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INVITED REVIEW

A comparison of a single bout of stretching or foam rolling on range of motion in healthy adults

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Abstract

Purpose Stretching and foam rolling are common warm-up exercises and can acutely increase the range of motion (ROM) of a joint. However, possible differences in the magnitude of change on ROM between these two interventions on the immediate and prolonged effects (e.g., 10 min after the intervention) are not yet well understood. Thus, the purpose of this review was to compare the immediate and prolonged effects of a single bout of foam rolling with a single bout of stretching on ROM in healthy participants.

Methods In total, 20 studies with overall 38 effect sizes were found to be eligible for a meta-analysis. For the main analysis, subgroup analysis, we applied a random-effect meta-analysis, mixed-effect model, respectively. The subgroup analyses included age groups, sex, and activity levels of the participants, as well as the tested muscles, the duration of the application, and the study design.

Results Meta-analyses revealed no significant differences between a single stretching and foam rolling exercise immediately after the interventions (ES = 0.079; P = 0.39) nor a difference 10 min (ES = −0.051; P = 0.65), 15 min (ES = −0.011; P = 0.93), and 20 min (ES = −0.161; P = 0.275) post-intervention. Moreover, subgroup analyses revealed no other significant differences between the acute effects of stretching and foam rolling ($P > 0.05$).

Conclusion If the goal is to increase the ROM acutely, both interventions can be considered as equally effective. Likely, similar mechanisms are responsible for the acute and prolonged ROM increases such as increased stretch tolerance or increased soft-tissue compliance.

Keywords Self-myofascial release · Foam roller · Flexibility · Extensibility · Healthy adults

Abbreviations

ES	Effect size
PNF	Proprioceptive neuromuscular facilitation
ROM	Range of motion

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Introduction

Stretching with its varying techniques (i.e., static, ballistic, dynamic, and proprioceptive neuromuscular facilitation) (Magnusson et al. 1998) and foam rolling with or without vibration can acutely increase joint range of motion (ROM) (stretching: Behm and Chaouachi 2011; Behm et al. 2016, 2021b; Konrad et al. 2017b, 2019; Behm 2018; Konrad and Tilp 2020b, a) (foam rolling: Behm 2018; Behm and Wilke 2019; Wilke et al. 2020; Behm et al. 2020; Nakamura et al. 2021b, a; Yahata et al. 2021). Studies, which compared the acute effects of stretching and foam rolling on ROM, have either reported no difference between stretching and foam rolling (Halperin et al. 2014), a favorable effect of foam rolling on ROM compared to stretching (Su et al. 2017), or a favorable effect of stretching on ROM compared to foam rolling (Fairall et al. 2017). According to a meta-analysis (Wilke et al. 2020), the magnitude of the changes following stretching and foam rolling on ROM are similar [the difference between stretching and foam rolling: effect size (ES) = 0.02; 95% CI: −0.67 to 0.73]. However, the main goal of Wilke et al. (2020) was to investigate the acute effects of foam rolling on ROM rather than comparing the acute effects of stretching and foam rolling on ROM. Hence, in the search code, the term "stretching" was not included and these authors might have overlooked some studies which investigated the acute effects of both stretching and foam rolling. Moreover, the search in the review of Wilke et al. (2020) was performed in February and March 2019 and only included nine comparative studies (foam rolling vs. stretching); hence, there is a need to update this meta-analysis with the recent and more expansive body of literature.

Apart from the immediate (i.e., acute) effects of foam rolling and stretching on ROM, the time course (i.e., prolonged effects) of the changes in ROM following these modalities is highly relevant for sports practice (i.e., time between stretching or foam rolling and the start of the competition or training). Whilst studies reported an increased ROM following stretching (Power et al. 2004; Konrad and Tilp 2020a) or foam rolling (Monteiro et al. 2018) for e.g., ≥30 min post-intervention, other studies showed no such changes up to that time point for both modalities (stretching: Kay et al. 2015; foam rolling: Nakamura et al. 2021b). Likely, the duration or intensity of the intervention may cause such contradicting findings. However, to get a better comparison on the time course effects on ROM between these two modalities (i.e., foam rolling vs. stretching), there is a need to perform a meta-analysis to clarify which intervention might cause a more prolonged effect for enhanced ROM.

Thus, the purpose of this review was to compare the immediate effects of a single bout of stretching versus a single bout of foam rolling on ROM in healthy participants. In addition, further goals were to compare the time course (i.e., 10, 15, and 20 min post-intervention) between single sessions of foam rolling and stretching on ROM and to summarize the mechanisms underlying ROM increases in both foam rolling and stretching based on the existing literature. According to the existing evidence, it was hypothesized that foam rolling compared to static stretching applied over the same duration would produce comparable immediate and time course effects in the increase in ROM.

Prolonged static stretching (>60 s per muscle group) in isolation (no aerobic or dynamic activities within the warm-up) has been reported to induce performance impairments (Behm and Chaouachi 2011; Kay and Blazevich 2012; Behm et al. 2016, 2021b). A recent meta-analysis (Konrad et al. 2021) reported a favorable effect on performance parameters for foam rolling when compared to static stretching but no such effect when foam rolling was compared to dynamic stretching. Additionally, when the rolling intervention was applied for more than 60 s, performance measures following foam rolling were more advantageous compared to stretching (Konrad et al. 2021). Hence, unlike static stretching, there was no duration threshold reported for foam rolling (Nakamura et al. 2021b). Thus, a validation of an alternative method for augmenting ROM without significant performance decrements such as foam rolling (Behm 2018; Behm and Wilke 2019; Wilke et al. 2020; Behm et al. 2020) could be beneficial to athletic or work performance.

