©Journal of Sports Science and Medicine (2021) **20**, 535-545
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2021.535

Review article

The Accumulated Effects of Foam Rolling Combined with Stretching on Range of Motion and Physical Performance: A Systematic Review and Meta-Analysis

Andreas Konrad [1]✉, Masatoshi Nakamura [2], Daniel Bernsteiner [1] and Markus Tilp [1]
[1] Institute of Human Movement Science, Sport and Health, Graz University, Austria
[2] Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Japan

Abstract

Although it is well known that both stretching and foam rolling can acutely increase the range of motion (ROM) and affect performance, the effects of a combined treatment (foam rolling and stretching) are not yet clear. Hence, the purpose of this meta-analysis was to compare the combined effect to that of stretching or foam rolling alone on both ROM and performance. We assessed the effect of a combined treatment on ROM and compared it to the effect of stretching, foam rolling, and a control condition by applying a random-effect meta-analysis. We also applied the same model to compare the effect of the combined treatment on performance. Moreover, by applying a mixed-effect model, we performed subgroup analyses with the stretching technique, type of foam rolling, tested muscles, type of task, and the order of the combined treatment. We found a significant overall effect on ROM change when comparing the combined treatment with the control condition (effect size (ES) = -0.332); however, no significant effect was found when comparing it to stretching (ES = 0.032) or foam rolling alone (ES = -0.225). The meta-analysis revealed no significant overall effect on performance when the combined treatment was compared to stretching alone (ES = -0.029). However, the subgroup analysis for performance revealed a superior effect for the combined treatment compared to stretching alone, but only if foam rolling was followed by stretching (ES = -0.17), and not vice versa. Athletes do not have to combine stretching with foam rolling since no additional effect was observed. However, to increase performance, the combination of foam rolling followed by stretching can lead to greater improvements.

Key words: Roller massage, stretching, myofascial release, strength, jump, power

Introduction

Stretching and foam rolling are commonly used in sports practice as part of a warm-up routine. It is well known that both treatments can increase the range of motion (ROM) acutely (Konrad et al., 2019; Konrad and Tilp, 2020a; 2020b; Nakamura et al., 2021). According to a recent meta-analysis (Wilke et al., 2020), the magnitude of the effect on ROM following stretching and foam rolling is similar. Thus, when the goal is to increase ROM, both stretching and foam rolling can be considered as adequate warm-up routines. However, study findings about the acute effects of a single application of stretching or foam rolling on performance parameters are not as unambiguous. While a single static stretching exercise with a duration of ≥60 s likely causes a pronounced impairment in performance (-4.6%), shorter stretching durations (<60 s) show only minor changes (-1.1%) (Behm et al., 2016). However, if dynamic stretching is applied, Behm et al. (2016) reported mean increases in performance of 1.3%. Thus, performance changes following stretching depend on the stretch duration and stretching technique (Behm et al., 2016; Behm and Chaouachi, 2011; Behm et al., 2021a; Kay and Blazevich, 2012), and are also likely dependent on the muscles stretched (Konrad et al., 2021 . For foam rolling, there seems to be, at least, no detrimental effect on performance (Wiewelhove et al., 2019; Cheatham et al., 2015). Wiewelhove et al. (2019) even reported in their meta-analysis a tendency of improvement in sprint performance but no change in muscle strength. Thus, a single foam rolling exercise might be a practical approach for acutely increasing ROM while expecting an increased or at least stable athletic performance.

Less information is available on the combined effect of stretching and foam rolling. A recent review (Anderson et al., 2021) compared dynamic stretching to the combined effect of a foam rolling treatment and dynamic stretching of the hamstrings on ROM and performance parameters, and included four studies in their analysis. The authors concluded that the combined treatment had only a slight additional effect on ROM when compared to dynamic stretching alone. For performance, two out of the four included studies reported a greater increase in jump height with the combined treatment compared to dynamic stretching alone. Moreover, for agility, two studies (out of the three that assessed agility) reported that the combined effects improved agility to a greater extent than dynamic stretching alone (Anderson et al., 2021). There is therefore some evidence that the combination of foam rolling with dynamic stretching has an accumulative effect on the various parameters (e.g., jump height and agility) compared to dynamic stretching alone. However, these results do not include a quantification of the effects based on a meta-analysis or include muscle groups other than the hamstrings. Moreover, since static stretching and dynamic stretching can lead to different acute changes in ROM (Amiri-Khorasani et al., 2011) and performance (Behm and Chaouachi, 2011; Behm et al., 2021a), vibration foam rolling might have a more pronounced effect on ROM compared to foam rolling without vibration (Wilke et al., 2020), so these two modalities should also be considered.

Hence, the purpose of this meta-analysis was to compare the combined effect of a foam rolling (vibration and non-vibration foam rolling) and stretching exercise

Received: 18 June 2021 / Accepted: 21 June 2021 / Published (online): 01 July 2021

(including all techniques) to that of stretching or foam rolling alone on both ROM and physical performance. A further goal was to distinguish between the effects of the stretching technique (static stretching, dynamic stretching), the type of foam rolling (vibration foam rolling, non-vibration foam rolling), the tested muscles (hamstrings, quadriceps, triceps surae, hip, shoulder), and the order of the combined treatment (either foam rolling followed by stretching, or vice versa) by the use of a subgroup analysis.

Methods

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

Search strategy

An electronic literature search was performed in PubMed, Scopus, and Web of Science. The search period ranged from 1990 until the 15th February 2021. The keywords for the online search were (“foam rolling” OR “self-myofascial release” OR “roller massage” OR “foam roller”) AND (stretch*), and they were the same for all the databases. The systematic search was done by three independent researchers (AK, MN, DB). In the first step, all the hits were screened by their abstract. If the content of a study remained unclear, the full text was screened to identify the relevant papers. Following this independent screening process, the researchers compared their findings. Disagreements were resolved by jointly reassessing the studies against the eligibility criteria. Overall, 169 papers were screened, from which nine papers were found to be eligible for this review. However, following the additional search of the references (search through the reference list) and citations (search through Google Scholar) of the nine already included papers, three more papers were identified as being relevant. Therefore, in total, 12 papers were included in this systematic review and were used for the meta-analysis. The whole search process is depicted in Figure 1.

Inclusion and exclusion criteria

This review considered studies that compared the combined effects of an acute bout of both stretching and foam rolling on ROM and/or performance parameters (e.g., strength, jump height) to the effects of foam rolling or stretching alone in healthy participants. We included studies in the English, German, and Japanese languages with crossover (pre- to post-comparison or post-comparison) or parallel group (pre- to post-comparison) designs. However, we excluded conference papers and theses.

Extraction of the data

From the included papers, the characteristics of the participants, the sample size, the study design, the characteristics of the intervention (e.g., stretching technique, vibration foam rolling vs. non-vibration foam rolling, duration), and the results of the main variables (ROM and/or performance parameters) were extracted. For the main variables, either the pre- and post-values (plus standard deviations) or the post-values (plus standard deviations) of the combined groups (stretching plus foam rolling) and the single intervention groups (foam rolling or stretching, but also from the control group,) were extracted. If the required data were missing, the authors of the studies were contacted via email.

