 potential studies were retrieved. We screened the titles and abstracts of these studies in terms of the inclusion and exclusion criteria and identified 26 studies after excluding the rest of the studies. Then, we assigned these studies to further screening by going through the full text and removing 18 articles. And then we finally included 8 studies in this review. Most of the studies were excluded based on undesired outcome measures and differences in the type of intervention. Out of 8 included studies, 7 studies were analyzed for quantitative analysis. A flow diagram of the retrieved literature is mentioned in (**figure 2**).

Participants

The detailed descriptive characteristics of the included studies and their treatment regimes are given in (**tables III, IV**). We have included eight articles collectively within age groups ranging from 18 to 40 years having 174 participants. All the studies demonstrated the inclusion of both 102 male and 72 female individuals.

Description of interventions and protocols

For the FR session, participants foam rolled over the (Quadricep femoris, Hamstring, Gluteus maximus, and Gastrocnemius), muscles. In three studies (27, 41, 51) participants foam rolled on lower quadrant muscles for 3 sets of 30 sec. In one study (50) participants foam rolled on lower quadrant muscles for 2 sets of 60 sec, and three studies (28, 30, 49) participants foam rolled on lower quadrant muscles for eight-minute and one study (41) foam rolled for 3 minutes. For the DS session, the participants performed DS of the Quadricep femoris, Hamstring, Gluteus maximus, and Gastrocnemius (stretch such as Straight leg march, Forward lunge with opposite arm reach, forward lunge with an elbow to instep, lateral lunge, trunk rotations, multidirectional skipping, Knee lift, leg swing, lateral shuffle, backpedal, front kick and downward dog stretch) for 2 sets of 60 sec. The exercise protocol has been described in (**tables III, IV**).

Outcome measures

Four trials measure the effects on lower quadrant flexibility immediately after DS and FR intervention (27, 28, 49, 50), whereas the other three trials measure the effects on lower quadrant flexibility after the five minutes of intervention (27, 41, 51). Four trials measure the effects on vertical jump height immediately after DS and FR intervention (27, 30, 49, 52). Two trials measure the effects on knee flexor muscle strength and knee extensor muscle strength (28, 41). No trials found measuring the effects of DS and FR on vertical jump height and knee flexor and extensor muscle strength after five-minute intervention. Flexibility is measured through different methods, namely, SRT (cm), MTT (degree), Straight leg raise test (degree), and Forward lunge technique (cm). The vertical jump was measured through the Countermovement jump (cm) while muscle (Hamstring and Quadricep) strength through peak torque in Newton-meter (Nm). The smallest sample size used among searched articles is 11 (49) and the largest sample size used is 30 (41).

Table III. Characteristics of the studies.

Authors and year	Design	Total participants	Intervention and comparator (muscle, dosage)	Outcome measure	Result
Behar & Jacobson, 2017	RCT	N = 14 well trained NCAA division football player (age 20.04 ± 1.41 years)	FR (left and right hamstring, quadriceps, gluteus maximus, gastrocnemius, 8 min each mscl for 60 sec) DS (left and right hamstring, quadriceps, gluteus maximus, gastrocnemius, 8 min)	Flexibility- Hip flexion ROM Knee flexor and knee extensor muscle strength- Torque	No significant differences were found for hip ROM, DS and FR showed equal increase on ROM No significant differences were found for peak knee flexion and extension isometric torque, neither DS nor FR improved peak knee flexion and extension isometric torque
Kopec *et al.*, 2017	RCT	N = 20 physically active (10 male and 10 female) (age 22.5 ± 4 years)	FR (Triceps surae, hamstrings, and quadriceps, 3 min each mscl for 30 sec) DS (Triceps surae, hamstrings, and quadriceps, 3 min each mscl for 30 sec)	VJ height- CMJ	No significant differences were found for CMJ, neither DS nor FR improved CMJ
Lopez *et al.*, 2021	RCT	N = 11 male tennis players (age 20.64 ± 3.56 years)	FR (Quadriceps, hamstrings, gluteus maximus and gastrocnemius, 8 min each mscl for 60 sec) DS (Quadriceps, hamstrings, gluteus and gastrocnemius, 8 min)	Flexibility- Thomas test VJ height- CMJ	No significant differences were found for hip ROM, DS and FR showed equal increase on ROM No significant differences were found for CMJ, neither DS nor FR improved CMJ
Pisirici *et al.*, 2020	RCT	N = 28 recreational active (14 female, 14 male) (age 21.5 ± 1.6 years)	FR (Hamstring, Gastrocsoleus, Plantar fascia, 16 min for both leg) DS (Hamstring, Gastrocsoleus, Plantar fascia, 10 min)	VJ height- CMJ	No significant differences were found for CMJ, DS and FR showed equal increase on CMJ
Siebert *et al.*, 2020	RCT	N = 14 Male sports students (age 23.7 ± 1.3 years)	FR (Bicep femoris, semi tendinosus, semi membranosus, 3 set × 30 sec) DS (Bicep femoris, semi tendinosus, semi membranosus, 3 set × 3 0 sec)	Flexibility- Hip flexion ROM	Increase in hip ROM after DS as compared to FR
Smith *et al.*, 2018	RCT	N = 29 healthy physically active (21 female and 8 male) (age 22 ± 3 years)	FR (Gluteus maximus, hamstrings, quadriceps, and calf muscles, 3 set × 30 sec) DS (Gluteus maximus, hamstrings, quadriceps, and calf muscles, walk 20 m distance each stretch for 4 reps)	Flexibility- S&R test VJ height- CMJ	Increase in ROM found immediately after FR as compared to DS No significant differences were found for ROM after five minutes post intervention, DS and FR showed equal increase on ROM Increase in VJ height after DS as compared to FR
Somers *et al.*, 2019	RCT	N = 28 recreational active (16 male and 12 female) (age 26.12 ± 4.03 years)	FR (Calf muscle, 2 set × 60 sec) DS (Calf muscle (DD stretch), 2 set × 60sec)	Flexibility- Ankle DF ROM	No significant differences were found for the ankle DF ROM, DS and FR showed equal increase in ankle DF ROM
Su *et al.*, 2015	RCT	N = 30 physically active adult (15 male and 15 female) (age 21.43 ± 1.48 years)	FR (Quadricep and Hamstring, 6 min 3set × 3 0sec) DS (Quadricep and Hamstring, 6 min)	Flexibility- S&R test and MT Test Knee flexor and knee extensor muscle strength- Torque	Increase in S&R test and MT test more after FR as compared to DS Increase in knee extension peak torque after both DS and FR but no increase in knee flexion peak torque after both DS and FR

