Journal of Athletic Training 2019;54(11):1171–1178
doi: 10.4085/1062-6050-474-18

www.natajournals.org

Jogging and Practical-Duration Foam-Rolling Exercises and Range of Motion, Proprioception, and Vertical Jump in Athletes

Natalia Romero-Franco, PhD*; Javier Romero-Franco, BSc†; Pedro Jiménez-Reyes, PhD‡

*Nursing and Physiotherapy Department, University of the Balearic Islands, Palma de Mallorca, Spain; †Unicaja Jaén Athletic Club, Spain; ‡Physical Activity and Sports Science Department, University Rey Juan Carlos, Madrid, Spain

Context: Foam-rolling exercises are frequently included in warmups due to their benefits for increasing range of motion (ROM). However, their effects on proprioception and vertical jump have not been analyzed and therefore remain unclear. Moreover, the effects of performing practical-duration foam-rolling exercises after typical warmup exercises such as jogging are unknown.

Objective: To analyze the effects of jogging and practical-duration foam-rolling exercises on the ROM, knee proprioception, and vertical jump of athletes.

Design: Randomized controlled study.

Setting: Sports laboratory and university track.

Patients or Other Participants: Thirty athletes were randomly classified into an experimental group (EG) or control group (CG).

Intervention(s): The EG performed 8-minute jogging and foam-rolling exercises. The CG performed 8-minute jogging.

Main Outcome Measure(s): Knee flexion, hip extension, active knee extension, ankle dorsiflexion (ADF), knee-joint position sense, and countermovement jump (CMJ) were evaluated before the intervention (baseline), after (post 0 min), and 10 minutes later.

Results: The EG exhibited higher values for ADF and CMJ at post 0 min (ADF: $P < .001$, d = 0.88; CMJ: $P < .001$, d = 0.52) and 10 minutes later (ADF: $P = .014$, d = 0.41; CMJ: $P = .006$, d = 0.22) compared with baseline. Although the CG also showed increased CMJ at post 0 min ($P = .044$, d = 0.21), the EG demonstrated a greater increase ($P = .021$, d = 0.97). No differences were found in the remaining ROM variables (knee flexion, hip extension, active knee extension: P values $> .05$). For knee-joint position sense, no differences were found ($P > .05$).

Conclusions: Combining jogging and practical-duration foam rolling may increase ADF and CMJ without affecting knee proprioception and hip or knee ROM. Jogging by itself may slightly increase ADF and CMJ, but the results were better and were maintained after 10 minutes when foam rolling was added.

Key Words: athletic performance, warmup exercise

Key Points

- Jogging and practical-duration foam-rolling exercises immediately improved ankle range of motion and vertical jump.
- Practical-duration foam-rolling exercises did not influence knee propriopception.

To optimize sport performance, a warmup helps athletes activate their biological and psychological potential.[1,2] Although the specific exercises, duration, and intensity may differ according to the sport modality,[3] the scientific literature[4] recommends a warmup that follows a 3-stage model: raise, activate and mobilize, and potentiate. In the raise stage, athletes engage in low-intensity activities to increase muscle temperature and, consequently, the effectiveness of peripheral mechanisms related to muscle-contraction velocity and strength.[2–4] The activate-and-mobilize stage comprises exercises involving key muscle groups to stimulate the effectiveness of the central mechanisms of neuromuscular function and muscle activation.[4] For the potentiate stage, authors[4] have considered high rates of force production and muscle-length changes at high velocity while stimulating the necessary neural pathways.

Jogging is frequently included in the raise stage, classically alongside static stretching as part of the activate-and-mobilize stage, followed by sport-specific dynamic exercises.[4] However, scientific evidence[5] of the deleterious effects of static stretching on vertical-jump performance and force output has encouraged coaches to substitute other activities. Foam rolling is an exercise that coaches are considering in place of static stretching during warmups.[6,7] The main reason is foam rolling's immediate effects on muscle extension and range of motion (ROM), which would allow it to replace static stretching without any concomitant deterioration in force production.[8]

Despite their relatively recent popularity among athletes, foam rollers and myofascial release have been used by physical therapists since the 1980s due to their immediate beneficial effects on ROM and muscle extensibility.[9] A later study[8] demonstrated these effects when bouts required more than 60 seconds. However, the results were more equivocal when only 1 bout of 60 seconds or less was performed over each region.[10–12] This aspect needs to be addressed because the average warmup time of athletes is often 20 to 40 minutes, of which athletes dedicate only 5 to 10 minutes to foam-rolling or similar exercises.[13] In fact, some researchers[8,14] found that shorter durations provided neutral effects on performance parameters, such as vertical jump and force output, whereas others found beneficial effects for performance variables such as efficiency during a lunge[12] and maximal voluntary contraction force.[15]

In this context, scientific evidence has recommended that 5 to 12 minutes of the aforementioned stages of a warmup are needed[1,4] and that athletes practice short-duration exercise protocols before training and competition.[13] Therefore, it is even more necessary to clarify the effects of foam-rolling exercises lasting less than 60 seconds.