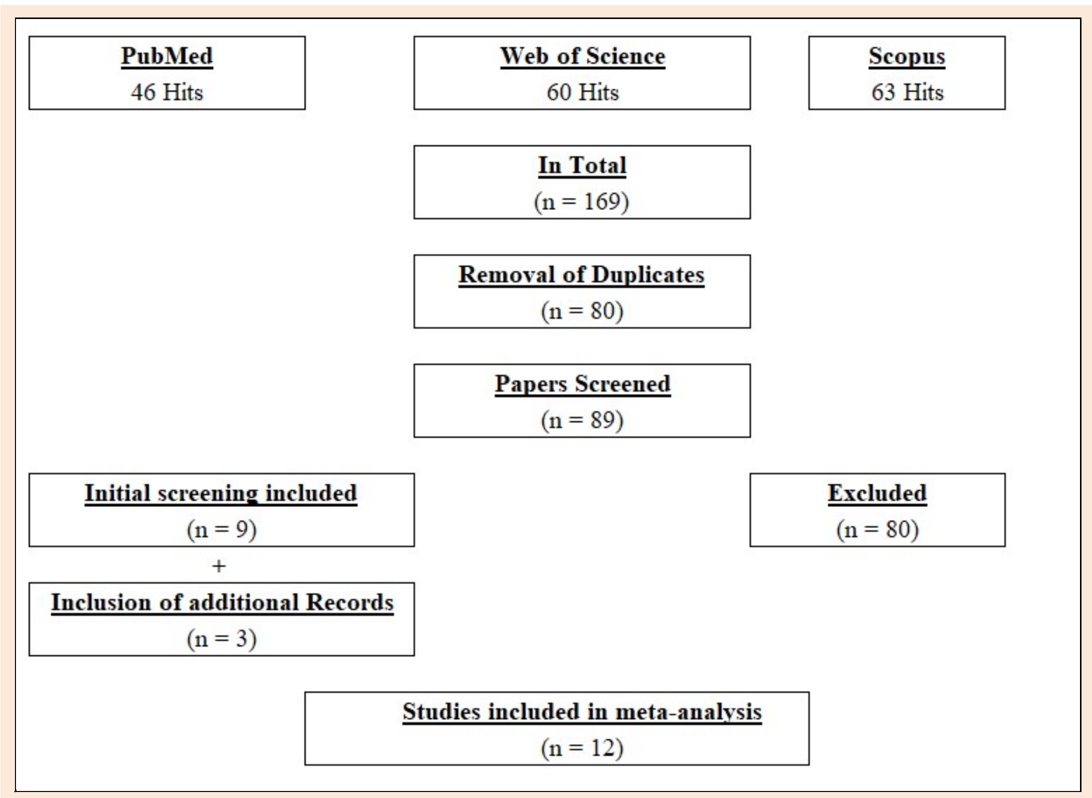

Figure 1. PRISMA flowchart.

Statistics and data synthesis

The meta-analysis was performed using Comprehensive Meta-Analysis software, according to the recommendations of Borenstein et al. (2009). By the use of a random-effect meta-analysis, we assessed the effect size of the ROM in terms of the standardized mean difference between the combined effects (foam rolling and stretching together) and stretching alone, between the combined effects and foam rolling alone, and between the combined effects and a control condition. Due to the smaller number of available studies for the performance parameters and the restriction that a minimum of three studies was necessary to perform a meta-analysis, we could only assess the effect size of the combined effects, compared to stretching alone. Moreover, by using a mixed-effect model, we performed subgroup analyses with the stretching technique (static stretching, dynamic stretching), the type of foam rolling (vibration foam rolling, non-vibration foam rolling), the tested muscles (hamstrings, quadriceps, triceps surae, hip, shoulder), and the order of the combined treatment (either foam rolling followed by stretching or stretching followed by foam rolling) in both the analyses of the ROM and performance parameters. In addition, for the performance parameters, we also performed a subgroup analysis for the type of task (strength, jump height, sprinting). A minimum of two effect sizes per subgroup was necessary to perform a subgroup analysis. To determine if there were differences between the effect sizes of the subgroups, Q-statistics were applied (Borenstein et al., 2009). According to the recommendations of Hopkins et al. (2009), we defined the effects for a 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. I^2 statistics were calculated to assess the heterogeneity among the included studies, and thresholds of 25%, 50%, and 75% were defined as having a low, moderate, and high level of heterogeneity, respectively (Behm et al., 2021b; Higgins et al., 2003). An alpha level of 0.05 was defined for the statistical significance of all the tests

Bias assessment and methodological quality

The methodological quality of the included studies was assessed using the PEDro scale. In total, 11 methodological issues were assessed by two independent researchers (AK, MN) and assigned with either one or no point. Hence, studies with a higher score represent higher methodological quality. If any conflict between the ratings of the two researchers was found, the methodological issues were reassessed and discussed. Moreover, the Egger's regression intercept test was applied to detect possible publication bias.

Results

Results of the search

In total, 12 studies compared the effects of a combined treatment (foam rolling plus stretching or stretching plus foam rolling) with the effects of stretching or foam rolling alone on ROM. Within these 12 studies, seven studies compared the effects of a combined treatment with stretching on performance parameters. Overall, 17 effect sizes could be extracted for the ROM parameters and 24 for the performance parameters. In summary,

267 participants (143 males and 124 females) with a mean age of 22.9 (±5.1 years) participated in the included studies. Out of the 267 participants 141 were athletes, 76 were physically active, and six were sedentary. The activity level of the remaining 44 was not defined. Table 1 presents the characteristics and outcomes of the 12 studies.

Risk of bias assessment and methodological quality

The Egger's regression intercept test indicated that no reporting bias was likely for the meta-analysis dealing with ROM and for the comparison of the combined treatment with stretching (intercept -0.59; P = 0.31), foam rolling (intercept 0.78; P = 0.81), or the control condition (intercept 0.32; P = 0.91). When comparing the effect on performance parameters between the combined treatment and stretching alone, the Egger's regression intercept test indicated a potential for reporting bias (intercept -1.51; P = 0.00). The average PEDro score value is 6.92 (±1.31), indicating a low risk of bias (Maher et al., 2003; Moran et al., 2021). The two assessors agreed for 125 out of the 132 criteria (12 studies × 11 scores). The mismatched outcomes were discussed and the assessors finally agreed on the scores presented in Table 2.

Range of Motion

Combined stretching/foam rolling vs. stretching alone

The meta-analysis with 17 effect sizes from 12 studies revealed no significant difference in ROM changes between the combined condition and the stretching condition alone (ES = 0.032; Z = 0.517; CI (95%) -0.090 to 0.155; P = 0.61; I^2 = 0.00) (see Figure 2). Fourteen out of the 17 effect sizes allowed us to calculate pre- to post-changes. The remaining three effect sizes were based on post-values only. The combined condition and the stretching condition alone (pre- to post-comparison) showed an average increase in ROM of 6.83% (CI (95%) -0.34% to 14.00%) and 5.26% (CI (95%) -1.59% to 12.10%), respectively. None of the subgroup analyses, including the stretching technique (static stretching, dynamic stretching) (Q = 0.01; P = 0.92), the type of foam rolling (vibration foam rolling, non-vibration foam rolling) (Q = 0.05; P = 0.83), and the order of the combined treatment (Q = 0.66; P = 0.42), revealed significant differences in ROM. However, we did not perform a subgroup analysis with the tested muscles, since there were subgroups with only one effect size.