Materials and methods

This systematic review with meta-analysis was conducted according to the suggestions from Moher et al. (2009) and meets the PRISMA guidelines.

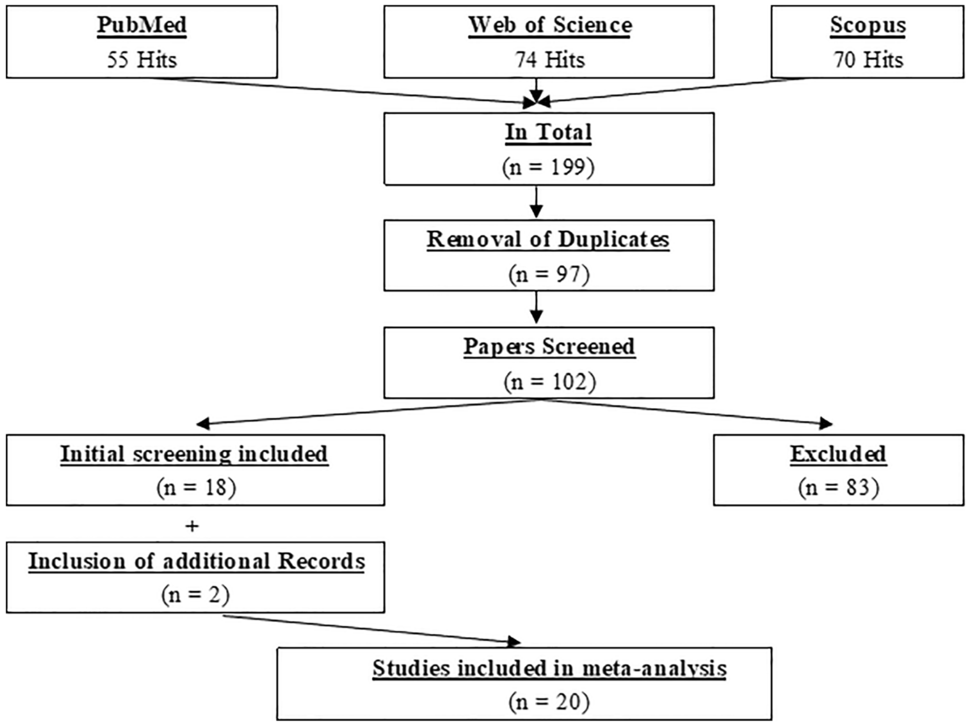
Search strategy

The electronic literature search was performed in three databases (i.e., PubMed, Scopus, and Web of Science) and the search period was until the 5th of November 2021. The keywords for the online search were the same for the various databases and were ("foam rolling" OR "self-myofascial release" OR "roller massage" OR "foam roller") AND (stretch*). The systematic and independent search was conducted by three researchers (AK, FP, and MN). All the hits were screened by their title and abstract. If the eligibility of a paper remained unclear, the full text was further screened. Following this independent search, the findings of the researchers were compared. Disagreements were resolved by jointly reassessing the studies against the eligibility criteria. Following the removal of 97 duplicates in total, 102 papers were screened, where finally 18 papers found to be eligible for the meta-analysis. Additionally, two further papers from researchers' libraries (AK, DB) were found to be eligible. No further eligible papers were found following an additional search of the references (search through the reference list) and citations (search through Google Scholar) of the already included papers. Consequently, in total, 20 papers (more than 2 × Wilke et al. (2020) meta-analysis) were included in the meta-analysis (see Fig. 1).

Inclusion and exclusion criteria

This review included studies which compared the acute and/or the immediate effects of a single stretching exercise and single foam rolling exercise on ROM in healthy participants. We included studies written in all languages and either a crossover design (i.e., pre- to post-comparison or post-comparison) or parallel group design (pre- to post-comparison). However, we

Fig. 1 PRISMA flowchart



excluded studies with a parallel group design where only post-intervention values were compared. Moreover, we excluded studies which investigated combined effects of foam rolling and stretching. We further excluded conference papers or theses.

Extraction of the data

From all the included papers, the characteristics of the participants (i.e., sex, activity level, and age), the sample size number, the study design (i.e., crossover, parallel design), the characteristics of the intervention (duration, stretching technique, vibration foam rolling vs. non-vibration foam rolling), the muscles tested by the ROM test, and the pre- and post-intervention values plus standard deviation of the main variable ROM of both groups (foam rolling, stretching) were extracted. If the full paper did not provide all the data required for the meta-analysis, the corresponding authors were contacted via email and Research Gate.