On the other hand, the novel character of foam rolling among athletes means that its immediate effects on proprioception, as a key parameter for sports movements and injury risk, are little known. To our knowledge, the effects of traditional rolling and vibration rolling on knee-repositioning tasks in college students have been compared in only 1 recent study.[16] Knee proprioception remained unaltered after traditional foam rolling; fewer proprioceptive errors occurred after performing 3 bouts of 30-second foam-rolling exercises on the hamstrings and quadriceps.

In addition, the immediate effects of foam rolling on countermovement jump (CMJ) have been investigated as the most appropriate vertical jump for monitoring fatigue and performance,[17] due to its high reproducibility and sensitivity to detecting neuromuscular fatigue. However, while some researchers[18,19] concluded that bouts of 30 to 60 seconds of foam rolling may immediately improve CMJ, others[8,14] did not find any change after a similar protocol. Apart from the controversial effects on ROM and CMJ when the foam rolling lasts less than 60 seconds[20] and its unclear influence on proprioception, little is known about its immediate effects after jogging in a typical warmup protocol for athletes.

Therefore, the purpose of our study was to analyze the immediate effects of jogging, followed by 45-second bouts of foam-rolling exercises, on athletes' ROM, proprioception, and CMJ performance. We hypothesized that athletes who included practical-duration foam rolling after jogging would demonstrate improved proprioception, ROM, and CMJ compared with their baselines and a control group (CG).

METHODS

Participants

Thirty collegiate athletes (18 men, 12 women) between 18 and 25 years old volunteered for this study. They were randomly assigned to either the EG (n = 15: 8 men and 7 women; age = 24.1 ± 4.2 years, height = 1.77 ± 0.07 m, mass = 70.1 ± 14.2 kg) or CG (n = 15: 10 men and 5 women; age = 25.0 ± 4.7 years, height = 1.75 ± 0.08 m, mass = 67.5 ± 5.6 kg). The inclusion criteria were (1) being an athlete, (2) being *free of injury* (defined as not having incurred any physical damage resulting in the need to miss or modify 1 or more training sessions or competitions) in both the upper and lower extremities during the previous 6 months, and (3) having competed in at least a regional athletic championship. Participants were excluded if they had undergone any surgical intervention to the lower extremities. Before starting the study, all participants read and signed an informed consent form, in accordance with the Declaration of Helsinki. The study was approved by the ethics committee of the local university.

Design

We designed a randomized controlled trial with repeated measures for this study. A sample of collegiate athletes volunteered for the study; they were randomly assigned to either the experimental group (EG) or CG. Software (Epidat version 3.1; SERGAS, Galicia, Spain) was used by an external clinical assistant for the randomization process. The EG performed a warmup that included 8 minutes of jogging and practical-duration foam-rolling exercises, whereas the CG performed 8 minutes of jogging. Jogging was performed on a track at an intensity of 8 km/h. Although participants were experienced athletes who exercised at this intensity in their daily warmup, they wore a global positioning system (model Forerunner 235; Garmin Ltd, Olathe, KS) that informed them about their jogging intensity every minute.[21] Participants in each group were not told of the existence of the other group to avoid potential bias. For the same reason, participants were not informed of the true objective of the study. Before, just after, and 10 minutes after the intervention, all participants were asked to perform a modified Thomas test, a popliteal-angle test, weight-bearing ankle dorsiflexion (ADF), a knee-joint position sense test, and a maximal CMJ in randomized order. Before the study, participants were familiarized with the testing procedures and the foam-rolling exercises. The tester did not know the group to which each participant belonged because the jogging and foam rolling were performed in a separate area. All tests and jogging were carried out in the sports laboratory in May 2016, whereas foam-rolling exercises were performed on the track next to the laboratory. To avoid the need for an extended period of testing time, no more than 2 athletes at a time performed the tests or intervention. Therefore, the trials occurred at different times on different days because of scheduling restrictions.

Procedures

We collected the anthropometric characteristics of participants by using a precision digital weight scale (±200 g; model PP1220; Tefal, Rumilly, France) and an adult height scale (model t201-t4; Asimed, Barcelona, Spain) before the start of the study. All test data were recorded by an independent tester who did not know the group assignments.

Modified Thomas Test. This test was used to evaluate the hip extension (HE) and knee flexion (KF) of the *dominant lower limb* (the preferred leg for kicking a ball). A mini digital inclinometer (50 × 50 × 32 mm; Limit, Alingsas, Sweden) was placed in the middle third of the anterior thigh to measure HE and on the tibial tuberosity along the anterior tibial crest to measure KF. The reliability of this method has been reported previously.[22,23] The