DS: dynamic stretching; FR: foam rolling; CMJ: countermovement Jump; ROM: range of motion; VJ: vertical jump; S&R test: sit and reach test; MT test: modified thomas test; DF: dorsiflexion; PF: plantarflexion; DD: downward dog.

Table IV. FR and DS regimes.

	FR				DS				
Author	**Types of FR used**	**Duration**	**Sets**	**Rest between each set**	**Types of DS used**	**Distance of walk**	**Duration**	**Sets**	**Rest between each set**
Behar & Jacobson, 2017	X	8 min (each msc for 60 sec)	X	X	Dynamic stretching of quadriceps, hamstring, gluteus maximus and gastrocnemius	X	8 min	X	X
Kopec *et al.*, 2017	High density (Gofit) foam roller	3 min each msc for 30 sec	X	X	DS for triceps surae, hamstrings, and quadriceps muscle	X	3 min, each msc for 30 sec	X	X
Lopez *et al.*, 2021	GRID foam roller	8 min (each mscl for 60 sec)	X	X	Straight leg march, Forward lunge with opposite arm reach, Forward lunge with elbow to instep, Lateral lunge, trunk rotations, Multidirectional skipping exercises	X	8 min	3 set	15 sec
Piscirici *et al.*, 2020	GRID X and NANO X foam roller	16 Min (8 min each leg) (3min hamstring ,3 min gastrosoleus, 2 min plantarfascia)	X	X	High knee walk, Straight-leg march, Hand walk, Lunge walk, Backward lunge walk, High knee skip, Lateral Shuffle, Back Pedal, Heels-up, High knee run	13 m distance for each DS	10 min	X	10 sec
Siebert *et al.*, 2020	GRID foam roller	X	3 set × 30 sec	30 sec	DS of hamstring (bicep femoris, semi tendinosus, semi membranosus	X	X	3 set × 30 sec	30 sec
Smith *et al.*, 2018	High density EVA foam roller	X	3 sets × 30 sec	30 sec	High Knee lift march, straight leg march, Knee flexion march, March with ankle dorsiflexion	20 m distance, each stretch for one side of body with 4 reps	X	X	X
Somers *et al.*, 2019	X	X	2 set × 60 sec	X	DD stretch	X	X	2 set × 60 sec	X
Su *et al.*, 2017	EVA foam roller	6 min	3 set × 30 sec	X	forward lunge and front kick)	X	6 min	3 × 60 sec	X

DS: dynamic stretching; FR: foam rolling; EVA: ethylene vinyl acetate foam roller; DD: downward dog.

Quality assessment

The quality assessment of the eight included studies (27,28,30,41,49-52) rated fair (score 5) and high (score 7 and 8) quality when scored on the PEDro scale. **Table II** shows the scores of the PEDro scale for each article included in the review. Two studies (30,50) were deemed to have high methodological quality and the remaining six studies (27, 28, 41, 49, 51, 52) were deemed to have fair quality.

Risk of bias assessment across studies

Figure 3 shows the overall risk of bias summary of all the studies. Common methodological shortfalls were lack of randomization process (n = 6) (27, 28, 41, 49, 51, 52) and lack of deviation from the intended intervention (n = 8) (27, 28, 30, 41, 49-52). Only two trials (30, 50) reported both randomization and concealed treatment allocation adequately. Two studies rated a moderate risk of bias (30, 50) and six studies rated a high risk of bias (27, 28, 41, 49, 51, 52).

Risk of bias assessment across lower quadrant flexibility

Four studies (27, 28, 49, 50) reported the effects of FR and DS on flexibility immediately after the intervention. Three studies had a high risk of bias (27, 28, 49) and one study by Somers *et al.* (50) had a moderate risk of bias. Two studies (28, 49) reported there were no statistically significant differences between DS and FR on the hip flexion ROM whereas study by Somers *et al.* (50) reported there were no statistically significant differences between DS and FR on ankle dorsiflexion (50). Study by Smith *et al.* (27), reported a significant percentage increase in ROM immediately after FR. Three studies reported the effects of FR and DS on flexibility after five minutes of intervention. All three studies had a high risk of bias (27, 41, 51). Smith *et al.* (27) reported there were no statistically significant differences between DS and FR on the SRT.

Risk of bias assessment across jump height

Four studies (27,30,49,52) reported the effects of FR and DS on vertical jump height immediately after the intervention. Study by Pişirici *et al.* (30), had a moderate risk of bias and three studies had a high risk of bias (27,49,52). Three studies (30, 49, 52) reported there were no statistically significant differences between DS and FR on countermovement jump (CMJ) whereas study by Pişirici *et al.* (30) reported a significant increase in CMJ after DS.

Risk of bias assessment across muscle strength

Two studies (28, 41) reported the effects of FR and DS on Muscle strength. Both studies had a high risk of bias. Behra and Jacobson (28) reported there were no statistically significant differences between DS and FR on peak knee flexion and extension isometric torque while Su *et al.* (41) reported knee extension peak torque improved significantly after FR and DS whereas knee flexion peak torque remained unchanged after FR and DS.