Statistics and data synthesis

The meta-analysis was conducted using the Comprehensive Meta-Analysis (CMA) software according to the suggestions of Borenstein et al. (2009). Consequently, a random-effect meta-analysis was used to assess the effect size (standardized mean difference) for the immediate and the time course effects. If any study reported more than one effect size, as suggested by Borenstein et al., (2009) the mean of all the outcomes (effect sizes) within one study was used for the analysis and defined with the term "combined" (see, i.e., Fig. 2). Although there is no general rule of thumb (Borenstein et al. 2009), we only performed a meta-analysis when ≥3 studies could be included in the respective analysis. Hence, the time course effects of 10, 15, and 20 min post-stretching could be assessed. Moreover, using a mixed-effect model, we conducted various subgroup analyses with age of the participants (i.e., ≤23.4 vs > 23.4 years; 23.4 = average age of all participants in this meta-analysis), activity level of the participants (sedentary/physical active vs. well trained/professional), tested muscle by the ROM test (hamstrings, quadriceps, triceps surae, shoulder), duration of the application (i.e., ≤60 s; > 60 s,), sex (i.e., mixed/female vs male), stretching technique (static stretching, dynamic stretching), and the study design (parallel design, crossover). Since only one out of the 20 studies included female subjects, we formed the subgroups mixed/female and male. Subgroup analysis on the time course effects was not possible, because only less than three studies (i.e., per subgroup) were available. Q-statistics were applied (Borenstein et al. 2009) to determine if there were differences between the effect sizes of the subgroups. Hopkins et al. (2009) suggested to define the standardized mean difference of < 0.2, 0.2–0.6, 0.6–1.2, 1.2–2.0, 2.0–4.0, and > 4.0 as trivial, small, moderate, large, very large, and extremely large, respectively. To assess the heterogeneity I^2 statistics were calculated among the effect sizes, and thresholds of 25%, 50%, and 75% were defined as having a low, moderate, and high level of heterogeneity, respectively (Higgins et al. 2003; Behm et al. 2021a). An alpha level of 0.05 was defined for the statistical significance of all the tests.

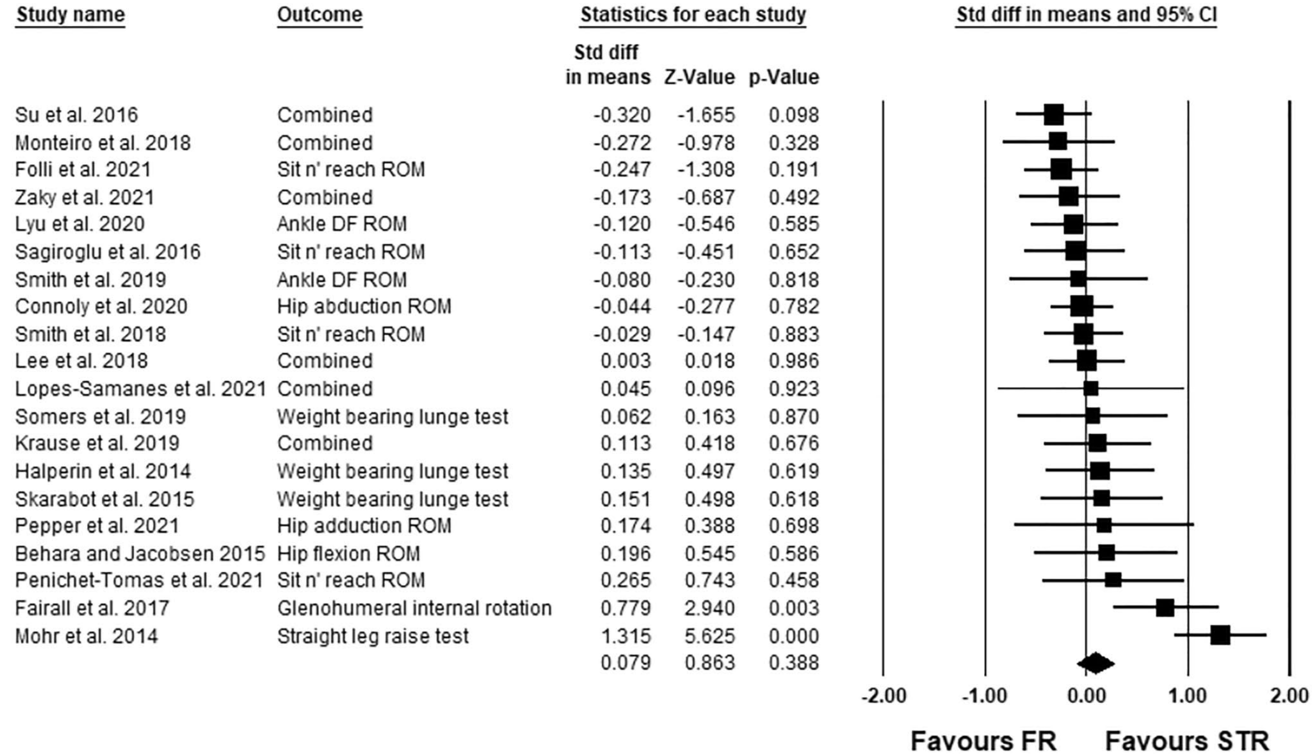


Fig. 2 Forest plot presenting the 20 included studies with overall 38 effect sizes. Std diff in means = standardized difference in means; CI = confidence interval; FR = foam rolling; STR = stretching; combined = mean of the selected outcomes of one study

Risk-of-bias assessment and methodological quality

To assess the methodological quality of the included studies, the PEDro scale was used. Two independent researchers (AK, MN) assessed 11 methodological issues by assigning with either one or no point. Note that studies with a higher score represent a higher methodological quality. If any conflict between the ratings of the two researchers was found, the methodological issues were reassessed and discussed. Moreover, to assess a possible publication bias, the statistics of the Egger's regression intercept test was used.

Results

Results of the search

In total, 20 studies investigated the immediate effects of both a single foam rolling exercise and a single stretching exercise on ROM, and overall, 38 effect sizes were included for this meta-analysis. Additionally, out of these 20 studies, the time course effects of 10, 15, and 20 min post-intervention were investigated by five, four, and three studies, respectively. In summary, 411 participants with a mean age of 23.4 (±4.9 years) participated in the included studies. Moreover, Table 1 presents the characteristics and outcome variables of these studies.

