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Research article

An Intense Warm-Up Does Not Potentiate Performance Before or After a Single Bout of Foam Rolling

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Abstract
Foam rolling (FR) is a common intervention used as a warm-up to increase the range of motion (ROM) of a joint, without changes in subsequent performance. It has been shown that, in similar techniques (e.g., stretching), an additional intense warm-up can lead to performance potentiation. However, to date, it is not clear if this also holds true for FR, and if this effect is similar in both sexes. Thus, the purpose of this study was to compare the effects of an intense warm-up either before or after FR with the effects of FR without any additional intense warm-up, in both females and males. In total, 27 volunteers (14 male, 13 female) visited the laboratory on three separate days. Each participant was randomly assigned to one of the three interventions. ROM was assessed with a Sit n' Reach box, and countermovement jump (CMJ) height with a force plate, both before and after the interventions. In addition, maximum voluntary isometric contraction (MVIC) peak torque and maximum voluntary dynamic contraction (MVDC) peak torque were assessed with a dynamometer. ROM increased to the same extent following the interventions in all groups, with a large magnitude of change ($P < 0.001$; $d = 1.12$ to 1.83). In addition, male participants showed significantly higher increases in ROM when the intense warm-up was performed after FR ($P < 0.001$; $d = 1.44$), but not without the intense warm-up ($P = 0.45$; $d = 0.57$) or when the intense warm-up was performed before FR ($P = 0.24$; $d = 0.69$). No significant changes in CMJ height, MVIC peak torque, or MVDC peak torque were observed ($P > 0.05$). We therefore conclude that the time-efficient athlete might skip further intense warm-up, besides FR, when the goal is to increase ROM and to sustain performance parameters.

Key words: Roller massage, myofascial release, warm-up, performance potentiation.

Introduction

A single foam rolling (FR) application can increase the range of motion (ROM) of a joint immediately after the treatment (Nakamura et al., 2021; Wilke et al. 2020), and the effect can last for more than 30 min (Monteiro et al. 2018). With regard to the acute effects of FR on performance, a recent meta-analysis (Wiewelhove et al. 2019) reported a tendency for immediate improvement ($P = 0.06$) in sprint performance (+0.7%; $ES = 0.28$), but negligible effects in jump or strength performance. Hence, according to this meta-analysis (Wiewelhove et al. 2019), and also other reviews (Cheatham et al. 2015), a single bout of a FR exercise is likely to neither increase nor decrease performance.

In contrast, when a long duration of stretching is used as a warm-up (i.e., ≥60 s per muscle group), decreases of strength and power performance have been consistently reported (Behm et al. 2016, 2021; Behm and Chaouachi 2011; Kay and Blazevich 2012). To counteract any such possible detrimental effect on performance, or even induce performance potentiation, Behm et al. (2016) suggested that an intense warm-up be implemented following a single stretching exercise. This finding has been supported by various studies that showed a post-stretching potentiation effect (Reid et al. 2018; Samson et al. 2012), or at least no negative effect (Blazevich et al. 2018; M. Reiner et al. 2021) when static, dynamic, or proprioceptive neuromuscular facilitation (PNF) stretching exercises were followed by intense warm-up activities (e.g., butt kick run or high knee run with high velocity). Interestingly, further studies (Takeuchi et al. 2021; Takeuchi and Nakamura 2020) have reported an increase in performance when light aerobic exercise (10-min on a stationary bike at 60 W) was conducted after static stretching, but a decrease in performance when aerobic exercise was performed before static stretching. This indicates that the chronological organization of an additional warm-up, i.e., either before or after a flexibility treatment, can affect the outcome.

Although beneficial effects of intense post-stretching activities (Reid et al. 2018; Samson et al. 2012) and post-stretching aerobic warm-up (Takeuchi et al., 2021) have been reported, to date, it is unclear if such activities can induce acute performance potentiation when also applied after a single FR treatment. Since isolated FR likely has no detrimental effect on performance parameters (Wiewelhove et al. 2019), it can be assumed that an additional intense warm-up post-FR can increase performance. However, based on the findings for stretching, if the warm-up is applied prior to FR, no such increase in performance can be expected.

Therefore, the purpose of this study was to investigate and compare the effects of a 2-min bout of FR of the hamstring muscles on ROM and performance parameters, with either an intense warm-up: 1) before the FR exercise, 2) after the FR exercise, or 3) without any additional intense warm-up. A secondary goal was to investigate if there was a difference in the effects between male and female participants in the respective interventions.