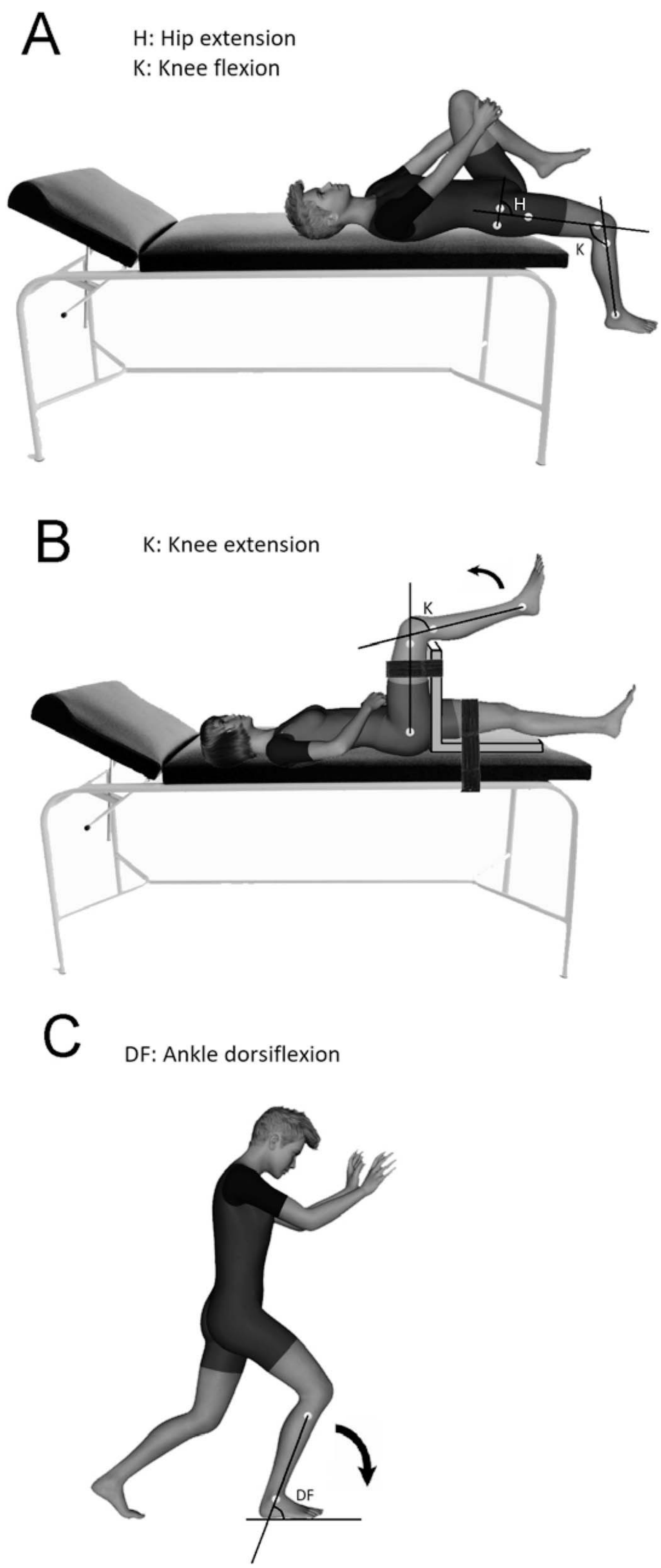

Figure 1. Evaluation of (A) hip extension and knee flexion (modified Thomas test), (B) hamstrings extensibility, and (C) ankle dorsiflexion.

variables for this test were HE and KF measured in degrees (Figure 1A).

Popliteal-Angle Test. This test was used to evaluate the knee extension (KE) of the dominant lower limb. Athletes were asked to lie supine, with the hips and knees flexed to 90°. To maintain hip flexion at 90°, they were positioned on a board designed for this purpose. The mini digital inclinometer was attached to the middle third of the leg, and the athlete was asked to extend the dominant knee. During the test, the contralateral limb was held in place by 1 belt around the thigh, just superior to the patella, and another over the anterior-superior iliac spine to avoid facilitating extension of the dominant knee by altering the pelvic-femoral angle. The foot remained in neutral position. The values provided by the inclinometer were recorded. The reliability of this method has been demonstrated.[24] The variable for this test was KE measured in degrees (Figure 1B).

Weight-Bearing Ankle Dorsiflexion. This procedure tests the ankle of the dominant lower limb. The mini digital inclinometer was placed on the tibial tuberosity along the anterior tibial crest. The angle of the tibia relative to the ground, as measured by the inclinometer, was then recorded by the tester. The reliability of this method has been shown.[25] The variable for this test was ADF measured in degrees (Figure 1C).

Joint Position Sense of the Knee. This test was carried out on the dominant knee in active leg movement (actively reaching and maintaining the knee position) and the closed kinetic chain. A mask was placed over the athletes' eyes so they could not see, and a digital inclinometer was attached to the distal third of the thigh. They were then positioned in the target joint position (40°–60° of KF) and asked to hold the position for 5 seconds and memorize the exact angle of the knee. On hearing the order "reposition," the athletes were asked to resume the target joint angle as accurately as possible and to maintain the position for 3 seconds until they were given the order to "return." The trial was repeated 3 times. The reliability of this method has been demonstrated.[26] The variables for this test were

- *Absolute angular error* (AAE): the difference between the target position and the mean of the repositioning tasks performed by the athlete without regard for the direction of the difference:

$$\begin{aligned} AAE = [&|(\text{Target Position} - \text{Trial } 1)| \\ &+|(\text{Target Position} - \text{Trial } 2)| \\ &+|(\text{Target Position} - \text{Trial } 3)|]/3 \end{aligned}$$

- *Relative angular error* (RAE): the difference between the target position and the mean of the repositioning tasks performed by the athlete, taking into account the direction of the difference and indicating whether the participant tended to underestimate or overestimate the target angle:

$$\begin{aligned} RAE = [&(\text{Target Position} - \text{Trial } 1) \\ &+(\text{Target Position} - \text{Trial } 2) \\ &+(\text{Target Position} - \text{Trial } 3)]/3 \end{aligned}$$