Risk-of-bias assessment and methodological quality

Egger's regression intercept test for the immediate effects (intercept 1.16; $P = 0.38$) but also for the time course effects 10 min post-intervention (intercept − 0.04; $P = 0.97$), 15 min post-intervention (intercept 0.72; $P = 0.14$), and 20 min post-intervention (intercept − 1.82; $P = 0.65$) indicate that no reporting bias is likely.

Moreover, a low risk of bias was indicated with an average PEDro score of 6.6 (±1.1; range 4–9). Both assessors agreed with 95.9% of the overall 220 (20 studies × 11 criteria) criteria. However, the mismatches were discussed and the assessors finally agreed with the scores presented in Table 2.

Main analysis for the immediate effects

The average percentage increase in ROM in the included studies following stretching, foam rolling was 7.2 ± 8.7%, 7.2 ± 5.5%, respectively. The meta-analysis revealed

Table 1 Participants' characteristics, details of the interventions, and the outcomes of the included studies ($n=20$)

Study	Participants	Type of stretching	Type of foam rolling	Intervention duration per muscle group	Outcome
Smith et al. (2018)	$N=29$ sedentary to physically active males and females (age $=22\pm3$)	Dynamic	Non-vibration	90 s for foam rolling/dynamic stretching, duration per muscle group not clear	Sit and Reach
Behara and Jacobson (2017)	$N=12$ well trained male Division 1 offensive lineman (age 20.0 ± 1.41)	Dynamic	Non-vibration	60 s for foam rolling/dynamic stretching, duration per muscle group not clear	Hip flexion ROM
Su et al. (2017)	$N=30$ physically active males and females (21.43 ± 1.5)	Static dynamic	Non-vibration	90 s foam rolling and static stretching; 180 s dynamic stretching	Sit-and-reach modified Thomas Test
Fairall et al. (2017)	$N=12$ male amateur softball players (age 36.92 ± 11.17)	Static	Non-vibration	120 s stretching; 180 s foam rolling	Glenohumeral internal rotation ROM
Škarabot et al. (2015)	$N=11$ highly trained male and female swimmers (age 15.3 ± 1)	Static	Non-vibration	90 s	Weight-bearing lunge test
Lee et al. (2018)	$N=30$ male college students (age 20.4 ± 1.2)	Static	Vibration non-vibration	90 s	Leg extension ROM leg flexion ROM
Lyu et al. (2020)	$N=20$ male recreational active (age 21 ± 1.01)	Static	Vibration	90 s	Ankle dorsiflexion ROM
Folli et al. (2021)	$N=29$ male and female healthy athletes (age 16 ± 1.23)	Static	Non-vibration	60 s	Sit-and-reach
Penichet-Tomas et al. (2021)	$N=8$ male well trained rowers (24.8 ± 3.8)	Static	Non-vibration	90 s	Sit-and-reach
Lopez-Samanes et al. (2021)	$N=11$ elite male tennis players (age 20.64 ± 3.56)	Dynamic	Non-vibration	60 s for foam rolling/dynamic stretching seconds per muscle group not clear	Straight leg raise test
Connolly et al. (2020)	$N=40$ males and females (activity level not stated) (males age 22.5 ± 1.8; Females age 23.6 ± 4.2)	Static	Non-vibration	60 s	Hip abduction ROM
Zaky et al. (2021)	$N=20$ elite female handball players (age 22.83 ± 1.52)	Dynamic	Non-vibration	60 s for foam rolling/dynamic stretching seconds per muscle group not clear	Shoulder flexion ROM shoulder extension ROM Shoulder internal rotation ROM Shoulder external rotation ROM
Krause et al. (2018)	$N=16$ males and females (activity level not stated) (males age 31.2 ± 4.8; Females age 33.5 ± 5.6)	Static	Non-vibration	120 s	Active knee flexion passive knee flexion
Sagiroglu et al. (2017)	$N=16$ male well trained combat athletes (age 23.9 ± 3.70)	Static	Non-vibration	60 s	Sit-and-reach
Halperin et al. (2014)	$N=14$ male and female recreational active (males age 23 ± 4; Females age 22 ± 3)	Static	Non-vibration	90 s	Weight-bearing lunge test
Monteiro et al. (2018)	$N=12$ male and female recreational active (age 27.88 ± 3.23)	Static PNF	non-vibration	60 s or 120 s	Shoulder flexion ROM Shoulder extension ROM

Table 1 (continued)

Study	Participants	Type of stretching	Type of foam rolling	Intervention duration per muscle group	Outcome
Somers et al. (2020)	N = 28 male and female physically active (Age foam rolling group 26.07 ± 4.83; Age stretching group 26.86 ± 4.75)	Dynamic	Non-vibration	120 s	Weight-bearing lunge test
Smith et al. (2019)	*N* = 33 males and females (activity level not stated) (males age 21.7 ± 1.7; females age 21.3 ± 2.0)	Static	Non-vibration	90 s	Ankle dorsiflexion ROM
Pepper et al. (2021)	N = 20 males and females (activity level not stated) (Age foam rolling group 27.1 ± 6.5; Age stretching group 26.7 ± 8.6)	PNF	Non-vibration	60 s	Hip adduction ROM
Mohr et al. (2014)	*N* = 20 recreational active (gender not stated) (Age foam rolling group 21.00 ± 2.21; Age stretching group 21.2 ± 2.44)	Static	Non-vibration	180 s	Straight leg raise test

PNF proprioceptive neuromuscular facilitation, *ROM* range of motion

no significant difference between the two modalities (ES = 0.079; Z = 0.863; CI (95%) − 0.101 to 0.259; $P = 0.39$; $I^2 = 60.18$). Moreover, Fig. 2 presents the forest plot of the meta-analysis, sorted from the lowest to the highest effect size.