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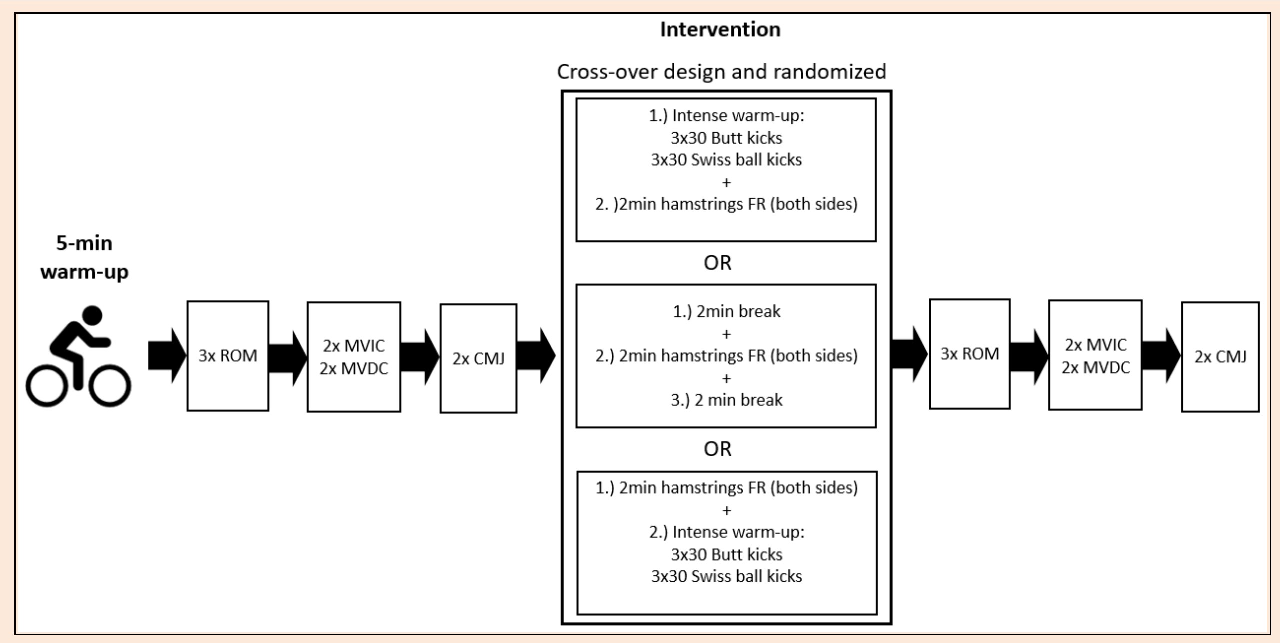

Figure 1. Schematic schedule of the study. Range of motion (ROM), maximum voluntary isometric contraction (MVIC), maximum voluntary dynamic contraction (MVDC), countermovement jump (CMJ), foam rolling (FR).

Methods

Study design

Participants were asked to visit the laboratory on three appointments within seven days (separated by ≥48 h), to complete the three interventions ("intense warm-up + FR", "FR + intense warm-up" or "FR only") in a randomized order (by picking cards). Every session started with a 5-min warm-up on a stationary bike (Monark, Ergomedic 874 E, Sweden) at 60 rev. min-1 and 60 W (Konrad et al. 2020). Before and after the interventions, a sit and reach test was conducted. Maximum voluntary isometric contraction (MVIC) peak torque and maximum voluntary dynamic contraction (MVDC) peak torque of the hamstring muscles were also recorded, along with countermovement jump (CMJ) height. A schematic schedule is presented in Figure 1.

Participants

An a priori sample size calculation (primary outcome variable: knee extension ROM) for a repeated-measures ANOVA based on data from Lee et al. (2018) (alpha = 0.05, beta = 0.8, f = 0.4) suggested a necessary group size of at least 15 participants. To be safe and to account for possible dropouts, we recruited 27 recreational to well-trained male and female soccer players (14 males; age: 23.6 ± 2.7 years; body mass: 77.8 ± 8.4 kg; height: 183. 0 ± 5.0 cm; 13 females; age: 19.3 ± 4.1 years; body mass: 57.4 ± 5.3 kg; height: 167.2 ± 4.7 cm). Prior to the study the investigator checked the participants' health status with various standardized questions. All participants confirmed that they had no current musculoskeletal pain or other orthopedic diseases in the lower extremity as well as other nonspecific musculoskeletal disorders (e.g., fibromyalgia). Especially no history of hamstring muscles injuries was reported. There was no history of surgery or other orthopedic injury in the back or lower extremities and participants confirmed that there was no neurological disorder, no metabolic disorder, and they took no medication that affects perception or proprioception. Moreover, participants were informed about the test procedure, but were naive to the hypotheses of the study. Participants or (if under 18) their legal representatives, signed a written informed consent form. Ethical approval was obtained from the Ethics Committee of the University of XX (approval code GZ. 39/68/63 ex 2020/21). The study was conducted in accordance with the Declaration of Helsinki.