Table 1. Characteristics of the included studies (n = 12).

Study Name	Treatment				Outcome	
	Participants	**Foam rolling**	**Stretching**	**Combined**	**Range of motion**	**Performance**
Smith, et al., 2018	N = 29; 8 male and 21 female (23 physically active/6 sedentary) (age 22 ± 3 years)	3 x 30 s/MTU: gluteals, hamstrings, quadriceps, and calf	Dynamic stretching 20 min: Dynamic movements of as large ROM as possible targeting gluteals, hamstrings, quadriceps, and calf	Foam rolling + dynamic stretching	Sit and reach	Vertical jump height (cm)
Lin et al., 2020	N = 40; 25 male and 15 female college badminton players (age 21.4 ± 1.5 years)	20 s/MTU with vibration: quadriceps, hamstrings, calf, rotator cuff, lower back	Dynamic stretching: 8 dynamic movements of the trunk + upper and lower extremities	Dynamic stretching + vibration foam rolling	Knee flexion Knee extension	CMJ height (cm) Agility (s)
Fairall et al., 2017	N = 12; 12 male softball players (age 36.92 ± 11.17 years)	2 x 60 s/MTU: infraspinatus	Static stretching: 3 x 30 s per stretch: sleeper stretch and cross-body stretch	Foam rolling + static stretching	Glenohumeral internal rotation ROM	-
Richman et al., 2019	N = 14; 14 female (8 volleyball, 6 basketball) players (age 19.8 ± 1.3 years)	30 s/MTU: hip flexors and quadriceps, adductors, tensor fasciae latae and gluteus, hamstrings, plantar flexors, and dorsiflexors	Dynamic stretching: For 5 min; participants performed their own routine	Foam rolling + dynamic stretching	Sit and reach	Squat jump height (cm) CMJ height (cm) Drop jump height (cm) Agility T-Test (s) Short sprint (s)
Škarabot et al., 2015	N = 11; 6 male and 5 female swimmers (age 15.3 ± 1.0 years)	3 x 30 s plantar flexors	Static stretching: 3 x 30 s plantar flexors	Foam rolling + static stretching	Dorsiflexion ROM	-
Hodgson et al., 2019	N = 12; 7 male and 5 female recreationally trained athletes (age range 18-30 years)	30 s/MTU: hamstrings and quadriceps	Static stretching: 2 x 30 s/MTU hamstrings and quadriceps	Static stretching (30 s/MTU) + foam rolling (30 s/MTU)	Hip flexion active Hip flexion passive Knee flexion active Knee flexion passive	CMJ height (inches) Hurdle jump height (inches) Hurdle jump contact time (s) Knee flexion peak torque (Nm) Knee extension peak torque(Nm)
Kyranoudis et al., 2019	N = 24 male soccer players; 11 in the control group (age 21.7 ± 1.1 years); 13 in the experimental group (age 21.6 ± 0.7 years).	30 s/MTU: quadriceps, hamstrings, adductors, gastrocnemius	Static stretching: 10 s/MTU quadriceps, hamstrings, adductors, gastrocnemius	Foam rolling + static stretching	Hip flexion ROM	CMJ height (cm) CMJ free height (cm)
Che Hsiu et al., 2021	N = 10; 10 female handball players (age 21 ± 1 years)	4 x 30 s/MTU with vibration: quadriceps and hamstrings	Dynamic stretching: 4 x 15 repetitions (5 x slow and 10 x as fast as possible) targeting the quadriceps and hamstring muscles	Dynamic stretching + vibration foam rolling	Knee extension Knee flexion	Hamstring strength 60°/s (Nm) Hamstring strength 240°/s (Nm) Quadriceps strength 60°/s (Nm) Quadriceps strength 240°/s (Nm)
Cunha et al., 2021	N = 18; 18 female recreationally trained athletes (age 24.0 ± 2.0 years)	60 s hamstrings	Dynamic stretching: 60 s dynamic movements targeting the hamstring muscles	Foam rolling + dynamic stretching	Straight leg raise	-

Table 1. Continues…

Study Name	Participants	Treatment			Outcome	
		Foam rolling	Stretching	Combined	Range of motion	Performance
Smith et al., 2019	N = 44; 26 male (age 21.7 ± 1.7 years) and 18 female athletes (age 21.3 ± 2.0 years); activity level not reported	3 x 30 s calf	Static stretching: 3 x 30 s calf	Foam rolling + static stretching	Ankle dorsiflexion	-
Peacock et al., 2014	N = 11; 11 male physically active individuals (age 22.2 ± 2.2 years)	30 s/MTU: thoracic/lumbar spine, gluteal, ham-string, calf, pectoral, quadriceps	Dynamic stretching: dynamic movements of the whole body either performed as 2 x 10 repetitions or 2 x 10 m	Foam rolling + dynamic stretching	Sit and reach	Vertical jump height (cm) Standing long jump (cm) 18.3 m pro agility (s) Indirect 1-RM bench press (kg) 37 m sprint (s)
Somers et al., 2020	N = 42; 24 male and 18 female physical therapy students (age 26.1 ± 4.0 years)	60 s calf	Dynamic stretching: 60 s in downward dog targeting the posterior chain	Foam rolling + dynamic stretching	Ankle dorsiflexion	-

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

	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	0	0	0	1	1	1	1	6
Lin et al., 2020	1	1	0	1	0	0	0	1	1	1	1	6
Fairall et al., 2017	1	1	0	1	0	0	0	1	1	1	1	6
Richman et al., 2019	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
Hodgson et al., 2019	1	1	1	1	0	0	0	1	1	1	1	7
Kyranoudis et al., 2019	1	1	0	1	0	0	0	1	1	1	1	6
Che Hsiu et al., 2021	1	1	0	1	0	0	0	1	1	1	1	6
Somers et al., 2020	1	1	1	1	0	1	1	1	1	1	1	9
Smith et al., 2019	1	1	1	1	0	1	1	1	1	1	1	9
Peacock et al., 2014	1	1	0	1	0	0	0	1	1	1	1	6
Cunha et al., 2021	1	1	1	1	0	1	1	1	1	1	1	9