- *Variable angular error* (VAE): the standard deviation (SD) of errors, providing information on the consistency with which the participant performed the different trials:

$$\begin{aligned}VAE = SD(&\text{Target Position} - \text{Trial 1}),\\ &(\text{Target Position} - \text{Trial 2}),\\ &(\text{Target Position} - \text{Trial 3})\end{aligned}$$

Countermovement Jump. Athletes performed a maximal CMJ from an initial upright position with hands on the waist and a countermovement in which the knees were bent to 90°. When jumping, the knees had to be extended up to 180° without flexing the hips. Participants performed 3 trial jumps, and the highest score was recorded. We used the iPhone application My Jump (Carlos Balsalobre, Madrid, Spain), whose validity and reliability have been reported earlier.[27] The variable for this test was CMJ height measured in centimeters.

Foam-Rolling Exercise Protocol. Participants in the EG were asked to move the foam roller over the following regions: posterior thigh, from the popliteal fossa to the ischial tuberosity; anterior thigh, from the anterior-superior iliac spine to the quadriceps tendon; and calf, from the popliteal fossa to the Achilles tendon (Figure 2). Participants applied one 45-second bout of foam rolling to each region and both legs (with 15 seconds of rest between legs). Thus, the entire protocol lasted about 6 minutes. A 15- × 45-cm foam roller (Adidas AG, Herzogenaurach, Germany) was used.

Statistical Analyses

Means and SDs were recorded for all variables. A Kolmogorov-Smirnov test indicated that the quantitative values were normally distributed. For the between-groups and within-group differences, we used a mixed model with linear procedures because we had designed a repeated-measures study with unequal intervals between measurements. We analyzed within-subject differences (time of measurement with 3 levels: before [baseline], immediately after the intervention [post 0 minutes], and 10 minutes after the intervention [post 10 minutes]) and between-subjects differences (intervention with 2 levels: CG and EG). The effect size was calculated using the Cohen coefficient (d) and interpreted as follows: $d \geq 0.8$, *large*; $0.8 > d > 0.2$, *moderate*; or $d \leq 0.2$, *small*.[28] For the calculations, SPSS (version 20; IBM Corp, Armonk, NY) for Windows was used. Statistical significance was set at $P < .05$ and confidence intervals (CIs) at 95%.

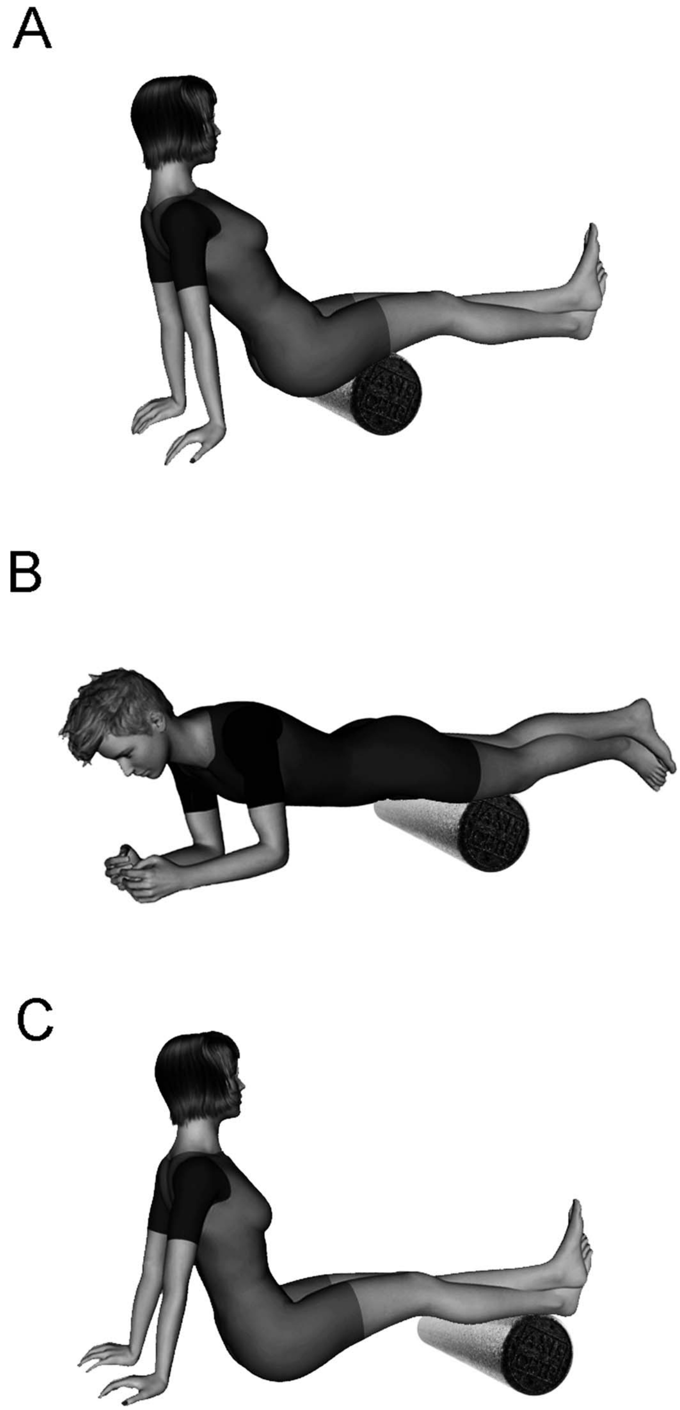

Figure 2. Foam-rolling exercises applied to the (A) hamstrings, (B) anterior thigh, and (C) calf region.