Procedures

Sit and reach test

A sit and reach test was performed to assess maximal hip flexion ROM. For the test procedure, a Sit n' Reach Trunk Flexibility Box (Fabrication Enterprises; Baseline Model 12-1086, New York, USA) was used. The participant was asked to sit on the ground, with their hips flexed and knees in parallel and fully extended. The participant's feet were placed firmly against the Sit n' Reach box, with the ankle joints in a neutral position (90°). For the starting position, the participant was asked to sit upright, holding both arms parallel to the ground, in front of their trunk. The index fingers of both hands were touching each other, and the legs were completely extended and relaxed. After the starting command, the participant was asked to bend forward and push the stretch indicator on the Sit n' Reach box as far away as possible. The participant was not allowed to bend their knees or push the stretch indicator with just one hand, to minimize trunk rotation during the measurement. If any evasive movement with the legs or trunk was detected, the trial was repeated. Furthermore, the participant was asked to move slowly, to avoid triggering a reflexive muscle activation (Kubo et al., 2002). Each participant was tested three times, with a 15 s break in between the trials. The average of the three trials was taken for further analysis (Konrad et al. 2021).

Maximum Voluntary Isometric Contraction (MVIC) peak torque

The MVIC knee flexor peak torque measurements were performed using an isokinetic dynamometer (Con-Trex MJ, CMV AG, Dübendorf, Switzerland). The participant was seated on the dynamometer, with the hip and knee angle of the dominant leg (test leg) at 80° and 110° (Hatano et al. 2019), respectively. A custom-made laser device was used to align the center of rotation of the dynamometer with the anatomical knee joint axis. During the first MVIC, the participant's exact position was recorded to ensure the same positioning during all the subsequent assessments on the dynamometer. The trunk and test leg were fixed with straps, to minimize evasive movements. The lever arm fixation was set about 2 cm above the medial malleolus (Morales-Artacho et al., 2017). The participant was asked to cross their arms in front of their chest and to perform two knee flexor MVICs for 5 s each. Moreover, the participant was asked to push as hard as possible and received strong verbal encouragement during the measurements. Between the two MVICs, the participant rested for 1 min. The attempt with the highest torque value was considered for further analysis.

Maximum Voluntary Dynamic Contraction (MVDC) peak torque

The MVDCs were performed in the same position as the MVIC trials. The leg was moved in a range of 90° to 130° knee flexion for three cycles with a velocity of 60°/s. The participant was asked to stay relaxed when the leg was moved into the knee extension position, but to contract the knee flexors as hard as possible while moving into the knee flexion position. Two trials were performed, and the one with the highest peak values within the three cycles was considered for further analysis.

Countermovement Jump (CMJ) height

A mobile force platform (Quattro Jump, Kistler GmbH, Winterthur, Switzerland) with a sampling frequency of 500 Hz was used to test CMJ height. The participant was asked to get into an upright hip-wide standing position on the plate. On command, the participant was asked to make a downward movement while bending their knees and hips to a position of personal choice (Heishman et al. 2019). After reaching the individual deepest position, the participant was instructed to jump as explosively and as high as possible. The hands were held on the hips during the whole procedure, to prevent a further accelerating impulse. The participant was asked to perform two jumps. Between each attempt, a 1-min break was scheduled. The values for the jump height (in cm), as measured and generated by the Kistler software, were saved, and the highest attempt was taken for further analysis.

Foam Rolling (FR) Intervention

A foam roller (Blackroll Standard foam roll, Bottighofen, Switzerland) was used for the intervention. The same FR protocol was followed in all three groups (i.e., "intense warm-up + FR", "FR + intense warm-up", or "FR only"). The rolling was applied unilaterally for 2 min on each posterior thigh, starting with the left leg, and followed by the right leg (= test leg for MVIC and MVDC). A metronome provided auditory signals to pace the movement, and the participant was asked to reach the starting position every 4 s (every 2 s from distal to proximal and every 2 s from proximal to distal), as suggested in a previous review (Behm et al. 2020). The starting position was always proximal to the knee, and the turn point was close to the ischial tuberosity. The participant was asked to move linearly forward and backward, and to add pressure on the middle region of the thigh. The participant rolled with their own bodyweight, and was asked to put as much pressure as possible on the tissue (i.e., to the point of discomfort; 7/10 on a visual analogue scale (VAS)).

Intense warm-up intervention for the hamstring muscles

Depending on the group allocation, the FR was conducted with either an intense warm-up performed before the FR (= intense warm-up + FR), after the FR (= FR + intense warm-up), or without any intense warm-up (= FR only). To account for the time of the warm-up, a 4-min break (i.e., standing position) was conducted after the FR in the FR only group. The intense warm-up consisted of two exercises, in which each exercise was performed in three sets, with a 15-s break in between each set. The first exercise was butt kicks, which were performed as quickly as possible for 30 ground contact times, with the right and left legs alternating. For the second exercise, the participant was instructed to lie in a prone position on the floor. The investigator placed a Swiss ball on the back of the participant, at the lumbar portion of the spine, and the participant was asked to kick the Swiss ball with their heels as quickly as possible, with the right and left legs alternating (see Figure 2).