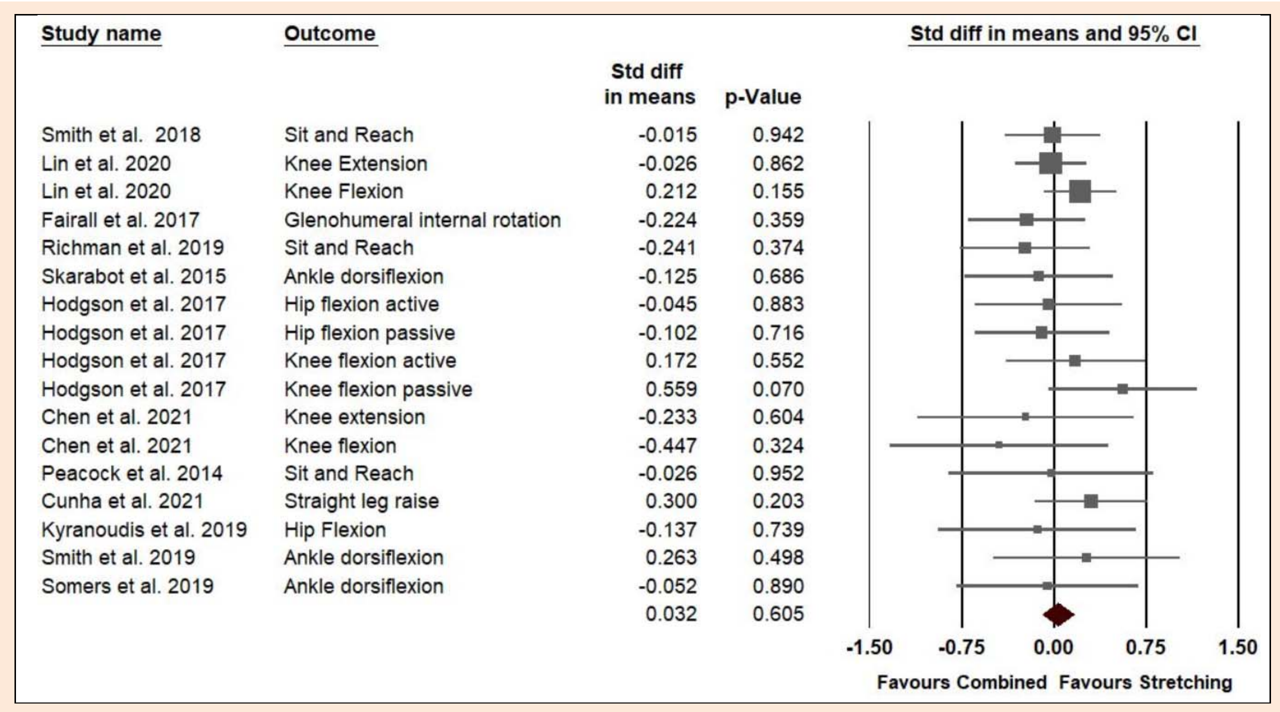

Figure 2. Forest plot presenting the combined effects compared to stretching on range of motion. (Std diff in means = standardized difference in means; CI = confidence interval).

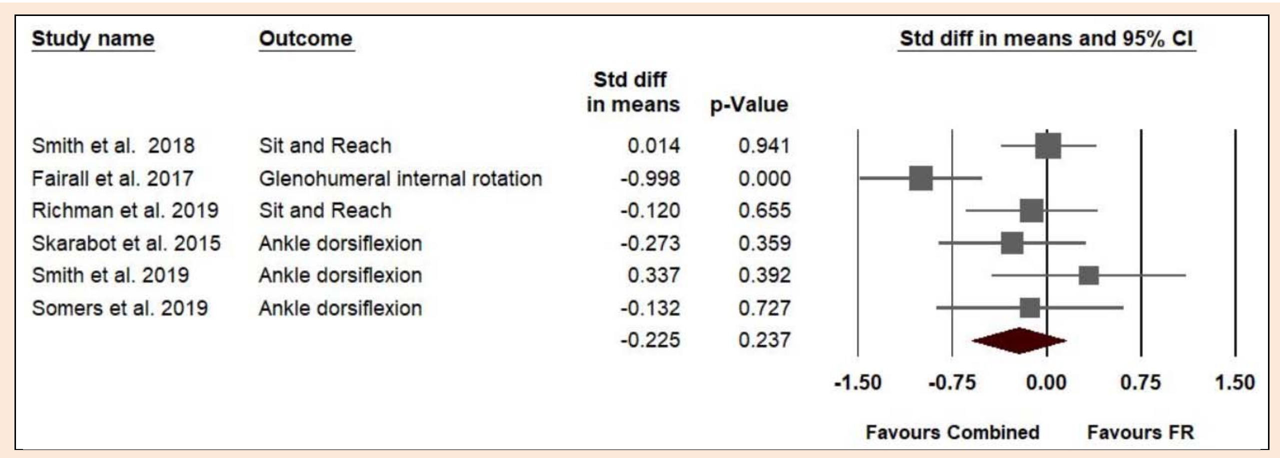

Figure 3. Forest plot presenting the combined effects compared to foam rolling on range of motion. (Std diff in means = standardized difference in means; CI = confidence interval; FR= foam rolling).

Combined stretching/foam rolling vs. foam rolling alone

The meta-analysis with six effect sizes from six studies revealed no significant difference in ROM changes when the combined condition was compared to the foam rolling condition alone (ES = -0.225; Z = -1.182; CI (95%) -0.597 to 0.148; p = 0.24; I^2 = 62.89) (see Figure 3). The combined condition and foam rolling condition alone (pre- to post-comparison) showed an average increase in ROM of 13.77% (CI (95%) -0.61% to 28.16%) and 7.19% (CI (95%) 2.48% to 11.89%), respectively.

The subgroup analyses differentiating between different stretching techniques revealed no significant difference in ROM (Q = 0.58; p = 0.45). A subgroup analysis including the type of foam rolling or the order of the combined treatment was not possible since only non-vibration foam rolling studies and studies where stretching was followed by foam rolling were part of this meta-analysis. However, we did not perform a subgroup analysis with the tested muscles since there were subgroups with only one effect size.

Combined stretching/foam rolling vs. control condition

The meta-analysis with six effect sizes from three studies revealed a significantly higher increase of a small magnitude in ROM in the combined condition compared to the control condition without any intervention (ES = -0.332; Z = -2.499; CI (95%) -0.593 to -0.072; p = 0.012; I^2 = 32.38) (see Figure 4). The six effect sizes of the combined condition and the control condition (pre- to post-comparison) showed an average change of 1.51% (CI (95%) -4.74% to 7.76%) and 0.21% (CI (95%) -1.16% to 1.59%), respect-

Received: 18 June 2021 / Accepted: 21 June 2021 / Published (online): 01 July 2021

tively. The subgroup analyses of the stretching technique (Q = 0.78; p = 0.38), the tested muscles (Q = 1.44; p = 0.49), and the order of the combined treatment (Q = 0.78; p = 0.38) revealed no significant difference in ROM changes. A subgroup analysis with the type of foam rolling was not possible since only non-vibration foam rolling studies were part of this meta-analysis.

Performance

A meta-analysis of the effects on performance was only possible with the combined condition and the stretching condition alone since there were insufficient studies and effect sizes for the foam rolling condition available.