Qualitative summary of strength of evidence (data synthesis)

To construct the best evidence synthesis, only 2 studies (30,50) were rated to be of moderate quality. Pişirici *et al.* (30) conducted 8 minutes of FR and DS on each leg, 3 minutes on the hamstring, 3 min on gastrocsoleus, and 2 min on the plantar fascia and observed equal improvement in CMJ for both DS and FR, whereas Somers *et al.* (50) conducted 2 sets of FR and 2 sets of DS, each set for 60 seconds on calf muscles and observed both FR and DS showed an equal increase in ankle dorsiflexion ROM (30, 50). However, there was no low risk of bias study. So, we have used two studies (30, 50) with a moderate risk of bias for a qualitative summary. Hence, the result of these studies should be followed with caution. Therefore, 2 sets of FR and 2 sets of DS, each set for a duration of 60 seconds on each muscle group of the lower quadrant are qualitatively summarized from studies.

Quantitative analysis

The meta-analysis was conducted on the selected studies by using the software to pool outcomes using the random effects model, SMD, SD, and sample size.

Quantitative analysis of lower quadrant flexibility

Three RCT studies (27,28,49) (n = 54 participants) supply information identifying the data associated with the effects of FR and DS on lower limb flexibility just immediately after the intervention. **Figure 4** reveals that there were no significant differences in DS and FR on lower limb flexibility just immediately after intervention (SMD 0.15 (95% CI -0.23, 0.52); $p = 0.45$, $I2 = 0\%$). Three RCT studies (27, 41, 51) (n = 73 participants) supply information identifying the data associated with the effects of FR and DS on lower limb flexibility after 5 minutes of intervention. **Figure 5** reveals that there were no significant differences in DS and FR on lower limb flexibility after 5 minutes of intervention (SMD 0.11 (95%CI -0.26-0.48); $p = 0.55$, $I2 = 20\%$).

Quantitative analysis of jump height

Four RCT studies (27, 30, 49, 52) (n = 60 participants) supply information identifying the data associated with the effects of FR and DS on jump height just immediately after the intervention. **Figure 6** reveals that there were no significant differences

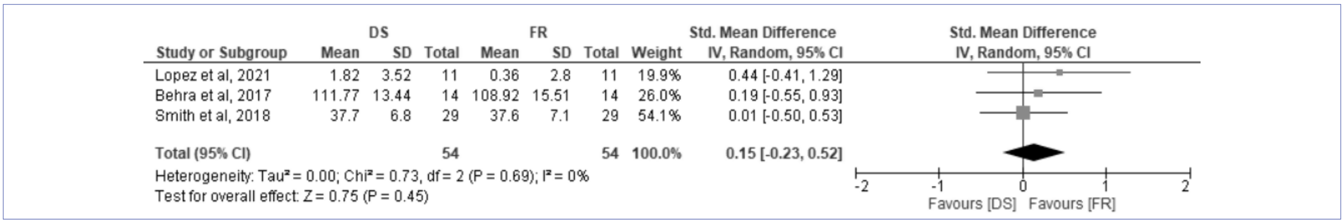

Figure 4. SMD (95%CI) of the comparison of effects of DS and FR groups on flexibility immediately after the intervention by pooling data from 3 studies.

SD: standard deviation; CL: confidence interval; DS: dynamic stretching; FR: foam rolling.

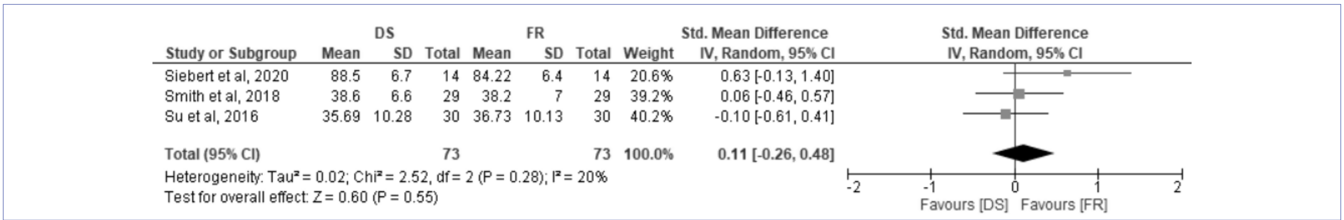

Figure 5. SMD (95%CI) of the comparison of effects of DS and FR groups on flexibility five minute post-intervention by pooling data from 3 studies.

SD: standard deviation; CL: confidence interval; DS: dynamic stretching; FR: foam rolling.

in DS and FR on vertical jump just immediately after intervention (SMD 0.20 (95%CI -0.12-0.53); p = 0.22, I2 = 0%).

Quantitative analysis of muscle strength

Two RCTs studies (28 ,41) (n = 44 participants) supply information identifying the data associated with the effects of FR and DS on leg extensor strength after the intervention. **Figure 7** reveals that there was no significant difference in DS and FR on leg extensor strength immediately after the intervention (SMD 0.28 (95%CI -0.34-0.89); p = 0.37, I2 = 48%). Two RCTs studies (28,41) (n = 44 participants) supply information identifying the data associated with the effects of FR and DS on leg flexor strength after the intervention. **Figure 8** reveals that there were no significant differences in DS and FR on leg flexor strength immediately after the intervention (SMD 0.69 (95%CI -0.52-1.91); p = 0.26, I2 = 85%).