Figure 2. Swiss ball kicking exercise.

Statistical analyses

SPSS (version 26.0, SPSS Inc., Chicago, Illinois) was used for all the statistical analyses. The variables tested were the results of the sit and reach test, MVIC peak torque, MVDC peak torque, and CMJ height. To determine the inter-day reliability of all parameters, intraclass correlation coefficients (ICCs, 2-way mixed-effect model, absolute agreement definition) of the pre-values of all conditions were used. To verify the normal distribution of the variables, a Shapiro-Wilk test was used.

Table 1. Pre and post mean values (± SD) of range of motion (ROM), countermovement jump (CMJ) height, maximum voluntary isometric contraction (MVIC) peak torque, and maximum voluntary dynamic contraction (MVDC) peak torque.

	Intense warm-up + FR				FR only				FR+ intense warm-up			
	Pre		Post		Pre		Post		Pre		Post	
ROM (cm)#	33.89	± 4.85	35.83	± 4.13*	33.89	± 4.77	35.63	± 4.18*	34.00	± 5.06	36.00	± 4.12*
CMJ (cm)	43.19	± 9.43	43.66	± 9.39	43.12	± 9.37	43.56	± 9.34	42.92	± 9.18	43.21	± 8.94
MVIC (Nm)	128.36	± 38.63	129.38	± 38.86	130.17	± 38.19	134.8	± 37.29	125.03	± 33.71	127.91	± 33.01
MVDC (Nm)	135.69	± 35.14	138.53	± 35.64	137.99	± 35.15	141.64	± 33.47	134.02	± 35.23	135.09	± 33.99

FR = foam rolling. # indicates a significant time effect, as well as a significant time × sex effect. * indicates a significant difference between pre and post values.

If the data showed a normal distribution, a three-way repeated-measures ANOVA [factors: time (pre vs. post); intervention (intense warm-up + FR vs. FR + intense warm-up vs. FR only); sex (male vs. female)]. Otherwise, a Friedman test was used to test the effects of the three different interventions (intense warm-up + FR vs. FR + intense warm-up vs. FR only). If there were significant results in the ANOVA with repeated measures or the Friedman test, post hoc tests such as a paired t-test or a Wilcoxon test (with both Bonferroni corrected) was performed with the pre and post values, respectively. Moreover, to check for possible differences between the interventions, a paired t-test or Wilcoxon test (both Bonferroni corrected) was performed with the delta values (pre–post), respectively. If there were significant results for sex, a paired t-test or a Wilcoxon test (both Bonferroni corrected) was performed with the delta values (pre–post) of the respective parameters of the male and female participants. Moreover, to check for baseline differences between the sexes, either a paired t-test or a Wilcoxon test (both Bonferroni corrected) was performed. Cohen's d was calculated following the suggestions of Cohen (1988). The effect size d was defined as 0.2, 0.5, and 0.8 for a small, medium, and large effect size, respectively. The statistical power and power analysis were calculated with G*Power open-source software. The alpha level was set to 0.05.

Results

The Pre and post values (±SD) for all the groups and parameters are presented in Table 1.

Reliability of the parameters

The ICC values (and coefficient of variation) between the pre-measurements of all test days ((i.e., "intense warm-up + FR", "FR + intense warm-up", or "FR only") for ROM, CMJ, MVIC, MVDC were 0.98 (14.1 to 14.9%), 0.99 (21.4 to 21.8%), 0.97 (27.0 to 30.1%), 0.93 (25.4 to 26.3%), respectively.

Range of Motion

The three-way repeated-measures ANOVA for ROM showed a significant time effect ($F_{1,12}$ = 67.67; $P < 0.001$; r = 0.85) and a significant time × sex effect ($F_{1,12}$ = 11.56; P = 0.005; r = 0.49), but no group effect ($F_{2,11}$ = 2.34; P = 0.14; r = 0.29), no sex effect ($F_{1,12}$ = 4.37; P = 0.06; r = 0.27), no group × sex effect ($F_{2,11}$ = 1.24; P = 0.33; r = 0.18), no time × group effect ($F_{2,11}$ = 0.46; P = 0.64; r = 0.08), and no time × group × sex effect ($F_{2,11}$ = 3.16; P = 0.083; r = 0.37).

The pairwise comparison showed a significant increase in ROM, with a large magnitude of change of 5.7% (d = 1.51), 5.9% (d = 1.12), and 5.1% (d = 1.83) in the intense warm-up + FR only group, FR + intense warm-up group, and FR only group, respectively.

The delta value (pre–post) comparison of ROM between the male and female participants showed a significant difference for the FR + intense warm-up group (P<0.001; d = 1.44), but not in the intense warm-up + FR group (P = 0.24; d = 0.69), or FR only group (P = 0.45; d = 0.57) (see Figure 3).