The meta-analysis with 24 effect sizes from seven studies revealed no significant difference in performance parameters between the combined condition and the stretching condition alone (ES = -0.029; Z = -0.503; CI (95%) -0.142 to 0.084; p = 0.62; $I^2 = 0.00$) (see Figure 5). Ten out of the 24 effect sizes allowed us to calculate pre- to post-changes. The remaining 14 effect sizes were based on post-values only. The combined condition and stretching condition alone (pre- to post-comparison) showed changes in performance of -0.41% (CI (95%) -3.02% to 2.19%) and -0.07% (CI (95%) -3.34% to 3.22%), respectively.

By comparing the order of the combined treatment (either foam rolling followed by stretching or vice versa), the subgroup analysis revealed a significant difference between the subgroups of “foam rolling followed by stretching vs. stretching alone” and “stretching followed by foam rolling vs. stretching alone” (Q = 5.53; p = 0.02). While stretching followed by foam rolling showed a similar magnitude of change as stretching alone (ES = 0.10; p = 0.21), the foam rolling followed by stretching exercise revealed a significant but trivial better effect than stretching alone (ES= -0.17; p = 0.04) (see Figure 5). Moreover, further subgroup analyses of the stretching technique (Q = 0.11; p = 0.74), the type of foam rolling (Q = 3.21; P = 0.07), and the type of task (strength, jump height, sprinting) (Q = 0.82; p = 0.66) revealed no significant difference in performance. However, we did not perform a subgroup analysis of the tested muscles since there were subgroups with only one effect size.

Discussion

The purpose of this review was to compare the effects of an acute bout of a combined treatment of stretching and foam rolling to the effects of stretching or foam rolling alone on both ROM and performance parameters in healthy subjects. For ROM, the meta-analysis revealed the superior effect of a combined treatment compared to the control condition (no stretching or foam rolling); however, no superior effect was found for the combined treatment compared to either stretching or foam rolling alone. In addition, further subgroup analyses of ROM (e.g., stretching technique, muscle groups tested) showed no differences between the modalities. With regard to performance, the meta-analysis revealed no difference between the combined treatment compared to stretching or foam rolling alone; however, the subgroup analysis of performance revealed the trivial but superior effect of the combined treatment compared to stretching alone, but only if the foam rolling was followed by stretching.

Three meta-analyses were performed for ROM. Thereby, the combined effects (stretching and foam rolling) were compared to a control condition, stretching alone, and foam rolling alone. The combined treatment had a superior effect on ROM compared to the control condition. Increases in ROM following a single stretching (Behm et al., 2016; Behm et al., 2021a; Behm and Chaouachi, 2011) or foam rolling treatment (Wilke et al., 2020) were reported by several studies. However, it is not clear if the increases in ROM have an accumulated effect when foam rolling and stretching are performed within one training session, compared to foam rolling or stretching alone. Anderson et al. (2021) reported in their review only a small additional effect when comparing a combined treatment with foam rolling and dynamic stretching to dynamic stretching alone. However, the authors did not perform a meta-analysis or include the static stretching technique, or consider other muscles than the hamstrings. Our meta-analysis included static stretching and different muscles, but neither showed any superior effect for a combined treatment compared to stretching alone or foam rolling alone.

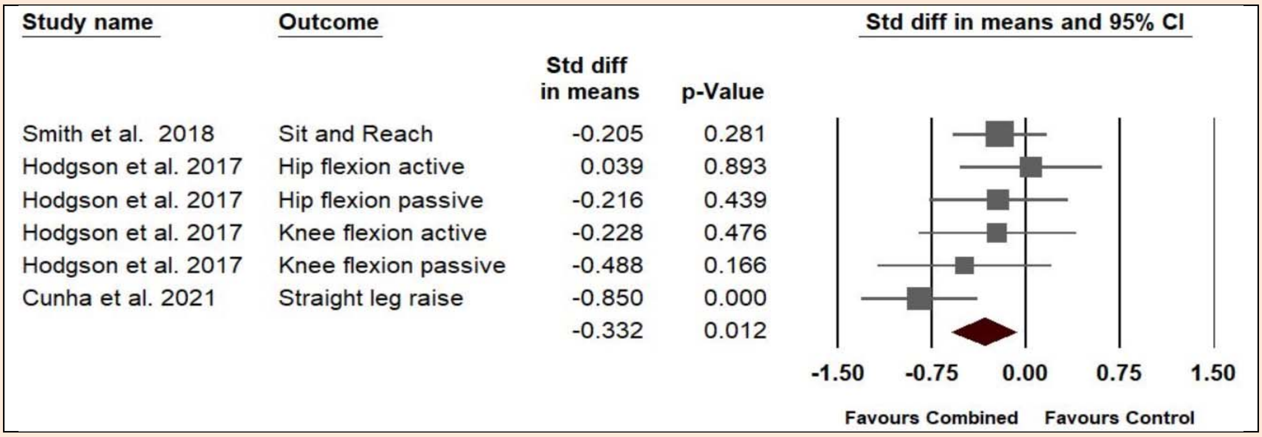

Figure 4. Forest plot presenting the combined effects compared control condition on range of motion. (Std diff in means = standardized difference in means; CI = confidence interval).