Subgroup analysis for the immediate effects

A summary of all the subgroup analyses is shown in Table 3. None of the analysis showed any significant difference between the subgroups as the age of the participants (i.e., ≤23.4 vs > 23.4 years) ($Q = 0.35$; $P = 0.56$), activity level of the participants (sedentary/physical active vs. well trained/professional) ($Q = 0.39$; $P = 0.53$), tested muscle by the ROM test (hamstrings, quadriceps, triceps surae, shoulder) ($Q = 0.57$; $P = 0.90$), duration of the application (i.e., > 60 s, ≤ 60 s) ($Q = 1.99$; $P = 0.16$), sex (i.e., mixed/female vs. male) ($Q = 2.23$; $P = 0.14$), stretching technique (static stretching, dynamic stretching) ($Q = 2.05$; $P = 0.15$), and the study design (parallel design, crossover) ($Q = 1.16$; $P = 0.28$).

Main analysis for the time course effects

The average percentage increase in ROM 10 min post-intervention in the included studies following stretching, foam rolling was 6.7 ± 3.6%, 7.6 ± 4.8%, respectively. Moreover, the average percentage increase in ROM 15 min post-intervention following stretching, foam rolling was 11.6 ± 7.0%, 10.5 ± 5.6%, respectively. Finally, the ROM 20 min post-intervention was 4.5 ± 3.7%, 5.9 ± 3.6%, for stretching, foam rolling, respectively. The meta-analyses on the time course revealed no significant difference between the modalities at 10 min, 15 min, 20 min post-intervention with an effect size of − 0.051 (Z = − 0.448; CI (95%) − 0.274 to 0.172; $P = 0.65$; $I^2 = 0.00$), − 0.011 ($Z = -0.083$; CI (95%) − 0.266 to 0.244; $P = 0.93$; $I^2 = 0.00$), − 0.161 ($Z = -1.092$; CI (95%) − 0.451 to 0.128; $P = 0.275$; $I^2 = 0.00$), respectively.

Moreover, Fig. 3 presents the forest plots of the meta-analyses (i.e., 10 min, 15 min, and 20 min).

Discussion

The purpose of this review was to compare the immediate and time course effects of a single foam rolling and stretching exercise on ROM. The results revealed no significant difference between the two modalities immediately after the interventions (ES = 0.079; $P = 0.39$) nor 10 min (ES = − 0.051; $P = 0.65$), 15 min (ES = − 0.011; $P = 0.93$), and 20 min (ES = − 0.161; $P = 0.28$) post-intervention.

Table 2 PEDro scale of the included studies; * = was not counted for the final score; 1 = one point awarded; 0 = no point awarded

Study	Inclusion criteria	Random allocation	Concealed allocation	Similarity at baseline	Subject blinding	Therapist blinding	Assessor blinding	>85% follow-up	Intention to treat analysis	Between-group comparison	Point estimates and variability	Total
Smith et al. (2018)	1	1	0	1	1	0	0	1	1	1	1	7
Behara and Jacobson (2017)	1	1	0	1	1	0	0	1	1	1	1	7
Su et al. (2017)	1	1	0	1	1	0	0	1	1	1	1	7
Fairall et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	6
Škarabot et al. (2015)	1	1	1	1	0	0	0	1	1	1	1	7
Lee et al. (2018)	1	1	0	1	1	0	0	1	1	1	1	7
Lyu et al. (2020)	1	1	0	1	1	0	0	1	1	1	1	7
Folli et al. (2021)	1	1	0	1	1	0	0	1	1	1	1	7
Penichet-Tomas et al. (2021)	1	0	0	1	0	0	0	1	1	1	0	4
Lopez-Samanes et al. (2021)	1	1	0	1	1	0	0	1	1	1	1	7
Connolly et al. (2020)	1	1	0	1	1	0	0	1	1	1	1	7
Zaky et al. (2021)	0	0	0	1	0	0	0	1	1	1	0	4
Krause et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	6
Sagiroglu et al. (2017)	1	1	0	1	1	0	0	1	1	1	1	7
Halperin et al. (2014)	1	1	0	1	1	0	0	1	1	1	1	7
Monteiro et al. (2018)	1	1	0	1	0	0	1	1	1	1	0	6
Somers et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	9
Smith et al. (2019)	0	1	1	1	0	1	1	1	0	1	0	7
Pepper et al. (2021)	1	1	0	1	0	1	1	1	1	1	0	7
Mohr et al. (2014)	1	1	0	1	0	0	0	1	1	1	1	6