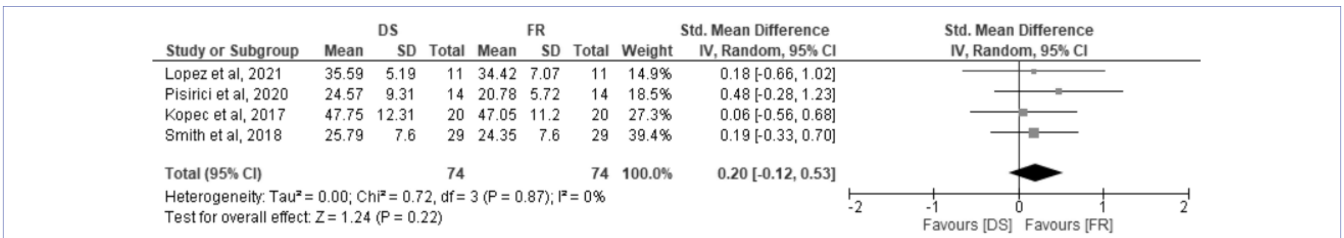

Figure 6. SMD (95%CI) of the comparison of effects of DS and FR groups on jump height immediately after the intervention by pooling data from 4 studies.

SD: standard deviation; CL: confidence interval; DS: dynamic stretching; FR: foam rolling.

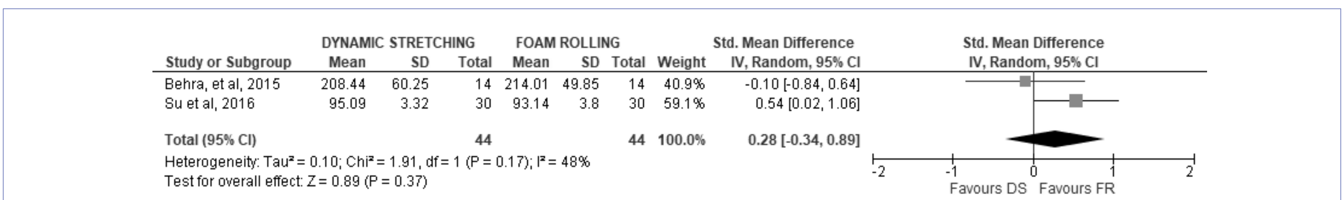

Figure 7. SMD (95%CI) of the comparison of effects of DS and FR groups on leg extensor strength immediately after the intervention by pooling data from 2 studies.

SD: standard deviation; CL: confidence interval; DS: dynamic stretching; FR: foam rolling.

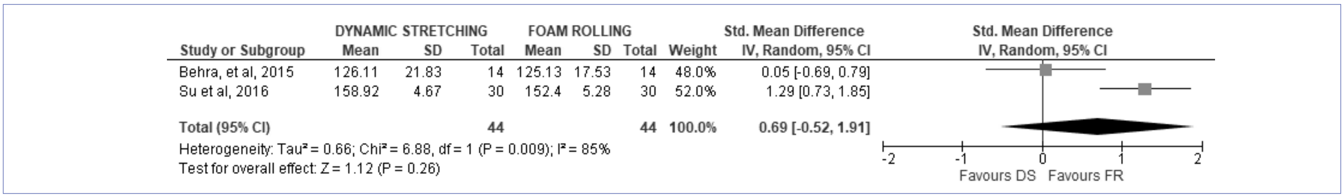

Figure 8. SMD (95%CI) of the comparison of effects of DS and FR groups on leg flexor strength immediately after the intervention by pooling data from 2 studies.

SD: standard deviation; CL: confidence interval; DS: dynamic stretching; FR: foam rolling.

DISCUSSION AND IMPLICATIONS

This is amongst the few review studies that compared the effects of FR and DS on lower limb flexibility, jump height, and muscular (Hamstring and Quadricep femoris) strength. The present review aimed to compare the acute effects (immediate and five minutes post-intervention) between DS and FR on lower quadrant flexibility, jump height, and muscular strength (Hamstring and Quadricep femoris) to help aid coaches, clinicians, and athletes regarding a more effective protocol for warm-up. The qualitative analysis described by two moderate-quality studies suggests that both DS and FR intervention have an equal effect on lower quadrant flexibility, jump height, and muscular strength (Hamstring and Quadricep femoris) in defined dosimetry proportion. Secondly, the results of the quantitative analysis suggest that there was no significant mean difference between FR and DS on lower quadrant flexibility, jump height, and muscle strength (Hamstring and Quadricep femoris) for the acute effects (immediately and five minutes post-intervention).

Lower quadrant flexibility

For the acute effects immediate and five minutes post-intervention, we pooled 4 studies (27, 28, 49, 50) and 3 studies (27,41,51) respectively that used lower quadrant flexibility as outcome measures. The results showed that DS intervention is not superior to FR for both immediate (p = 0.15) and five minutes post-intervention (p = 0.11). The previous literature (50) has found an increase in lower quadrant flexibility when a comparison was done between FR and DS. It was found that both DS and FR have equal effects on lower quadrant flexibility and neither of the interventions produced superior results than the others. Our study results are also in line with studies that demonstrated DS and FR are equally effective in terms of increasing lower quadrant flexibility in athletes and physically active population (28,49). It must however be emphasized that these results may not be generalized owing to the evident heterogeneity at the immediate and five minutes post-intervention time points. A previous study has explained that even though FR and DS have equal effects on lower limb flexibility, their mechanisms of action were different from each other (49). An increase in lower limb flexibility after DS can be supposed to be due to a combination of multidimensional activities (posterior kinetic chain) which leads to extensive movement and supports ROM through a positive effect on the stretch-shortening cycle (56, 57). Additionally, an increase in lower limb muscle ROM after DS can be due to an increase in temperature that leads to a decrease in the viscous resistance of muscles (58) and enhances tissue extensibility (without entering pain-tolerated intensity) resulting in greater angular displacement (59, 60). The foam roller is supposed to place direct and sweeping pressure on the soft tissue to stretch the tissue and give rise to friction between the soft tissue of the body and the foam roller, resulting in greater flexibility (29, 61). The friction created between the fascia and foam roller causes warming of the fascia and generates fluid gel-like extracellular substance; the thixotropic property of fascia (21). Changes in the thixotropic property of fascia, altered tissue stiffness, and increased tolerance to the stretch may be mechanisms behind increased lower limb ROM after FR (21, 62).