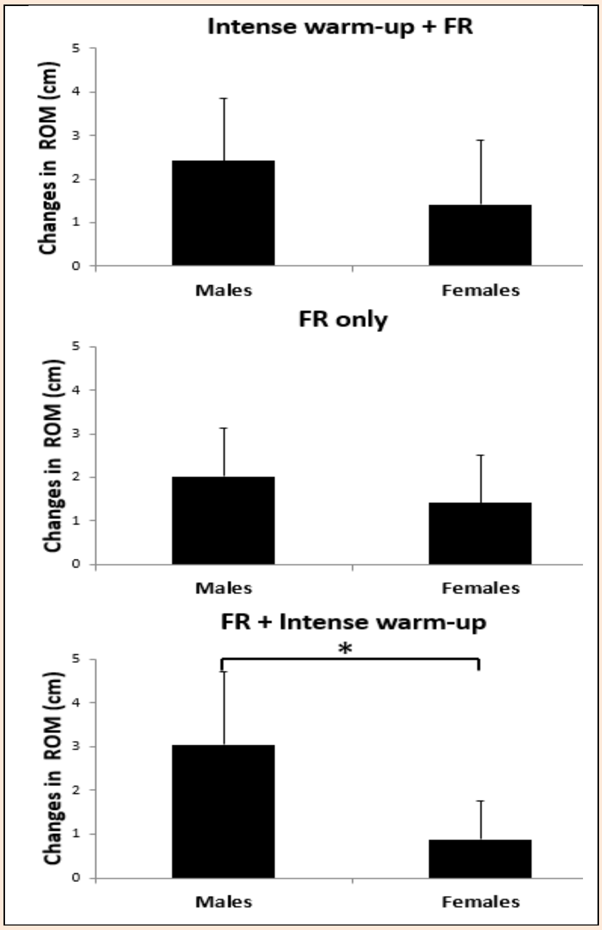

Figure 3. Changes in range of motion (ROM) presented as separate male and female participants in the respective groups. * indicates a significant difference between the male and female participants.

The baseline sex comparison showed significantly higher ROM in females compared to males, in all three conditions (see Table 2).

Table 2. Pre mean values (± SD) of the male and female participants for range of motion (ROM), countermovement jump (CMJ) height, maximum voluntary isometric contraction (MVIC) peak torque, and maximum voluntary dynamic contraction (MVDC) peak torque.

	Intense warm-up + FR				FR only				FR + intense warm-up			
	Male		Female		Male		Female		Male		Female	
ROM (cm)	31.86	± 5.32	36.08	± 3.22*	31.68	± 5.26	36.28	± 2.70*	31.46	± 5.15	36.73	± 3.33*
CMJ (cm)	51.04	± 5.07	34.73	± 3.94*	50.71	± 5.32	34.95	± 4.45*	50.28	± 5.18	34.99	± 4.71*
MVIC (Nm)	159.91	± 25.61	94.38	± 10.52*	161.19	± 24.28	96.77	± 13.76*	154.50	± 16.10	93.31	± 8.82*
MVDC (Nm)	163.66	± 22.46	105.58	± 15.32*	167.47	± 17.44	106.24	± 15.53*	159.56	± 28.06	106.52	± 16.02*

FR = foam rolling. * indicates a significant difference between the male and female participants. Please note that all the significant differences have a large magnitude of difference, with Cohen's d ranging from 0.95 to 4.66.

Countermovement jumps

The three-way repeated-measures ANOVA for CMJ height showed a significant sex effect ($F_{1,12} = 63.42$; $P < 0.001$; $r = 0.84$), but no group effect ($F_{2,11} = 0.65$; $P = 0.54$; $r = 0.11$), no time effect ($F_{1,12} = 3.78$; $P = 0.08$; $r = 0.24$), no group × sex effect ($F_{2,11} = 1.25$; $P = 0.32$; $r = 0.19$), no time × group effect ($F_{2,11} = 0.06$; $P = 0.94$; $r = 0.11$), no time × sex effect ($F_{1,12} = 0.12$; $P = 0.74$; $r = 0.01$), and no time × group × sex effect ($F_{2,11} = 0.19$; $P = 0.83$; $r = 0.03$). The baseline sex comparison showed a significantly higher CMJ height in males compared to females, in all three conditions (see Table 2).

Maximum Voluntary Isometric Contractions

The Friedman test revealed no significant effect for the MVIC peak torque ($X^2 = 9.94$; $P = 0.08$).

The baseline sex comparison showed significantly higher MVIC peak torque in males compared to females, in all three conditions (see Table 2).

Maximum Voluntary Dynamic Contractions

The Friedman test revealed no significant effect for MVIC peak torque ($X^2 = 6.63$; $P = 0.25$).

The baseline sex comparison showed significantly higher MVDC peak torque in males compared to females, in all three conditions (see Table 2).