RESULTS

Range of Motion

The ROM data for the ankle, knee, and hip joints before the intervention and at post 0 and post 10 minutes are presented in Table 1. The mixed-model linear analysis revealed a group × time interaction for ADF ($F = 3.181$, $P = .049$), in which increases from baseline were higher in the EG than the CG group ($P = .023$, $d = 0.96$). Within-group differences revealed that ADF in the EG at post 0 and post 10 minutes was greater than baseline ($P < .001$, $d = 0.88$, and $P = .014$, $d = 0.41$, respectively). A main time effect was found for HE during the modified Thomas test ($F = 9.680$, $P < .001$): both the EG and CG displayed increased HE at post 0 and post 10 minutes compared with their baseline values ($P = .008$ and $P = .017$, respectively). A main group effect occurred for KF during the modified Thomas test ($F = 3.933$, $P = .050$), such that the EG exhibited higher KF values than the CG ($P = .032$). The remaining variables showed no significant interactions (P values $> .05$).

Proprioception

The proprioception data before the intervention and at post 0 and post 10 minutes are provided in Table 2. No

Table 1. Range-of-Motion Tests

Test, ° Group	Baseline, Mean ± SD	Postintervention Mean ± SD	Postintervention Within-Group Change Score From Baseline[a]	Postintervention Between-Groups Difference in Change Score[a]	10 Minutes Later Mean ± SD	10 Minutes Later Within-Group Change Score From Baseline[a]	10 Minutes Later Between-Groups Difference in Change Score[a]
Ankle dorsiflexion[b]							
Experimental	39.8 ± 5.5	46.1 ± 7.9	6.3[c] (3.4, 9.0)	1.7 (−7.3, 4.0)	43.0 ± 7.5	3.2[d] (0.6, 5.9)	0.0 (−6.0, 6.0)
Control	42.9 ± 4.4	44.4 ± 5.8	1.5 (−1.4, 4.6)		43.0 ± 6.5	0.1 (−3.8, 4.2)	
Popliteal angle: knee extension							
Experimental	34.5 ± 12.3	28.9 ± 14.3	−5.6 (−11.9, 0.6)	4.7 (−5.1, 14.5)	35.8 ± 15.4	1.3 (−5.7, 8.3)	1.2 (−10.0, 12.4)
Control	31.8 ± 15.4	33.6 ± 8.6	1.8 (−7.1, 10.8)		37.0 ± 12.0	5.2 (−1.1, 11.5)	
Thomas: hip extension[e]							
Experimental	17.2 ± 9.9	22.7 ± 6.5	−5.5[d] (−1.3, −9.7)	3.8 (−3.7, 11.2)	21.9 ± 6.2	−4.7[d] (−8.5, −0.9)	3.9 (−3.6, 11.3)
Control	14.7 ± 10.9	18.9 ± 13.1	−4.1[f] (−6.9, −1.4)		18.0 ± 13.3	−3.3[d] (−6.1, −0.4)	
Thomas: knee flexion[g]							
Experimental	20.5 ± 6.8	18.1 ± 8.6	−2.4[d] (−4.8, 0.0)	4.2[d] (−5.8, 14.2)	19.6 ± 9.3	−0.9 (−4.8, 3.0)	2.1 (−15.5, 11.2)
Control	24.5 ± 3.9	26.1 ± 5.7	1.6 (−2.5, 5.7)		21.3 ± 6.9	−3.2 (−8.6, 2.4)	

[a] Values are given as mean (95% confidence interval).
[b] Significant group-by-time interaction.
[c] $P < .001$.
[d] $P < .05$.
[e] Significant main time effect.
[f] $P < .01$.
[g] Significant main group effect.

differences were found for proprioceptive errors (AAE, RAE, and VAE: P values $> .05$).

Countermovement Jump

The CMJ values are given in Table 3. The mixed-model linear analysis revealed group × time interactions for CMJ ($F = 3.166$, $P = .050$), in which the EG showed greater increases from baseline to post 0 minutes compared with the CG ($P = .021$, d = 0.97). Within-group differences indicated that the EG's CMJ was higher at post 0 and post 10 minutes compared with baseline ($P < .001$, d = 0.52, and $P = .006$, d = 0.22, respectively), whereas the CG exhibited increased CMJ at post 0 minutes compared with baseline ($P = .044$, d = 0.21).