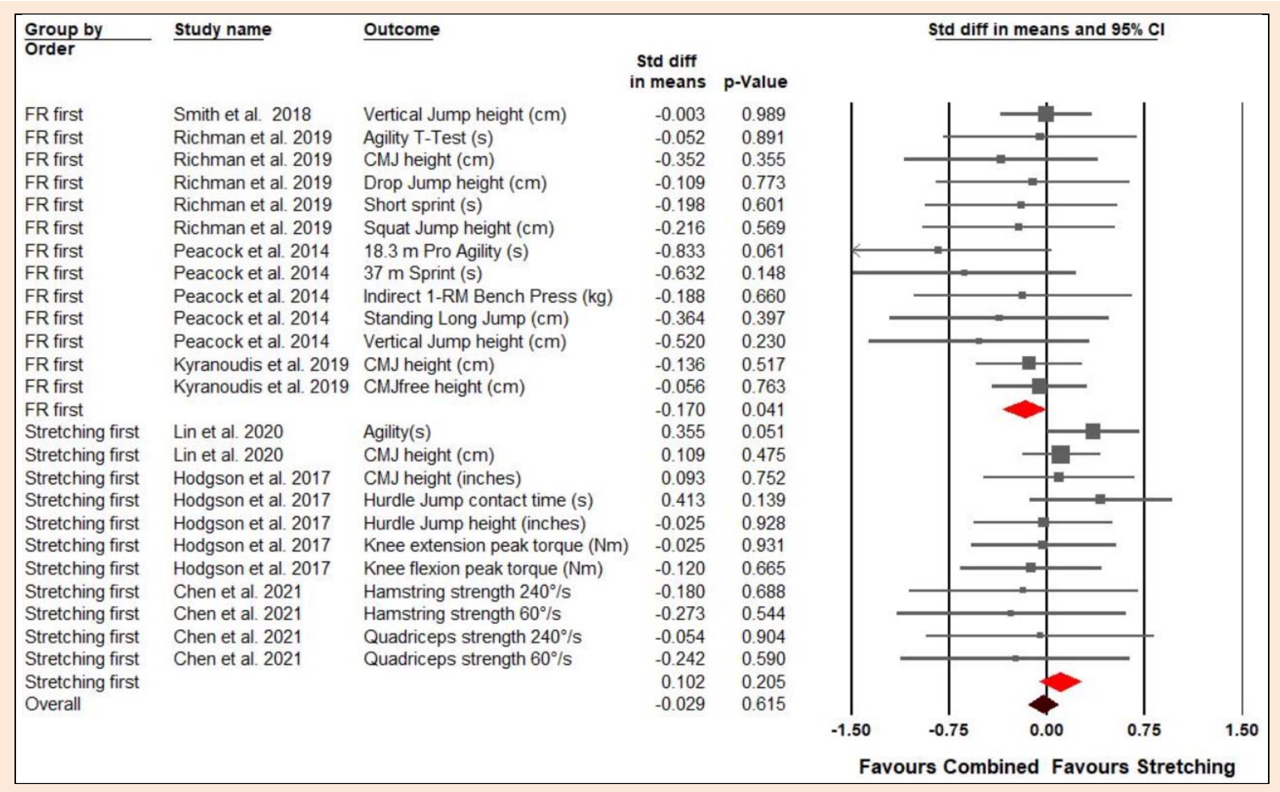

Figure 5. Forest plot presenting the combined effects compared to stretching on performance parameters, including a subgroup analysis with the order of the combined treatment (Std diff in means = standardized difference in means; CI = confidence interval; FR= foam rolling).

We would have expected that a change in tissue compliance (e.g., muscle or tendon stiffness), which has been reported following an acute bout of stretching (Kato et al., 2010; Kay et al., 2015; Konrad et al., 2017), and the additional changes in stretch or pain tolerance following foam rolling (Nakamura et al., 2021), might have led to greater gains in ROM compared to stretching or foam rolling alone. However, this was not observed in this meta-analysis. A possible reason for the lack of an additional effect in the combined treatment might be a saturation effect for ROM, which has also been observed following a certain duration of stretching (Mizuno, 2019) and foam rolling (Nakamura et al., 2021). Mizuno (2019) reported a similar amount of increase in ROM when comparing 10 s of static stretching with 100 s. Moreover, Nakamura et al. (2021) reported no further changes in ROM following a single foam rolling treatment applied for 300 s compared to 90 s. Hence, if the single treatment of stretching or foam rolling exceeds a certain duration, no additional changes in ROM can be expected. The duration range of the combined treatment of the included studies when foam rolling was combined with static stretching was between 40 s and 210 s (mean: 134.0 ± 77.9 s). Hence, the assumed saturation following a combined treatment for ROM is not unlikely. According to the results of our meta-analysis, it can be recommended that foam rolling (with a duration range between 30 s and 120 s; mean 66.0 ± 36.9 s) or stretching (with a duration range between 10 s and 90 s; mean 65.7 ± 28.8 s) could be performed to increase the ROM of a joint acutely, rather than a more time-consuming combined treatment This goes in line with previous recommendations on foam rolling (Behm et al., 2020) or stretching (Behm, 2018). Wilke et al. (2020) reported in a recent meta-analysis that foam rolling and stretching have a similar magnitude of change on ROM, so that athletes could apply either stretching or foam rolling to increase ROM, according to their preference. However, several studies have reported enhanced recovery and reduced delayed-onset muscle soreness (DOMS) following foam rolling (MacDonald et al., 2014; Nakamura et al., 2020; Pearcey et al., 2015), but not following a stretching exercise (Afonso et al., 2021; Henschke 2011). Therefore, if a secondary goal is to reduce DOMS, besides the increase in ROM, foam rolling is likely the better treatment.

With regard to the effects on performance parameters, due to the lack of studies and effect sizes, a comparison was only possible between the combined treatment and a stretching treatment alone (but not foam rolling or a control condition). The meta-analysis revealed no significant changes between the combined treatment and stretching alone. This is in contrast to the review by Anderson et al. (2021), who concluded that foam rolling and dynamic stretching might have a superior effect compared to dynamic stretching alone. The authors reported that two out of four studies found a greater increase in vertical jump height compared to dynamic stretching alone. Moreover, two out of three studies included in their review reported a greater effect on agility following a combined treatment (foam rolling and dynamic stretching) compared to dynamic stretching alone. However, Anderson et al. (2021) only included studies with dynamic stretching and studies assessing ROM with a sit and reach test. Consequently, several studies that investigated the combined effects on performance parameters with other stretching techniques and other muscles were excluded. In the present meta-analysis, we analyzed 12 studies in total, including seven studies of dynamic stretching and five of static stretching. Several reviews reported major differences in the effects between static and dynamic stretching if applied prior to a sports event. Static stretching with a long duration (≥60 s) likely causes a decrease in performance, while dynamic stretching can lead to an increase in performance (Behm et al., 2016; Behm et al., 2021a; Behm and Chaouachi, 2011). A recent meta-analysis of the acute effects of foam rolling on performance (Wiewelhove et al., 2019) reported a tendency of improvement (P = 0.06) in sprint performance (+0.7%), but negligible effects on jump or strength performance. This is in accordance with another review (Cheatham et al., 2015) that reported that a single bout of a foam rolling exercise likely does not induce changes in performance parameters. Therefore, similar to the results of Anderson et al. (2021), we expect that a combination of a foam rolling and dynamic stretching treatment will likely lead to a greater increase in performance than dynamic stretching alone. However, our subgroup analysis of the different stretching techniques (static stretching, dynamic stretching) did not reveal a significant effect of the combined treatment including dynamic stretching compared to dynamic stretching alone. Hence, according to our meta-analysis, dynamic stretching alone can lead to a similar performance changes as the combined treatment. Therefore, foam rolling does not necessarily have to be included if the goal is to increase performance. Similar to the results for the dynamic stretching group, no difference between the combined treatment and the static stretching treatment alone was shown by the meta-analysis.

Further subgroup analyses showed no significant differences between the different muscles tested (e.g., quadriceps, hamstrings), the type of foam rolling (vibration foam rolling, non-vibration foam rolling), or the type of task (e.g., strength, power). However, a significant difference could be detected between the orders of the combined treatment. Stretching followed by foam rolling showed a similar magnitude of change on performance as stretching alone; however, the foam rolling followed by stretching exercise revealed a significantly but trivial better effect than stretching alone (see Figure 5). A possible mechanism for why foam rolling before stretching can lead to a favorable effect compared to stretching alone is unclear and should be investigated in future studies.

Conclusion

It can be concluded that athletes under time constraints do not have to combine stretching with foam rolling in order to increase their ROM because the combination does not lead to any additional effects. However, if the goal is to also increase performance (e.g., strength, speed), the combination of foam rolling followed by stretching (but not vice versa) should be favored compared to stretching alone.