Discussion

The purpose of this study was to compare the effects of a 2-min bout of FR of the hamstring muscles with either an intense warm-up performed before or after the FR exercise, or no intense warm-up. We measured the effect on ROM and performance parameters, i.e., CMJ height, MVIC peak torque, and MVDC peak torque. While no changes between pre and post intervention were found in any group, in CMJ height, MVIC peak torque, and MVDC peak torque, the ROM significantly increased to the same extent following the intervention in all groups (intense warm-up + FR, FR + intense warm-up, and FR only). The baseline values for the male participants showed significantly lower ROM, but higher CMJ height, MVIC peak torque, and MVDC peak torque, compared to the values for the female participants. In addition, male participants showed significantly higher increases in ROM compared to female participants following the FR + intense warm-up, but not following the intense warm-up + FR or FR only.

Increased ROM following a single bout of FR only was recently reported by a meta-analysis (Wilke et al. 2020). Moreover, according to the analysis of Wilke et al. (2020), the muscles treated in our study (i.e., hamstrings) showed the highest effect size (ES = 1.00), compared to other muscles (e.g., triceps surae ES = 0.43), for an acute increase in ROM. Such differences in the changes in ROM between joints/muscles might be explained by a more limited ROM of the ankle joint compared to the hip or knee joints, due to the bone and ligament structures (Brockett and Chapman 2016; Halperin et al. 2014). Hence, this probably limits the potential for a substantial increase in ankle joint flexibility after FR. A further subgroup analysis performed by Wilke et al. (2020) showed that there was a significant increase in studies dealing with female participants or both sexes (ES = 0.95), while only a non-significant increase was reported for male participants (ES = 0.35). Hence, we assumed that there would be higher increases of ROM in female compared to male participants, at least in the FR condition without any intense warm-up. However, our data showed no significant difference between male (+2.0 cm) and female (+1.4 cm) participants in the ROM increases following the FR only intervention (see Figure 3). Surprisingly, when an intense warm-up was included after the FR intervention, male participants showed a significantly higher increase in ROM (+3.0 cm) than female participants (+0.9 cm). In addition, although not significant (P = 0.08), male participants showed higher increases in ROM (+2.4 cm) when the intense warm-up was conducted before FR, compared to the female participants (+1.4 cm). Absolute changes in ROM were higher in males compared to females, following all interventions. Since female participants already had a significantly higher sit and reach ROM than male participants before the intervention (see Table 2), male participants likely had greater potential for an increase in ROM. Controversially, Nakamura et al. (2021b) reported no significant differences between male and female participants in ankle joint ROM increases following a single bout of FR, although females also had higher baseline ROM values than males in their study.

In addition, our results showed that all three interventions (intense warm-up + FR, FR + intense warm-up, and FR only) increased ROM similarly. This has also been reported in similar studies of stretching, both with and without post-stretching (M. Reiner et al. 2021) or pre-stretching (Takeuchi et al., 2021) warm-up activities. This indicates that it is not necessary to include further warm-up exercises, besides stretching and FR, if the goal is to acutely increase ROM.

Potential mechanism for the acute increases in ROM in all three groups in (intense warm-up + FR, FR + intense warm-up, and FR only) may be attributed to decreased muscle stiffness (Reiner et al. 2021) and/or an increased stretch tolerance (Nakamura et al., 2021) as reported following a single FR exercise. Additionally, thixotropic effects might be related to the increase in ROM following foam rolling (Behm and Wilke 2019). 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).

No significant changes in performance parameters were detected in any group when comparing pre and post values. This is in line with the current literature on single FR treatments (Cheatham et al. 2015; Nakamura et al., 2021; Wiewelhove et al. 2019). Meanwhile, studies with additional warm-up, with the goal to induce potential performance enhancement, have not been conducted to date. However, it has to be noted that studies which have combined the effects of FR with dynamic stretching (i.e., movements with a high amplitude over a full ROM) have reported either significant increases (Peacock et al. 2014) or no significant changes (Richman et al., 2019) in performance. The goal of our study, however, was to induce an activation of the target muscle (i.e., hamstrings) with quick movements, rather than slower dynamic stretching movements, throughout the whole ROM (i.e., dynamic stretching).

Although, to date, no studies have investigated the effects of an additional intense warm-up for FR, some studies of stretching, where a warm-up was performed after stretching, reported either no change or even an increase in performance (Blazevich et al. 2018; Reid et al. 2018; M. Reiner et al. 2021; Samson et al. 2012; Takeuchi et al. 2021; Takeuchi and Nakamura 2020). Samson et al. (2012) found an increase in sprint performance after the combination of stretching (static or dynamic) and intense post-stretching activities. Moreover, another study showed a favorable effect in strength and jump height following several static stretching conditions of various durations (30 s, 60 s, 120 s) with intense post-stretching activities, compared to the same stretching conditions without intense post-stretching activities (Reid et al. 2018). Even light aerobic activity (60 W for 10 min) performed after a static stretching exercise increased the subsequent torque output (Takeuchi et al., 2021). However, when the aerobic activity was performed before the stretching, a decrease in torque was reported (Takeuchi et al., 2021). Furthermore, Reiner et al. (2021) reported no change in MVIC peak torque when intense post-stretching activities were performed after a PNF stretching exercise. However, a decrease in MVIC torque was reported when PNF stretching was performed without intense post-stretching activities. Combining the present results with those from the literature on FR and stretching, it appears that an additional warm-up, especially following the intervention, is able to counteract the detrimental effects of stretching, but is not able to increase performance following FR.