DISCUSSION

As we hypothesized, our main finding was that jogging followed by practical-duration foam-rolling exercises as part of a warmup may increase ADF and maximal CMJ. However, contrary to our hypothesis, foam rolling did not affect knee proprioception or knee or hip ROM. Although athletes who performed jogging showed improvements in ADF and CMJ, the results were better and maintained for at least 10 minutes only when foam rolling was added. It is important to highlight that jogging, whether followed by foam rolling or not, helped to increase hip ROM. In this way, our protocol would include jogging as the raise stage of the warmup proposed by previous authors[1] and foam-rolling exercises in the activate-and-mobilize stage.[4] The

Table 2. Knee Proprioception

Error, ° Group	Baseline, Mean ± SD	Postintervention Mean ± SD	Postintervention Within-Group Change Score From Baseline[a]	Postintervention Between-Groups Difference in Change Score[a]	10 Minutes Later Mean ± SD	10 Minutes Later Within-Group Change Score From Baseline[a]	10 Minutes Later Between-Groups Difference in Change Score[a]
Absolute angular							
Experimental	2.3 ± 1.6	1.1 ± 0.9	−1.2 (−2.1, −0.3)	1.4 (−0.2, 3.0)	1.5 ± 2.7	−0.8 (−2.0, 0.3)	1.0 (−0.5, 2.5)
Control	3.2 ± 1.5	2.5 ± 3.2	−0.7 (−2.8, 1.4)		2.5 ± 1.3	−0.7 (−2.3, 0.9)	
Relative angular							
Experimental	1.2 ± 2.6	0.4 ± 1.4	−0.8 (−2.2, 0.5)	0.3 (−2.5, 1.8)	0.2 ± 2.0	−1.0 (−2.9, 0.9)	1.3 (−3.4, 0.8)
Control	−2.0 ± 2.9	0.1 ± 4.1	2.0 (−0.6, 4.6)		−1.1 ± 3.95	0.8 (−1.7, 3.3)	
Variable angular[b]							
Experimental group	1.3 ± 0.7	1.0 ± 0.6	−0.3 (−0.7, 0.2)	0.0 (−0.6, 4.0)	1.9 ± 1.0	0.6[c] (−0.1, 1.0)	1.2[d] (0.6, 1.7)
Control group	1.7 ± 0.6	1.0 ± 0.7	−0.7[c] (−1.2, −0.2)		0.8 ± 0.5	−1.1 (−0.5, 1.0)	

[a] Values are given as mean (95% confidence interval).
[b] Significant group-by-time interaction.
[c] $P < .05$.
[d] $P < .01$.

Table 3. Vertical (Countermovement) Jump

Height, cm[a] Group	Baseline, Mean ± SD	Postintervention Mean ± SD	Postintervention Within-Group Change Score From Baseline[b]	Postintervention Between-Groups Difference in Change Score[b]	10 Minutes Later Mean ± SD	10 Minutes Later Within-Group Change Score From Baseline[b]	10 Minutes Later Between-Groups Difference in Change Score[b]
Experimental	31.6 ± 7.7	35.6 ± 8.0	4.0[c] (3.1, 4.9)	0.8 (−5.9, 7.4)	33.3 ± 8.1	1.7[d] (0.6, 2.9)	2.7 (−3.7, 8.9)
Control	34.4 ± 10.4	36.4 ± 9.1	1.9[e] (0.1, 3.8)		35.9 ± 7.7	1.5 (−0.9, 3.8)	

[a] Values are given as mean (95% confidence interval).
[b] Significant group-by-time interaction.
[c] $P < .001$.
[d] $P < .01$.
[e] $P < .05$.

practical-duration foam-rolling protocol we used resembles many athletic warmups.[3]

Among the ROM variables, the ADF results are especially relevant because of their role in lower extremity biomechanics and the injury risk in athletes. Previous researchers[29] showed that athletes with limited ADF often displayed external rotation of the talus near maximal dorsiflexion, which suggests a medially limited gliding motion of the talocrural joint. This limited movement may reduce bony conformity during maximal dorsiflexion, which can result in a higher risk of inversion ankle sprain. Halperin et al[15] reported improved ADF 10 minutes after three 30-second bouts of foam rolling to the calf region (at a cadence of 1 second), which is similar to 1 exercise in our protocol. In contrast, Skarabot et al[30] found no improvement in ADF after a similar intervention (ie, three 30-second bouts of foam rolling to the calf region). An important difference between the studies is that Skarabot et al[30] did not require participants to perform any warmup activity before the foam-rolling exercises, whereas Halperin et al[15] included 10 single-legged heel raises as a warmup. In our study, jogging followed by 45-second bouts of foam-rolling exercises helped to increase ADF before training and may consequently reduce the risk of injury. However, the preventive role of foam rolling is unclear and requires prospective studies for confirmation.

With regard to the modified Thomas test, we found increased HE in both the EG and CG. This may have been a direct result of the jogging that both groups performed. Jogging would certainly increase muscle temperature and, in turn, muscle viscosity, improving the extensibility of the hip flexors and thus HE. Consistent with our results, Bushell et al found immediate benefits in HE after three 60-second bouts of foam rolling to the anterior thigh.[31] Similarly, Vigotsky et al[32] analyzed the effects of two 60-second bouts on the anterior thigh and reported a slight increase in HE. The main differences in our study were the jogging and the shorter duration of the foam-rolling exercises (45-second bouts).