Table 3 Statistics of the subgroup analysis

Subgroup	Number of measures	Std diff in means (95% CI)	*P* value	*Q*-statistics
Age of the participants				
≤23.4 years	13	0.05 (− 0.176 to 0.283)	0.65	
>23.4 years	7	0.14 (− 0.142 to 0.424)	0.33	
Overall	20	0.09 (− 0.090 to 0.267)	0.33	($Q=0.22$; df (Q) = 1; $P=0.64$)
Activity level of the participants				
Sedentary/physical active	15	0.1 (− 0.125 to 0.325)	0.38	
Well trained/professional	5	− 0.01 (− 0.276 to 0.254)	0.94	
Overall	20	0.05 (− 0.118 to 0.225)	0.54	($Q=0.39$; df (Q) = 1; P = 0.53)
Muscle tested				
Hamstrings	9	0.11 (− 0.224 to 0.451)	0.51	
Quadriceps	4	− 0.54 (− 0.376 to 0.268)	0.74	
Triceps surae	5	0.013 (− 0.240 to 0.265)	0.92	
Shoulder	3	0.112 (− 0.542 to 0.766)	0.74	
Overall	21	0.026 (− 0.150 to 0.009)	0.76	($Q=0.57$; df (Q) = 3; $P=0.90$)
Duration of the intervention				
≤60 s	5	− 0.14 (− 0.328 to 0.059)	0.17	
>60 s	11	0.12 (− 0.175 to 0.409)	0.43	
Overall	16	− 0.06 (− 0.219 to 0.103)	0.48	($Q=1.99$; df (Q) = 1; $P=0.16$)
Sex				
Male	7	0.13 (− 0.122 to 0.376)	0.32	
Mixed/female	12	− 0.09 (− 0.225 to 0.047)	0.19	
Overall	19	− 0.04 (− 0.159 to 0.080)	0.51	($Q=2.23$; df (Q) = 1; $P=0.14$)
Stretching technique				
Static stretching	6	− 0.13 (− 0.341 to 0.077)	0.22	
Dynamic stretching	14	0.1 (− 0.138 to 0.336)	0.41	
Overall	19	− 0.03 (− 0.188 to 0.126)	0.7	($Q=2.05$; df (Q) = 1; $P=0.15$)
Study design				
Crossover	16	− 0.03 (− 0.148 to 0.097)	0.68	
Parallel	4	0.4 (− 0.370 to 1.178)	0.31	
Overall	20	0.015 (− 0.136 to 0.106)	0.81	($Q=1.16$; df (Q) = 1; $P=0.28$)

Negative values of Std diff (= standardized difference) in means indicate a favorable effect for foam rolling (and vice versa).

Moreover, subgroup analyses revealed no differences ($P>0.05$) between the age groups of the participants (i.e., ≤23.4 vs >23.4 years), activity levels of the participants (sedentary/physical active vs. well trained/professional), tested muscle by the ROM test (hamstrings, quadriceps, triceps surae, shoulder), duration of the application (i.e., >60 s, ≤60 s), sex (i.e., mixed/female vs. male), stretching technique (static stretching, dynamic stretching), and the study design (parallel design, crossover).

Similarly, to Wilke et al. (2020), we have not found a difference in the immediate (i.e., acute) effect on ROM between stretching and foam rolling. However, in the meta-analysis of Wilke et al. (2020), the main focus was on investigating the acute effects of foam rolling on ROM rather than comparing the acute effects of stretching and foam rolling on ROM. Hence, in the search code of Wilke et al. (2020), the term "stretching" was not included and the search was performed up to February 2019. Consequently, Wilke et al. (2020) found nine studies to be eligible to compare the acute effects of foam rolling and stretching, whilst we found a further 11, and hence, in total 20 studies to be eligible. Although the results were similar, we believe that including approximately twofold more studies in our meta-analysis strengthens the evidence that stretching and foam rolling can be considered equally to increase the ROM. Additionally, our meta-analysis was the first which compared the time course effects (i.e., 10 min, 20 min, 30 min post-intervention) of foam rolling and stretching on ROM. Similar to the immediate effects, no differences were found between the modalities.

Various studies have reported that stretching (Behm and Chaouachi 2011; Behm et al. 2016, 2021b; Konrad et al. 2017b, 2019; Behm 2018; Konrad and Tilp 2020b,a) and