A possible reason for the lack of performance potentiation after FR might be that our outcome and treatment were mainly based on the hamstring muscles. The aforementioned studies dealing with stretching and warm-up applied the intervention either on multiple muscles (e.g., Reid et al. 2018; Samson et al. 2012) or on the plantar flexors only (M. Reiner et al. 2021; Takeuchi et al. 2021; Takeuchi and Nakamura 2020). Hence, it cannot be ruled out that performance potentiation might be possible when FR is combined with an intense warm-up for some muscles (e.g., triceps surae, quadriceps), but not all muscles (e.g., hamstrings). Future studies will have to take this into account, and should investigate potential differences between the various leg muscles when an intense warm-up is added to an FR protocol.

A possible limitation of this study was that different pressures between the sessions of the FR exercise can influence the results. Thus, we have placed great value to remember the participants at every session to apply pressure until the point of discomfort imaging a 7 out of 10 visual analogue scale (VAS). However, even if there would have been slight variations between the pressures applied between the sessions within a single participant, this would have been likely cancelled out since we have chosen a randomized cross-over trial with a high sample size. Future studies should take those possible pressure variations into account by e.g., using force plates for monitoring the force applied during the foam rolling exercises.

Conclusion

In conclusion, this study was the first to investigate the effects of adding an intense warm-up (either before or after FR) on ROM and performance parameters (MVIC peak torque, MVDC peak torque, CMJ height). Although we observed an increase in ROM in all groups, no such changes could be detected in the performance parameters. Male participants showed a higher increase in ROM compared to female participants when the warm-up was performed after the FR exercise. Hence, athletes with time restrictions might skip further intense warm-up, besides FR, when the goal is to increase ROM and to sustain performance parameters.

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References

Behm, D. G. (2018) The Science and Physiology of Flexibility and Stretching. In *The Science and Physiology of Flexibility and Stretching*. https://doi.org/10.4324/9781315110745

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., Kay, A. D., Trajano, G. S. and Blazevich, A. J. (2021)

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. and Wilke, J. (2019) Do Self-Myofascial Release Devices Release Myofascia? Rolling Mechanisms: A Narrative Review. *Sports Medicine* **49**, 1173-1181. https://doi.org/10.1007/s40279-019-01149-y

Blazevich, A., Gill, N. D., Kvorning, T., Kay, A. D., Goh, A. G., Hilton, B. And Behm, D. G. (2018) No Effect of Muscle Stretching within a Full, Dynamic Warm-up on Athletic Performance. *Medicine & Science in Sports & Exercise* **50**(6), 1258-1266. https://doi.org/10.1249/MSS.0000000000001539

Brockett, C. L. and Chapman, G. J. (2016) Biomechanics of the ankle. *Orthopaedics and Trauma* **30**(3), 232-238. https://doi.org/10.1016/j.mporth.2016.04.015

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.

Cohen, J. (1988). The effect size. *Statistical Power Analysis for the Behavioral Sciences.* 77-83.

Halperin, I., Aboodarda, S. J., Button, Duane C. andersen, L. L. and Behm, D. G. (2014) Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *International Journal of Sports Physical Therapy* **9**(1), 92-102.

Hatano, G., Suzuki, S., Matsuo, S., Kataura, S., Yokoi, K., Fukaya, T. and Iwata, M. (2019) Hamstring stiffness returns more rapidly after static stretching than range of motion, stretch tolerance. and isometric peak torque. *Journal of Sport Rehabilitation* **28**(4), 325-331. https://doi.org/10.1123/jsr.2017-0203

Heishman, A., Daub, B., Miller, R., Brown, B., Freitas, E. and Bemben, M. (2019) Countermovement Jump Inter-Limb Asymmetries in Collegiate Basketball Players. *Sports* **7**(5), 103. https://doi.org/10.3390/sports7050103

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

Konrad, A., Bernsteiner, D., Budini, F., Reiner, M. M., Glashüttner, C., Berger, C. and Tilp, M. (2020) Tissue flossing of the thigh increases isometric strength acutely but has no effects on flexibility or jump height. *European Journal of Sport Science* **21**(12), 1648-1658. https://doi.org/10.1080/17461391.2020.1853818