Knee flexion was also assessed using the modified Thomas test. It improved only in the EG, suggesting that the improvement was specific to the foam-rolling exercises. The fascial release could influence the extensibility of the knee extensors more than jogging alone. In agreement with our findings, Bradbury-Squires et al[12] found 10% and 16% increased knee ROM after five 20-second and five 60-second bouts, respectively, of foam rolling to the anterior thigh. In contrast, Vigotsky et al[32] reported no difference in KF after two 60-second bouts of foam rolling to the anterior thigh. Although our protocol included only one 45-second bout of foam rolling to the anterior thigh, this was compounded by similar exercises for the calf and hamstrings regions, which may have directly influenced the knee joint and its ROM.

The popliteal-angle test appeared to indicate that jogging and foam-rolling exercises were insufficient to increase active KE. This may have been due largely to the active nature of this test, which requires muscle activation of the knee extensors and extensibility of the knee flexors. Yet these structures are mostly passive during foam-rolling exercises. Similar results were found by Couture et al, who described no effects on hamstrings extensibility using a popliteal-angle test after several 10- and 30-second bouts of hamstrings foam rolling.[10]

For the proprioception variables, no differences in AAE, RAE, or VAE were exhibited after jogging or combined with practical-duration foam rolling. To our knowledge, only 1 group[16] has evaluated knee-joint position sense after foam-rolling exercises. The authors compared the effects of 30-second bouts of traditional foam rolling with vibration foam rolling to the hamstrings and quadriceps of young adults. Consistent with our results, proprioceptive errors did not change from baseline after foam-rolling exercises. Researchers[33,34] who considered the effects of physical activity on proprioception often concluded that active exercises, such as a dynamic warmup, may improve proprioceptive acuity. Foam rolling is a passive intervention, and the duration of jogging in our study was short, which might explain the lack of improvement in these variables.

Finally, regarding CMJ, both groups improved their maximal height, indicating the influence of jogging on this variable agreed with that in previous studies. However, the results were higher for those athletes who also performed practical-duration foam-rolling exercises. In contrast to our findings, other investigators who evaluated CMJ found neutral effects after foam rolling, which is traditionally considered an appropriate substitute for static stretching; the latter tends to cause deterioration in force output variables such as CMJ height. Our results are important because foam rolling may help to improve CMJ performance, contrary to the detrimental effects frequently demonstrated after static stretching. However, future work is needed to establish this.

Our study had certain limitations. First, all of our participants were healthy athletes. Future investigations are needed to analyze the effects on injured athletes and identify possible differences during the rehabilitation process. Moreover, we considered a follow up of only 10 minutes after the foam-rolling exercises because that is a frequent transition time between the warmup and the main part of the training session. Yet it would be interesting to evaluate the effects 20 or 30 minutes or even longer after the foam-rolling protocol because the time between warmup and the start of a major competition can be more than 10 minutes in many sports.[35,36] Also, the time to take all the measurements could have influenced the results. For this reason, the order of tests was always randomized. In addition, our sample size was small; because of the unknown effects of foam-rolling exercises and the time needed to perform them before the training sessions, some athletes chose not to participate. Furthermore, our eligibility criteria required that participants had no injuries in the previous 6 months, thereby reducing the number of athletes who could participate.[37] Future authors should include longer-duration foam-rolling programs (ie, several weeks) to investigate medium- and long-term effects and follow up to describe their possible influence on injury risk. Different durations of foam rolling should be considered in future studies.

CONCLUSIONS

A foam-rolling protocol comprising 45-second bouts to the hamstrings, quadriceps, and calf regions after 8 minutes of jogging may increase ADF and CMJ without affecting knee ROM and proprioception. Although jogging alone may also increase ankle ROM and CMJ performance, these benefits were maintained 10 minutes later only when foam rolling was conducted. Jogging, whether followed by foam rolling or not, also helped to improve the hip ROM of collegiate athletes.

Sports and health professionals should include foam-rolling exercise after jogging in their training sessions because of the beneficial effects on important variables such as ADF, which is an important factor in sports biomechanics and injury risk, and CMJ, which is a useful method of monitoring sports performance and neuromuscular fatigue. Foam rolling may be an important part of the warmup before a training session or competition.

ACKNOWLEDGMENTS

We thank the athletes and coaches from Unicaja Jaén Athletic Club who volunteered their time and effort for this study.