Acknowledgements
This study was supported by a grant (Project J 4484) from the Austrian Science Fund (FWF). The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

References

Afonso, J., Clemente, F. M., Nakamura, F. Y., Morouço, P., Sarmento, H., Inman, R. A. and Ramirez-Campillo, R. (2021) The Effectiveness of Post-exercise Stretching in Short-Term and Delayed Recovery of Strength, Range of Motion and Delayed Onset Muscle Soreness: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Frontiers in Physiology* **12**. https://doi.org/10.3389/fphys.2021.677581

Amiri-Khorasani, M., Abu Osman, N. A. and Yusof, A. (2011) Acute effect of static anddynamic stretching on hip dynamic range of motion during instep kicking in professional soccer players. *Journal of Strength and Conditioning Research*, **25(6)**, 1647-1652. https://doi.org/10.1519/JSC.0b013e3181db9f41

Anderson, B. L., Harter, R. A. and Farnsworth, J. L. (2021) The Acute Effects of Foam Rolling and Dynamic Stretching on Athletic Performance: A Critically Appraised Topic. *Journal of Sport Rehabilitation* **30(3)**, 501-506. https://doi.org/10.1123/JSR.2020-0059

Behm, D. G., Kay, A. D., Trajano, G. S. and Blazevich, A. J. (2021a) Mechanisms underlying performance impairments following prolonged static stretching without a comprehensive warm-up. *European Journal of Applied Physiology* **121**, 67-94. https://doi.org/10.1007/s00421-020-04538-8

Behm, D. G., Alizadeh, S., Anvar, S. H., Drury, B., Granacher, U. and Moran, J. (2021b) Non-local Acute Passive Stretching Effects on Range of Motion in Healthy Adults: A Systematic Review with Meta-analysis. *Sports Medicine* **51**, 945-959. https://doi.org/10.1007/s40279-020-01422-5

Behm, D. G., Alizadeh, S., Hadjizadeh Anvar, S., Mahmoud, M. M. I., Ramsay, E., Hanlon, C. and Cheatham, S. (2020) Foam Rolling Prescription: A Clinical Commentary. *Journal of Strength and Conditioning Research* **34**, 3301-3308. https://doi.org/10.1519/JSC.0000000000003765

Behm, D. G., Blazevich, A. J., Kay, A. D. and McHugh, M. (2016) Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied Physiology, Nutrition, and Metabolism* **41(1)**, 1-11. https://doi.org/10.1139/apnm-2015-0235

Behm, D. G. and Chaouachi, A. (2011) A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology* **111(11)**, 2633-2651. https://doi.org/10.1007/s00421-011-1879-2

Behm, D. G. (2018) Recommendations for stretching prescription. In The Science and Physiology of Flexibility and Stretching. Routledge. https://doi.org/10.4324/9781315110745-6

Borenstein, M., Hedges, L. V, Higgins, J. P. T. and Rothstein, H. R. (2009) Introduction to Meta-Analysis. https://doi.org/10.1002/9780470743386

Che Hsiu, C., Chiu, C.H., Tseng, W.C., Ye, X., Chen, C.H., Wu, C.Y. and Chang, C.K. (2021) Acute Effects of Combining Dynamic Stretching and Vibration Foam Rolling Warm-up on Lower-Limb Muscle Performance and Functions in Female Handball Players. *The Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003998

Cheatham, S. W., Kolber, M. J., Cain, M. and Lee, M. (2015) The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: a systematic review. *International Journal of Sports Physical Therapy* **10(6)**, 827-838.

Cunha, J. C. O. M. de, Monteiro, E. R., Fiuza, A., Neto, V. G. C., Araujo, G. S., Telles, L. G. S. and Novaes, J. S. (2021) Acute Effect of Foam Rolling Before Dynamic Stretching on the Active Hip Flexion Range-of-Motion in Healthy Subjects. *Journal of Exercise Physiology Online* **24(2)**, 81-90.

Fairall, R. R., Cabell, L., Boergers, R. J. and Battaglia, F. (2017) Acute effects of self-myofascial release and stretching in overhead athletes with GIRD. *Journal of Bodywork and Movement*

Therapies **21(3)**, 648-652. https://doi.org/10.1016/j.jbmt.2017.04.001

Henschke, N. (2011, December 1) Stretching before or after exercise does not reduce delayed-onset muscle soreness. *British Journal of Sports Medicine* **45**, 1249-1250. https://doi.org/10.1136/bjsports-2011-090599

Higgins, J. P. T., Thompson, S. G., Deeks, J. J. and Altman, D. G. (2003) Measuring inconsistency in meta-analyses. *British Medical Journal*, **327**, 557-560. https://doi.org/10.1136/bmj.327.7414.557

Hodgson, D. D., Quigley, P. J., Whitten, J. H. D., Reid, J. C. and Behm, D. G. (2019) Impact of 10-minute interval roller massage on performance and active range of motion. *Journal of Strength and Conditioning Research* **33(6)**, 1512-1523. https://doi.org/10.1519/JSC.0000000000002271

Hopkins, W. G., Marshall, S. W., Batterham, A. M. and Hanin, J. (2009) Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise* **41(1)**, 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Kato, E., Kanehisa, H., Fukunaga, T. and Kawakami, Y. (2010) Changes in ankle joint stiffness due to stretching: The role of tendon elongation of the gastrocnemius muscle. *European Journal of Sport Science* **10(2)**, 111-119. https://doi.org/10.1080/17461390903307834

Kay, A. D. and Blazevich, A. J. (2012) Effect of Acute Static Stretch on Maximal Muscle Performance: A Systematic Review. *Medicine and Science in Sports and Exercise* **44(1)**, 154-164. https://doi.org/10.1249/MSS.0b013e318225cb27

Kay, A. D., Husbands-Beasley, J. and Blazevich, A. J. (2015) Effects of Contract-Relax, Static Stretching, and Isometric Contractions on Muscle-Tendon Mechanics. *Medicine and Science in Sports and Exercise* **47(10)**, 2181-2190. https://doi.org/10.1249/MSS.0000000000000632

Konrad, A., Reiner, M. M., Thaller, S. and Tilp, M. (2019) The time course of muscle-tendon properties and function responses of a five-minute static stretching exercise. *European Journal of Sport Science* **19(9)**, 1195-1203. https://doi.org/10.1080/17461391.2019.1580319

Konrad, A., Budini, F. and Tilp, M. (2017) Acute effects of constant torque and constant angle stretching on the muscle and tendon tissue properties. *European Journal of Applied Physiology* **117(8)**, 1649-1656. https://doi.org/10.1007/s00421-017-3654-5

Konrad, A., Močnik, R., Titze, S., Nakamura, M. and Tilp, M. (2021) The Influence of Stretching the Hip Flexor Muscles on Performance Parameters. A Systematic Review with Meta-Analysis. *International Journal of Environmental Research and Public Health* ***18*(4)**, 1936. https://doi.org/10.3390/ijerph18041936

Konrad, A. and Tilp, M. (2020a) The acute time course of muscle and tendon tissue changes following one minute of static stretching. *Current Issues in Sport Science* **5**. https://doi.org/10.15203/ciss_2020.003

Konrad, A. and Tilp, M. (2020b) The time course of Muscle-Tendon unit function and structure following three minutes of static stretching. *Journal of Sports Science and Medicine* **19(1)**, 52-58. https://pubmed.ncbi.nlm.nih.gov/32132827/