Jump height

The results showed that FR is not superior to DS when being examined for vertical jump height. Our study is in line with study by Pisirici *et al*. (30) who investigated 8 minutes of DS and 8 minutes of FR on recreational active participants and found DS and FR to be equally effective in improving vertical jumping scores. In contrast study by Kopec *et al*. (52), investigated 3 minutes of DS and 3 minutes of FR on physically active participants and found that neither DS nor FR significantly improved vertical jump score. Likewise, one of the studies by Lopez *et al*. (49) also investigated 8 minutes of DS and 8 minutes of FR on tennis players and found neither DS nor FR significantly improved vertical jumping scores. This conflicting result may be due to many reasons such as a lack of agreement on clinical standards for evaluation, intervention, and application dose (63) and also there is no consensus on type, intensity, pressure applied, cadence volume and duration of FR and DS (41). Kopec *et al*. (52) explained the reasons why DS had no significant impact on a vertical jump and described that stretch used in their study may not have been specific for the CMJ. DS negatively influences the time-to-peak power which may be due to the alterations in the length-tension relationship and force-velocity relationships which decreases neuromuscular compliance and attenuates the optimal power production (64). Findings also suggest differences in the application of pace and amount of pressure applied to the muscles during FR plays a crucial role in the effect of VJ outcome but in some studies, the participants moved on FR at their own pace, and the pressure applied to the FR by each participant was also not standardized (65). This can be the plausible reason why FR had no significant impact on vertical jumping.

Muscular strength

The results showed that FR intervention is not superior to DS when being examined for knee extensor and flexor strength. Our study is per Su *et al*. (41) who found the application of DS and FR equally effective in increasing knee extension peak torque with a medium effect size but found a non-significant increase in knee flexion peak torque after FR and DS. An increase in knee extension peak torque for DS may be due to an increase in muscle temperature and post-activation potentiation (PAP) (66, 67). The improvement in knee extensor muscle strength after DS also may be a result of the contraction phase instead of the stretching phase during the DS movement (41). Additionally, the author described that the rise in knee extension peak torque after FR might be due to the measurement error (41). Su *et al*. (41) clarified that there was a non-significant finding in knee flexion peak torque as the movements employed for DS did not provide a chance for repeated contractions of the hamstrings muscle. Another study by Behra and Jacobson (28) found no significant difference in the improved peak knee flexion and extension strength between DS and FR.

Rationale for the results

A feasible explanation for the lack of a significant difference between two modalities FR and DS is likely based on the reality that the included studies differ considerably in their interventions. These variations were primarily in the DS technique, the FR technique, and treatment duration (30-180 s) (66). The methodology of selected studies included in this review for analysis of outcomes used different dosages for DS and FR intervention. This difference in dosages could be the reason behind the non-significant results. Secondly, types of dynamic movement used, types of foam roller used (Grid, Ethylene vinyl acetate, High-density), speed, and amount of pressure applied to the targeted muscles during FR, these factors were not uniform in all included studies. In addition, the determinants of speed in the DS protocol, *i.e*., synergy between the lower quadrant muscle groups and the duration of the protocol also play a role in deciding the significance of the physiological changes and athletic performance (30). The FR intervention duration is also an important determinant for muscle performance *i.e*., short duration time (< 30 sec) has been reported to be insufficient for performance enhancement. Therefore, it is advised to apply FR for a longer duration (60-120 sec), especially when used on large muscle groups (66). Thirdly, the studies included in this review for analysis of lower limb flexibility did not utilize a uniform assessment tool. This heterogeneity might have precluded the result of the pooled outcome.

Clinical implications

DS intervention plays a vital role as the mainstay intervention in the warm-up protocol for the athlete and physically active populations. Its efficacy was required to be systematically analyzed and compared with the FR intervention. DS and FR increase lower limb flexibility, decrease muscle stiffness and reduce the risk of lower limb injury, these components help the athlete to increase performance (23, 28, 49). Athletes can confidently execute DS and FR intervention in their warm-up protocol as a strategy to increase athletic performance (33, 34). FR intervention achieves deep tissue release to the targeted muscle group, while a dynamic stretch promotes tissue lengthening of the entire posterior chain (30, 49, 52). An athlete can execute FR if the athlete requires myofascial loosening such as in the condition of facial adhesion otherwise, the athlete can execute DS as it requires lesser equipment (30, 49, 52). The above information stresses the important role of physiological changes during the execution of technique in sporting activities (68).

Strengths, limitations, and future recommendations

This is one of the few research studies investigating the acute effects (immediate and five minutes post-intervention) of FR and DS and the study extracts its strength from the vigorous search strategy used for the location and identification of all the possible studies. We examined the immediate effect and five-minute post-intervention effects of DS and FR. The present study involved four authors (ND, DK, SM & SS) in the review process of the study who identified the whole literature relevant to the study criteria to avoid individual error or bias within the study selection process. This review encloses data from 174 athletes and physically active populations. Also, the search and screening of studies were done systematically and according to guidelines to minimize bias. The results from this present review would be beneficial for the athletes, coaches, and clinicians in helping them to decide the mode of warm-up.

There are a few limitations of the present study; firstly there might be a related language bias in this review as we included only English language studies. Secondly, we included studies from limited setup data bases therefore might have missed including the studies published in other databases thereby, obtaining a bias. Thirdly, some of the included studies in the review had a small sample size which might have resulted in reduced statistical power. Lastly, another limitation might be the lack of standardized protocol used by included studies like duration, intensity, speed, controlled pressure, types of foam roller used, types of DS used and muscle(s) targeted. This could have impacted the results of the study and therefore the conclusion of this review should be viewed from this perspective.