Konrad, A., Reiner, M. M., Bernsteiner, D., Glashüttner, C., Thaller, S. and Tilp, M. (2021) Joint flexibility and isometric strength parameters are not relevant determinants for countermovement jump performance. *International Journal of Environmental Research and Public Health* **18**(5), 2510. https://doi.org/10.3390/ijerph18052510

Kubo, K., Kanehisa, H. and Fukunaga, T. (2002) Effects of resistance and stretching training programmes on the viscoelastic properties of human tendon structures in vivo. *The Journal of Physiology* **538(1)**, 219-226. https://doi.org/10.1113/jphysiol.2001.012703

Lee, C. L., Chu, I. H., Lyu, B. J., Chang, W. D. and Chang, N. J. (2018) Comparison of vibration rolling, nonvibration rolling. and static stretching as a warm-up exercise on flexibility, joint proprioception, muscle strength. and balance in young adults. *Journal of Sports Sciences* **36(22)**, 2575-2582. https://doi.org/10.1080/02640414.2018.1469848

Monteiro, E. R., Wakefield, B., Ribeiro, M. S., Fiuza, A. G., Cunha, J. C. O. W., Novaes, G. S. and Novaes, J. S. (2018) Anterior and posterior thigh self-massage and stretching acutely increases shoulder range-of-motion/Automassagem e alongamento nas regioes anterior e posterior de coxa aumentam de forma aguda a amplitude articular de ombro. *Motricidade* **14**(S1), 174-183.

Morales-Artacho, A. J., Lacourpaille, L. and Guilhem, G. (2017) Effects of warm-up on hamstring muscles stiffness: Cycling vs foam rolling. *Scandinavian Journal of Medicine and Science in Sports* **27**(12), 1959-1969. https://doi.org/10.1111/sms.12832

Nakamura, M., Konrad, A., Ryosuke, K., Sato, S., Yahata, K., Yoshida, R. and Wilke, J. (2021) Sex differences in the mechanical and neurophysiological response to roller massage of the plantar flexors. *Journal of Sports Science and Medicine* ***20*****(4)**, 665-671. https://doi.org/10.52082/jssm.2021.665

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. In *Journal of Sports Science and Medicine* **20**, 62-68. https://doi.org/10.52082/jssm.2021.62

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.

Reid, J. C., Greene, R., Young, J. D., Hodgson, D. D., Blazevich, A. J. and Behm, D. G. (2018) The effects of different durations of static stretching within a comprehensive warm-up on voluntary and evoked contractile properties. *European Journal of Applied Physiology* **118**(7), 1427-1445. https://doi.org/10.1007/s00421-018-3874-3

Reiner, M. M., Glashüttner, C., Bernsteiner, D., Tilp, M., Guilhem, G., Morales-Artacho, A. and Konrad, A. (2021) A comparison of foam rolling and vibration foam rolling on the quadriceps muscle function and mechanical properties. *European Journal of Applied Physiology* **121**(5), 1461-1471. https://doi.org/10.1007/s00421-021-04619-2

Reiner, M., Tilp, M., Guilhem, G., Morales, A., Nakamura, M. and Konrad, A. (2021) Effects of a single proprioceptive neuromuscular facilitation stretching exercise with and without post-stretching activation on the muscle function and mechanical properties of the plantar flexor muscles. *Frontiers in Physiology* **12**, 732654. https://doi.org/10.3389/fphys.2021.732654

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

Samson, M., Button, D. C., Chaouachi, A. and Behm, D. G. (2012) Effects of dynamic and static stretching within general and activity specific warm-up protocols. *Journal of Sports Science and Medicine* **11**(2), 279-285. https://pubmed.ncbi.nlm.nih.gov/24149201

Takeuchi, K. and Nakamura, M. (2020) Influence of Aerobic Exercise After Static Stretching on Flexibility and Strength in Plantar Flexor Muscles. *Frontiers in Physiology* **11**, 1604. https://doi.org/10.3389/fphys.2020.612967

Takeuchi, K., Takemura, M., Nakamura, M., Tsukuda, F. and Miyakawa, S. (2021) The effects of using a combination of static stretching and aerobic exercise on muscle tendon unit stiffness and strength in ankle plantar-flexor muscles. *European Journal of Sport Science* 1-7. https://doi.org/10.1080/17461391.2020.1866079

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

- An intense warm-up either performed before or after FR did not change performance parameters.
- The ROM increased to the same extent following the intense warm-up + FR, FR + intense warm-up, and FR only.
- Baseline values for males showed significantly lower ROM, but higher CMJ height, MVIC peak torque, and MVDC peak torque, compared to females.
- Males showed significantly higher increases in ROM following the FR + intense warm-up, but not after the intense warm-up + FR or FR only.

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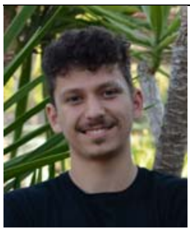

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