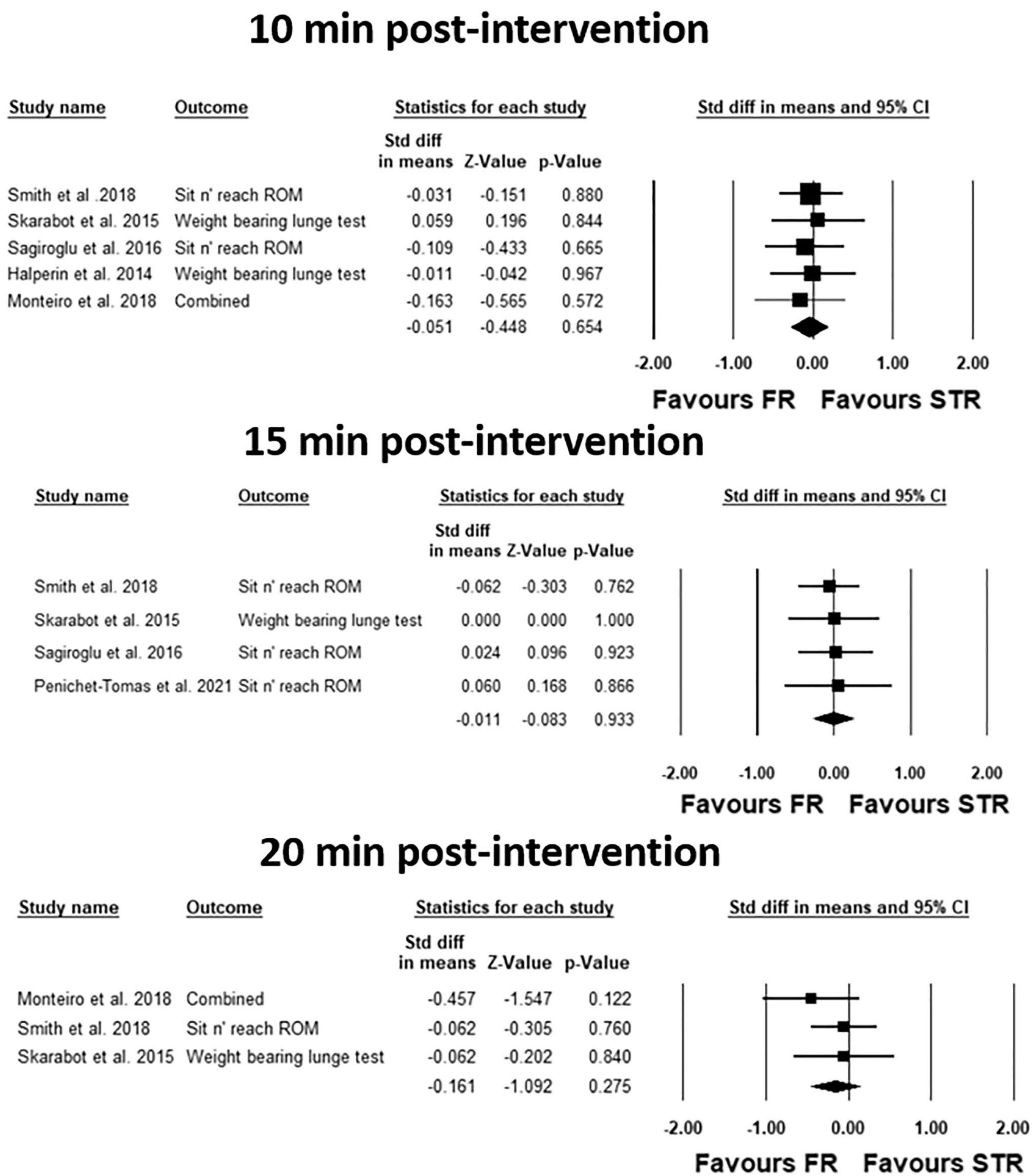


Fig. 3 Forest plots presenting the time course effects 10 min, 15 min, and 20 min post-intervention. Std diff in means = standardized difference in means; CI = confidence interval; FR = foam rolling; STR = stretching; combined = mean of the selected outcomes of one study

foam rolling (Behm 2018; Behm and Wilke 2019; Wilke et al. 2020; Behm et al. 2020; Nakamura et al. 2021b, a; Yahata et al. 2021) can increase the ROM of a joint acutely. However, the mechanism behind such an increase in ROM in both stretching and foam rolling is debated. Following a single bout of stretching, the acute increase in ROM is often associated with a decrease in soft-tissue stiffness (muscle: Kay et al. 2015; Konrad et al. 2019); tendon: (Kubo et al.

2001; Kato et al. 2010)) and/or changes in the tolerance to stretch (i.e., pain perception) (Magnusson et al. 1996; Konrad et al. 2017a). Similarly, in foam rolling, the acute increases in ROM may be attributed to decreased muscle stiffness (Behm 2018; Behm and Wilke 2019; Reiner et al. 2021b) or an increased stretch tolerance (Nakamura et al. 2021b). Additionally, thixotropic effects might be related to the increase in ROM following foam rolling (Behm and Wilke 2019) as well as with stretching (Behm 2018). The applied friction or tension on the treated muscle, skin, and fascia could have an impact on fluid viscosity and, hence, lead to less resistance to a movement (Behm 2018; Behm and Wilke 2019). Bringing these findings together, it is likely that similar mechanisms are responsible for the acute (immediate) increase in ROM following both foam rolling and stretching (see Fig. 4). Hence, this might also explain that there was no difference in the magnitude of change between the two interventions in our meta-analysis. Concerning the time course effects, it was reported that a decrease in muscle stiffness following an acute bout of stretching was returned to baseline after five minutes (Mizuno et al. 2013; Konrad et al. 2019; Konrad and Tilp 2020b), although the ROM was reported to be increased up to 120 min with a similar protocol (Power et al. 2004). Hence, there seems to be evidence that functional changes (e.g., increase in ROM) last longer compared to structural changes (e.g., decrease in tissue stiffness). Consequently, other mechanism than tissue stiffness such as thixotropic effects (Behm 2018) or changes in tolerance to stretch or pain (Magnusson et al. 1996) likely play a role for the continuing increase in ROM especially following stretching exercises and, hence, probably following foam rolling, as well.