Further, high-quality studies are recommended in the future that compare the effect of FR and DS on lower quadrant flexibility, jump height, and muscular strength (Quadricep femoris and Hamstring) using a standardized protocol of FR and DS. Secondly, there is also a lack of evidence-based study that compares the effect of FR and DS on a longer time course after post-intervention, hence in the future, studies that investigate the longer time course effect of DS and FR after post-intervention on lower quadrant flexibility and sports performance can be done. Also, in the future higher-quality RCTs evaluating muscle activity through EMG analysis and the muscle properties like viscoelastic properties, dynamic stiffness, and muscle tone should be assessed with a myoton device.

CONCLUSIONS

In conclusion, FR is not superior to DS *i.e.*, both of these tools of rehabilitation exert and augment similar gains in lower quadrant flexibility, jump height, and muscular strength (Quadricep femoris and Hamstring). Until additional high-quality studies become available that allow making specific recommendations regarding (FR: duration, types of foam roller, applied pressure, intensity and DS: stretch frequency, stretch duration, stretch velocity and types of DS used) we can recommend athletes to include either DS or FR in their warm-up protocol. The dosimetry synthesized from a moderate quality article suggests including 2 sets of FR and 2 sets of DS, with each set performed for duration of 60 seconds on the lower quadrant muscle group.

FUNDINGS

None.

DATA AVAILABILITY

All the data are available in the manuscript and derived from cited published studies.

CONTRIBUTIONS

All authors: design, data analsysis. NH, SS, SS, RKS: databases searching. NH, DK, SM, SS, SS: terms searching, critical review.

ACKNOWLEDGMENTS

The authors are thankful to the Vice-Chancellor of the university for providing the necessary facilities for research.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Woods K, Bishop P, Jones E. Warm-up and stretching in the prevention of muscular injury. Sports Med. 2007;37(12):1089-99. doi: 10.2165/00007256-200737120-00006.
2. Stienen GJ, Kiers JL, Bottinelli R, Reggiani C. Myofibrillar ATPase activity in skinned human skeletal muscle fibres: fibre type and temperature. J Physiol. 1996;493(2):299-307. doi: 10.1113/jphysiol.1996.sp021384.
3. Needham RA, Morse CI, Degens H. The acute effect of different warm-up protocols on anaerobic performance in elite youth soccer players. J Strength Cond Res. 2009;23(9):2614-20. doi: 10.1519/JSC.0b013e3181b1f3ef.
4. Fletcher IM, Jones B. The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. J Strength Cond Res. 2004;18(4):885-8. doi: 10.1519/14493.1.
5. Sale DG. Postactivation potentiation: Role in human performance. Exerc Sport Sci Rev. 2002;30(3):138-43. doi: 10.1097/00003677-200207000-00008.
6. Pagaduan JC, Pojskić H, Užičanin E, Babajić F. Effect of various warm-up protocols on jump performance in college football players 2012. J Hum Kinet. 2012;35(1):127-32. doi: 10.2478/v10078-012-0086-5.
7. Tsolakis C, Bogdanis GC. Acute effects of two different warm-up protocols on flexibility and lower limb explosive performance in male and female high level athletes. J Sports Sci Med. 2012;11(4):669-75. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/pmid/24150077/.

8. Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: A prospective study. Am J Sports Med. 2003;31(1):41-6. doi: 10.1177/03635465030310011801.
9. Gleim GW, McHugh MP. Flexibility and its effects on sports injury and performance. Sports Med. 1997;24(5):289-99. doi: 10.2165/00007256-199724050-00001.
10. Shadmehr A, Hadian MR, Naiemi SS, Jalaie S. Hamstring flexibility in young women following passive stretch and muscle energy technique. J Back Musculoskelet Rehabil. 2009;22(3):143-48. doi: 10.3233/BMR-2009-0227.
11. Dantas MH, Daoud R, Trott A, Nodar-Junior RJ, de- Souza CM. Flexibility: components, proprioceptive mechanisms and methods. Biomed Hum Kinet. 2011;3(3):39-43. doi: 10.2478/v10101-011-0009-2.
12. Çımenlı O, Koç H, Çımenlı F, Kaçoğlu C. Effect of an eight-week plyometric training on different surfaces on the jump-ing performance of male volleyball players. J Phys Educ Sport. 2016;16(1):162-69. doi: 10.7752/jpes.2016.01026.
13. Meylan C, McMaster T, Cronin J, Mohammad NI, Rogers C, Deklerk M. Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. J Strength Cond Res. 2009;23(4):1140-47. doi: 10.1519/JSC.0b013e318190f9c2.
14. Bui HT, Farinas MI, Fortin AM, Comtois AS, Leone M. Comparison and analysis of three different methods to evaluate vertical jump height. Clin Physiol Funct Imaging. 2015;35(3):203-9. doi: 10.1111/cpf.12148.
15. Fischetti F, Cataldi S, Greco G. Lower-limb plyometric training improves vertical jump and agility abilities in adult female soccer players. J Phys Educ Sport. 2019;19(2):1254-61. doi: 10.7752/jpes.2019.02182.
16. Stone MH. Position statement: explosive exercises and training. Natl Strength Cond Assoc J. 1993;15(3):7-15. Available at: https://journals.lww.com/nsca-scj/Abstract/1993/05000/POSITION_STATEMENT__Explosive_Exercise_and.2.aspx.
17. Stiff M. Biomechanical foundation of strength and power training. Biomech Sports. 2008;103-39. doi: 10.1002/9780470693797.ch6.
18. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med. 2016;46(10):1419-49. doi: 10.1007/s40279-016-0486-0.
19. Curry BS, Chengkalath D, Crouch GJ, Romance M, Manns PJ. Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. J Strength Cond Res. 2009;23(6):1811-19. doi: 10.1519/JSC.0b013e3181b73c2b.
20. Behm DG, Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. Eur J Appl Physiol. 2011;111(11):2633-51. doi: 10.1007/s00421-011-1879-2.
21. Schleip R. Fascial plasticity - A new neurobiological explanation: Part 1. J Bodyw Mov Ther. 2003;7(1):11-9. doi: 10.1016/S1360-8592(02)00067-0.
22. Douglas PM, Margaret JT. Guidelines to the Implementation of a Dynamic Stretching Program. Strength Cond J. 1999;21(6):53-5. Available at: https://journals.lww.com/nsca-scj/Citation/1999/12000/Guidelines_to_the_Implementation_of_a_Dynamic.14.aspx.
23. McNair PJ, Stanley SN. Effect of passive stretching and jogging on the series elastic muscle stiffness and range of motion of the ankle joint. Br J Sports Med. 1996;30(4):313-18. doi: 10.1136/bjsm.30.4.313.
24. McGowan CJ, Pyne DB, Thompson KG, Rattray B. Warm-up strategies for sport and exercise: Mechanisms and applications. Sports Med. 2015;45(11):1523-46. doi: 10.1007/s40279-015-0376-x.
25. Little T, Williams AG. Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. J Strength Cond Res. 2006;20(1):203-07. doi: 10.1519/R-16944.1.
26. Yamaguchi T, Ishii K. Effects of static stretching for 30 seconds and dynamic stretching on leg extension. J Strength Cond Res. 2005;19(3):677-83. doi: 10.1519/15044.1.
27. Smith JC, Pridgeon B, Hall CM. Acute Effect Of Foam Rolling and Dynamic Stretching on Flexibility and Jump height. J Strength Cond Res. 2018;32(8):2209-15. doi: 10.1519/JSC.0000000000002321.
28. Behara B, Jacobson BH. Acute Effects of Deep Tissue Foam Rolling and Dynamic Stretching on Muscular Strength, Power, and Flexibility in Division I Linemen. J Strength Cond Res. 2017;31(4):888-92. doi: 10.1519/JSC.0000000000001051.
29. MacDonald GZ, Penney MDH, Mullaley ME, et al. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. J Strength Cond Res. 2013;27(3):812-21. doi: 10.1519/JSC.0b013e31825c2bc1.
30. Pişirici P, Ekiz MB, C I. Investigation of the acute effect of myofascial release techniques and dynamic stretch on vertical jump performance in recreationally active individuals. J Phys Educ Sport. 2020;20(3):1569-79. doi: 10.7752/jpes.2020.03215.
31. Barnes MF. The basic science of myofascial release. Morphologic change in connective tissue. J Bodyw Mov Ther. 1997;1(4):231-38. doi: 10.1016/S1360-8592(97)80051-4.
32. Macdonald GZ, Button DC, Drinkwater EJ, Behm DG. Foam rolling as a recovery tool after an intense bout of physical activity. Med Sci Sports Exerc. 2014;46(1):131-42. doi: 10.1249/MSS.0b013e3182a123db.
33. Kalichman L, David CB. Effect of self-myofascial release on myofascial pain, muscle flexibility, and strength: A narrative review. J Bodyw Mov Ther. 2017;21(2):446-51. doi: 10.1016/j.jbmt.2016.11.006.
34. Cheatham SW, Kolber MJ, Cain M, Lee M. The effects of self-myofascial release using a foam roller or roller massager on joint range of motion, muscle recovery, and performance: A Systematic Review. Int J Sports Phys Ther. 2015;10(6):827-38. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/pmid/26618062/.
35. Wilke J, Muller AL, Giesche F, Power G, Ahmedi H, Behm DG. Acute Effects of Foam Rolling on Range of Motion in Healthy Adults: A Systematic Review with Multilevel Meta-analysis. Sports Med. 2020;50(2):387-402. doi: 10.1007/s40279-019-01205-7.
36. Opplert J, Babault N. Acute Effects of Dynamic Stretching on Muscle Flexibility and Performance: An Analysis of the Current Literature. Sports Med. 2018;48(2):299-325. doi: 10.1007/s40279-017-0797-9.
37. Verhagen AP, de Vet HC, de Bie RA, et al. The Delphi list: A criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. J Clin Epidemiol. 1998;51(22):1235-41. doi: 10.1016/S0895-4356(98)00131-0.
38. Valenzuela PL, Morales JS, Castillo-García A, et al. Effects of exercise interventions on the functional status of acutely hospitalised older adults: A systematic review and meta-analysis. Ageing Res Rev. 2020;61:101076. doi: 10.1016/j.arr.2020.101076.

39. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther. 2003;83(8):713-21. doi: 10.1093/ptj/83.8.713.
40. Jackson AW, Baker AA. The relationship of the sit and reach test to criterion measures of hamstring and back flexibility in young females. Res Q Exerc Sport. 1986;57(3):183-86. doi: 10.1080/02701367.1986.10605395.
41. Su H, Chang NJ, Wu WL, Guo LY, Chu IH. Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. J Sport Rehabil. 2017;26(6):469-77. doi: 10.1123/jsr.2016-0102.
42. Tucker J. The Psoas and Iliacus: Functional Testing. Dynamic Chiropractic. 2007. Available at: http://www.dynamicchiropractic.com/mpacms/dc/article.php?id=52363. Last access date: 05/06/2022.
43. Cejudo A, de Baranda PS, Ayala F, Santonja F. Test-retest reliability of seven common clinical tests for assessing lower extremity muscle flexibility in futsal and handball players. Phys Ther Sport. 2015;16(2):107-13. doi: 10.1016/j.ptsp.2014.05.004.
44. Bennell KL, Talbot RC, Wajswelner H, Techovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. Aust J Physiother. 1998;44(3):175-80. doi: 10.1016/s0004-9514(14)60377-9.
45. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol. 1983;50(2):273-82. doi: 10.1007/BF00422166.
46. Lopez-Samanes A, Moreno-Perez D, Mate-Munoz JL, et al. Circadian rhythm effect on physical tennis performance in trained male players. J Sports Sci. 2017;35(21):2121-28. doi: 10.1080/02640414.2016.1258481.
47. Heyward VH. Advanced Fitness Assessment and Exercise Prescription. Champaign, IL. Hum Kinet Publishers, Inc., 2010.
48. Pincivero DM, Lephart SM, Karunakara RA. Reliability and precision of isokinetic strength and muscular endurance for the quadriceps and hamstrings. Int J Sports Med. 1997;18(2):113-7. doi: 10.1055/s-2007-972605.
49. Lopez-Samanes A, Coso JD, Hernández-Davó JL, et al. Acute effects of dynamic versus foam rolling warm-up strategies on physical performance in elite tennis players. Biol Sport. 2021;38(4):595-601. doi: 10.5114/biolsport.2021.101604.
50. Somers K, Aune D, Horten A, Kim J, Rogers J. Acute Effects of Gastrocnemius/Soleus Self-Myofascial Release Versus Dynamic Stretching on Closed-Chain Dorsiflexion. J Sport Rehabil. 2020;29(3):287-93. doi: 10.1123/jsr.2018-0199.
51. Siebert T, Donath L, Borsdorf M, Stutzig N. Effect of Static Stretching, Dynamic Stretching, and Myofascial Foam Rolling on Range of Motion During Hip Flexion: A Randomized Crossover Trial. J Strength Cond Res. 2022;36(3):680-685. doi: 10.1519/JSC.0000000000003517.
52. Kopec TJ, Bishop PA, Esco MR. Influence of Dynamic Stretching and Foam Rolling on Vertical Jump. Athl Train Sports Health Care. 2017;9(1):33-38. doi: 10.3928/19425864-20161003-01.
53. Moreno-Perez V, Soler A, Ansa A, et al. Acute and chronic effects of competition on ankle dorsiflexion ROM in professional football players. Eur J Sports Sci. 2020;20(1):51-60. doi: 10.1080/17461391.2019.1611930.
54. Higgins JPT, Thomas J, Chandler J, et al. Cochrane Handbook for Systematic Reviews of Interventions. Wiley, 2019. doi: 10.1002/9781119536604.
55. Faraone SV. Interpreting estimates of treatment effects: implications for managed care. P T 2008;33(12):700-11. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/pmid/19750051/.
56. Turki O, Chaouachi A, Behm DG, et al. The effect of warm-ups incorporating different volumes of dynamic stretching on 10- and 20-m sprint performance in highly trained male athletes. J Strength Cond Res. 2012;26(1):63-72. doi: 10.1519/JSC.0b013e31821ef846.
57. Calanni L, Combi F, Rampi L, Negro M, Spairani L, D'Antona G. Study of the Activation and Oxygenation of Multifidus and Gluteus Medius Muscles During Stretching of the Lower Limb Posterior Chain: Comparison Between Two Different Executions Techniques. Muscles Ligaments Tendons J. 2020;10(3):424-9. doi: 10.32098/mltj.03.2020.10.
58. Bishop D. Warm up II: Performance changes following active warm up and how to structure the warm up. Sports Med. 2003;33(7):483-98. doi: 10.2165/00007256-200333070-00002.
59. Amiri-Khorasani M, Kellis E. Acute effects of different agonist and antagonist stretching arrangements on static and dynamic range of motion. Asian J Sports Med. 2015;6(4):e26844. doi: 10.5812/asjsm.26844.
60. Melo RR, Cerqueira MS, Barbosa GM, et al. Static Stretching at Pain-Tolerated Intensity Is Not Necessary to Increase Knee Range of Motion in Amateur Soccer Players: a Randomized Trial. Muscles Ligaments Tendons J. 2021;11(3):536-46. doi: 10.32098/mltj.03.2021.19.
61. Schleip R. Fascial plasticity new neurobiological explanation Part 2. J Bodyw Mov Ther. 2003;7(2):104-16. doi: 10.1016/S1360-8592(02)00076-1.
62. Cheatham SW, Stull KR. Roller massage: A Commentary on clinical standards and survey of physical therapy professionals- Part 1. Int J Sports Phys. 2018;13(4):763-72. doi: 10.26603/ijspt20180763.
63. Franco BL, Signorelli GR, Trajano GS, Costa PB, de Oliveira CG. Acute effects of three different stretching protocols on the Wingate test performance. J Sports Sci Med. 2012;11(1):1-7. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/pmid/24149116/.
64. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, Riebe D. The effects of myofascial release with foam rolling on performance. J Strength Cond Res. 2014;28(1):61-8. doi: 10.1519/JSC.0b013e3182956569.
65. Abbate F, Sargeant AJ, Verdijk PW, Haan AD. Effects of high-frequency initial pulses and posttetanic potentiation on power output of skeletal muscle. J Appl Physiol. 2000;88(1):35-40. doi: 10.1152/jappl.2000.88.1.35
66. 66. Konrad A, Tilp M, Nakamura M. A Comparison of the effects of foam rolling and stretching on physical performance: A Systematic Review and Meta-Analysis. Front Physiol. 2021;12:720531. doi: 10.3389/fphys.2021.720531.
67. 67. Giovanelli N, Vaccari F, Floreani M, et al. Short-term effects of rolling massage on energy cost of running and power of the lower limbs. Int J Sports Physiol Perform. 2018;13(10):1337-43. doi: 10.1123/ijspp.2018-0142.
68. 68. Monasterio E, Brymer E, Stewart I. Conceptualising performance enhancement in extreme sports: Combining physiological and psychological perspectives. Muscles Ligaments Tendons J. 2020;10(2):309-14. doi: 10.32098/mltj.02.2020.16.