Kyranoudis, A., Arsenis, S., Ispyrlidis, I., Chatzinikolaou, A., Gourgoulis, V., Kyranoudis, E. and Metaxas, T. (2019) The acute effects of combined foam rolling and static stretching program on hip flexion and jumping ability in soccer players. *Journal of Physical Education and Sport* **19(2)**, 1164-1172. https://doi.org/10.7752/jpes.2019.02169

Lin, W. C., Lee, C. L. and Chang, N. J. (2020) Acute effects of dynamic stretching followed by vibration foam rolling on sports performance of badminton athletes. *Journal of Sports Science and Medicine* **19(2)**, 420-428. https://pubmed.ncbi.nlm.nih.gov/32390736/

Macdonald, G. Z., Button, D. C., Drinkwater, E. J. and Behm, D. G. (2014) Foam rolling as a recovery tool after an intense bout of physical activity. *Medicine and Science in Sports and Exercise* **46(1)**, 131-142. https://doi.org/10.1249/MSS.0b013e3182a123db

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M. and Elkins, M. (2003) Reliability of the PEDro Scale for Rating Quality of Randomized Controlled Trials. *Physical Therapy* **83(8)**, 713-721. https://doi.org/10.1093/ptj/83.8.713

Mizuno, T. (2019) Is There a Sex Difference in the Minimum Number of Static Stretch Repetitions That Should Be Recommended to Improve Flexibility? *International Journal of Sport and Health Science* **17(0)**, 80-87. https://doi.org/10.5432/ijshs.201836

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D. G. (2009) Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Plos Medicine* **6(7)**, e1000097. https://doi.org/10.1371/journal.pmed.1000097

Moran, J., Ramirez-Campillo, R., Liew, B., Chaabene, H., Behm, D. G., García-Hermoso, A. and Granacher, U. (2021) Effects of Bilateral and Unilateral Resistance Training on Horizontally Orientated Movement Performance: A Systematic Review and Meta-analysis. *Sports Medicine* **51**, 225-242. https://doi.org/10.1007/s40279-020-01367-9

Nakamura, M., Onuma, R., Kiyono, R., Yasaka, K., Sato, S., Yahata, K. and Konrad, A. (2021) Acute and Prolonged Effects of Different Durations of Foam Rolling on Range of Motion, Muscle Stiffness, and Muscle Strength. *Journal of Sports Science and Medicine* **20(1)**, 62-68. https://doi.org/10.52082/jssm.2021.62

Nakamura, M., Yasaka, K., Kiyono, R., Onuma, R., Yahata, K., Sato, S. and Konrad, A. (2020) The Acute Effect of Foam Rolling on Eccentrically-Induced Muscle Damage. *International Journal of Environmental Research and Public Health* **18(1)**, 75. https://doi.org/10.3390/ijerph18010075

Peacock, C. A., Krein, D. D., Silver, T. A., Sanders, G. J. and VON Carlowitz, K.-P. A. (2014) An Acute Bout of Self-Myofascial Release in the Form of Foam Rolling Improves Performance Testing. *International Journal of Exercise Science* **7(3)**, 202-211.

Pearcey, G. E. P., Bradbury-Squires, D. J., Kawamoto, J. E., Drinkwater, E. J., Behm, D. G. and Button, D. C. (2015) Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *Journal of Athletic Training* **50(1)**, 5-13. https://doi.org/10.4085/1062-6050-50.1.01

Richman, E. D., Tyo, B. M. and Nicks, C. R. (2019) Combined Effects of Self-Myofascial Release and Dynamic Stretching on Range of Motion, Jump, Sprint, and Agility Performance. *Journal of Strength and Conditioning Research* **33(7)**, 1795-1803. https://doi.org/10.1519/JSC.0000000000002676

Škarabot, J., Beardsley, C. and Štirn, I. (2015) Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. *International Journal of Sports Physical Therapy* **10(2)**, 203-212.

Smith, J. C., Pridgeon, B. and Hall, M. C. (2018) Acute Effect of Foam Rolling and Dynamic Stretching on Flexibility and Jump Height. *Journal of Strength and Conditioning Research* **32(8)**, 2209-2215. https://doi.org/10.1519/JSC.0000000000002321

Smith, J. C., Washell, B. R., Aini, M. F., Brown, S. and Hall, M. C. (2019) Effects of Static Stretching and Foam Rolling on Ankle Dorsiflexion Range of Motion. *Medicine and Science in Sports and Exercise* **51(8)**, 1752-1758. https://doi.org/10.1249/MSS.0000000000001964

Somers, K., Aune, D., Horten, A., Kim, J. and Rogers, J. (2020) Acute Effects of Gastrocnemius/Soleus Self-Myofascial Release Versus Dynamic Stretching on Closed-Chain Dorsiflexion. *Journal of Sport Rehabilitation* **29(3)**, 287-293. https://doi.org/10.1123/jsr.2018-0199

Wiewelhove, T., Döweling, A., Schneider, C., Hottenrott, L., Meyer, T., Kellmann, M. and Ferrauti, A. (2019) A Meta-Analysis of the Effects of Foam Rolling on Performance and Recovery. *Frontiers in Physiology* **10**, 376. https://doi.org/10.3389/fphys.2019.00376

Wilke, J., Müller, A. L., Giesche, F., Power, G., Ahmedi, H. and Behm, D. G. (2020) Acute Effects of Foam Rolling on Range of Motion in Healthy Adults: A Systematic Review with Multilevel Meta-analysis. *Sports Medicine* **50(2)**, 387-402. https://doi.org/10.1007/s40279-019-01205-7

Key points

- This is the first meta-analysis to have compared the combined effects of foam rolling and stretching with the effects of stretching or foam rolling alone.
- The meta-analysis revealed a significant overall effect on ROM of the combined treatment when compared to no intervention.
- The results showed no favorable effect on ROM or performance when compared to the effect of stretching or foam rolling alone.
- The subgroup analysis revealed that, if the goal is to increase performance, the combination of foam rolling followed by stretching (but not vice versa) should be favored compared to stretching alone.

AUTHOR BIOGRAPHY

Andreas KONRAD
Employment
Institute of Human Movement Science, Sport and Health, University of Graz
Degree
PhD, MSc, BSc
Research interests
Biomechanics, muscle performance, training science, muscle-tendon-unit, soccer science
E-mail: andreas.konrad@uni-graz.at

Masatoshi NAKAMURA
Employment
Lecture, Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Niigata, Japan
Degree
PhD
Research interests
Physical therapy, stretching, exercise physiology, flexibility
E-mail:
masatoshi-nakamura@nuhw.ac.jp

Daniel BERNSTEINER
Employment
Institute of Human Movement Science, Sport and Health, University of Graz
Degree
BSc
Research interests
Training science, biomechanics
E-mail:
daniel.bernsteiner@edu.uni-graz.at

Markus TILP
Employment
Institute of Human Movement Science, Sport and Health, University of Graz
Degree
PhD
Research interests
Biomechanics, training science, muscle-tendon-unit, sports game analysis
E-mail: markus.tilp@uni-graz.at

✉ **Mag. Dr. Andreas Konrad, BSc MSc**
Institute of Human Movement Science, Sport and Health, University of Graz, Mozartgasse 14, A-8010 Graz, Austria