There are always limitations to any investigation. Future studies need to explore the effects of a greater range of rolling durations as the present selection of studies primarily employed 60 s (8 studies) to 90 s (8 studies) of rolling with only two studies each intervening with 120 s or 180-s of rolling. It would be of interest to note whether shorter or longer durations provide similar increases in ROM. Furthermore, 5/20 studies tested ROM with the sit-and-reach test. The ROM measured in the sit-and-reach test can be attenuated by a restrictive lower back even if the rolling had favourable effects on the hamstrings extensibility. Hence, the rolling-induced effects on hamstrings extensibility with this type of hip flexion testing could have been underestimated. Only 3/20 studies monitored upper body ROM (i.e., shoulders) and thus the extent of possible rolling-induced ROM differences may be influenced by anatomical location

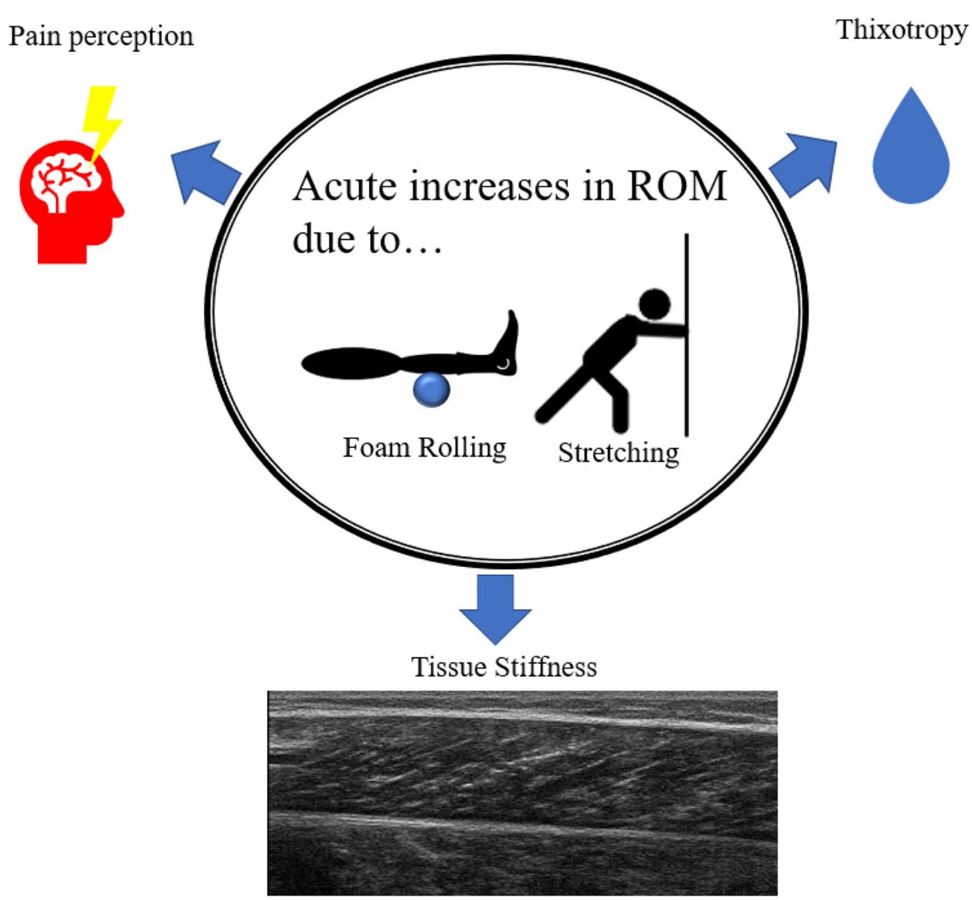


Fig. 4 Potential mechanism for acute increase in range of motion (ROM) following a single bout of stretching or foam rolling

and should be further considered. As is typical of exercise or sport science research, the predominant mean age of the participants was between 20 and 27 years with only two studies each examining participants with an average age between 31–37 and 15–16 years respectively. Additional studies are suggested to examine youth at different stages of peak height velocity (pubescence) as well middle-aged and elderly populations. Furthermore, the vast majority of foam rolling-related studies report on the effects of rolling on ROM and performance but very few evaluate mechanisms (e.g., Krause et al. 2018; Nakamura et al. 2021a; Reiner et al. 2021b; Pepper et al. 2021). As three of the four studies that reported on mechanisms were published within the last year, it is hoped that this is a sign of a trend for more research involving mechanistic measures.

Based on an integration of Konrad et al. (2021) (i.e., favorable effects on performance for foam rolling when compared to static stretching) and the present findings, we would rather recommend foam rolling than prolonged static stretching in isolation (i.e., no additional dynamic activities) as a warm-up when flexibility and performance should be optimized. However, it has to be noted that, when post-stretching dynamic activities are performed following static, dynamic stretching, or proprioceptive neuromuscular facilitation (PNF) for stretching durations up to 120 s, no negative or positive effect on performance was reported (Samson et al. 2012; Blazevich et al. 2018; Reid et al. 2018; Reiner et al. 2021a).

Conclusion

The present review revealed no difference between a single bout of stretching and foam rolling exercise immediately after the interventions but also 10, 15, and 20 min post-intervention. Neither of the subgroup analyses revealed a significant difference between the acute effects of stretching and foam rolling such as the age groups of the participants (i.e., ≤25 vs >25 years), activity levels of the participants (sedentary/physical active vs. well trained/professional), tested muscle by the ROM test (hamstrings, quadriceps, triceps surae, shoulder), duration of the application (i.e., >60 s, ≤60 s), sex (i.e., mixed/female vs. male), stretching technique (static stretching, dynamic stretching), and the study design (parallel design, crossover). Hence, if the goal is to increase the ROM acutely, both interventions can be considered equally effective. However, foam rolling rather than isolated static stretching without aerobic or dynamic activities within the warm-up should be implemented as a warm-up when ROM and performance (e.g., jumping) are equally important determinants for the subsequent training or competition. Likely, similar mechanisms are responsible for the acute and prolonged ROM increases such as increased stretch tolerance or soft-tissue compliance.

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Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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