REFERENCES

1. McGowan CJ, Pyne DB, Thompson KG, Rattray B. Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Med*. 2015;45(11):1523–1546.
2. Skof B, Strojnik V. The effect of two warm-up protocols on some biomechanical parameters of the neuromuscular system of middle distance runners. *J Strength Cond Res*. 2007;21(2):394–399.
3. Bishop D. Warm up II: performance changes following active warm up and how to structure the warm up. *Sports Med*. 2003;33(7):483–498.
4. Racinais S, Cocking S, Périard JD. Sports and environmental temperature: from warming-up to heating-up. *Temperature (Austin)*. 2017;4(3):227–257.
5. Winchester JB, Nelson AG, Landin D, Young MA, Schexnayder IC. Static stretching impairs sprint performance in collegiate track and field athletes. *J Strength Cond Res*. 2008;22(1):13–19.
6. Cheatham SW, Kolber MJ, Cain M, Lee M. 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. *Int J Sports Phys Ther*. 2015;10(6):827–838.
7. Schroeder AN, Best TM. Is self myofascial release an effective preexercise and recovery strategy? A literature review. *Curr Sports Med Rep*. 2015;14(3):200–208.
8. MacDonald GZ, Penney MD, Mullaley ME, et al. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res*. 2013;27(3):812–821.
9. Hanten WP, Chandler SD. Effects of myofascial release leg pull and sagittal plane isometric contract-relax techniques on passive straight-leg raise angle. *J Orthop Sports Phys Ther*. 1994;20(3):138–144.
10. Couture G, Karlik D, Glass SC, Hatzel BM. The effect of foam rolling duration on hamstring range of motion. *Open Orthop J*. 2015;9:450–455.
11. Junker DH, Stöggl TL. The foam roll as a tool to improve hamstring flexibility. *J Strength Cond Res*. 2015;29(12):3480–3485.
12. Bradbury-Squires DJ, Noftall JC, Sullivan KM, Behm DG, Power KE, Button DC. Roller-massager application to the quadriceps and knee-joint range of motion and neuromuscular efficiency during a lunge. *J Athl Train*. 2015;50(2):133–140.
13. Cheatham SW. Roller massage: a descriptive survey of allied health professionals. *J Sport Rehabil*. 2018:1–10.
14. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, Riebe D. The effects of myofascial release with foam rolling on performance. *J Strength Cond Res*. 2014;28(1):61–68.
15. Halperin I, Aboodarda SJ, Button DC, Andersen LL, Behm DG. Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *Int J Sports Phys Ther*. 2014;9(1):92–102.
16. Lee CL, Chu IH, Lyu BJ, Chang WD, Chang NJ. 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. *J Sports Sci*. 2018:36(22):2575–2582.
17. Jiménez-Reyes P, Pareja-Blanco F, Cuadrado-Peñafiel V, Ortega-Becerra M, Párraga J, González-Badillo JJ. Jump height loss as an indicator of fatigue during sprint training. *J Sports Sci*. 2018;37(9):1029–1037.
18. Giovanelli N, Vaccari F, Floreani M, et al. Short-term effects of rolling massage on energy cost of running and power of the lower limbs. *Int J Sports Physiol Perform*. 2018;13(10):1337–1343.
19. Peacock CA, Krein DD, Silver TA, Sanders GJ, Von Carlowitz KA. An acute bout of self-myofascial release in the form of foam rolling improves performance testing. *Int J Exerc Sci*. 2014;7(3):202–211.
20. Beardsley C, Škarabot J. Effects of self-myofascial release: a systematic review. *J Bodyw Mov Ther*. 2015;19(4):747–758.
21. Karboviak RJ. Using GPS technology to monitor intensity, speed, and training volume in outdoor athletes. *Strength Cond J*. 2005;27(2):24–25.
22. Clapis PA, Davis SM, Davis RO. Reliability of inclinometer and goniometric measurements of hip extension flexibility using the modified Thomas test. *Physiother Theory Pract*. 2008;24(2):135–141.
23. Ferber R, Kendall KD, McElroy L. Normative and critical criteria for iliotibial band and iliopsoas muscle flexibility. *J Athl Train*. 2010;45(4):344–348.
24. Gabbe BJ, Bennell KL, Wajswelner H, Finch CF. Reliability of common lower extremity musculoskeletal screening tests. *Phys Ther Sport*. 2004;5(2):90–97.
25. Konor MM, Morton S, Eckerson JM, Grindstaff TL. Reliability of three measures of ankle dorsiflexion range of motion. *Int J Sports Phys Ther*. 2012;7(3):279–287.

26. Romero-Franco N, Montaño-Munuera JA, Jiménez-Reyes P. Validity and reliability of a digital inclinometer to assess knee joint position sense in a closed kinetic chain. *J Sport Rehabil*. 2017;26(1):jsr.2015-0138.
27. Balsalobre-Fernández C, Glaister M, Lockey RA. The validity and reliability of an iPhone app for measuring vertical jump performance. *J Sports Sci*. 2015;33(15):1574–1579.
28. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. New York, NY: Taylor & Francis; 2013.
29. Kobayashi T, Yoshida M, Yoshida M, Gamada K. Intrinsic predictive factors of noncontact lateral ankle sprain in collegiate athletes: a case-control study. *Orthop J Sports Med*. 2013;1(7):2325967113518163.
30. Škarabot J, Beardsley C, Štirn I. Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. *Int J Sports Phys Ther*. 2015;10(2):203–212.
31. Bushell JE, Dawson SM, Webster MM. Clinical relevance of foam rolling on hip extension angle in a functional lunge position. *J Strength Cond Res*. 2015;29(9):2397–2403.
32. Vigotsky AD, Lehman GJ, Contreras B, Beardsley C, Chung B, Feser EH. Acute effects of anterior thigh foam rolling on hip angle, knee angle, and rectus femoris length in the modified Thomas test. *PeerJ*. 2015;3:e1281.
33. Romero-Franco N, Jiménez-Reyes P. Effects of warm-up and fatigue on knee joint position sense and jump performance. *J Mot Behav*. 2017:49(2):117–122.
34. Magalhães T, Ribeiro F, Pinheiro A, Oliveira J. Warming-up before sporting activity improves knee position sense. *Phys Ther Sport*. 2010;11(3):86–90.
35. Ingham SA, Fudge BW, Pringle JS, Jones AM. Improvement of 800-m running performance with prior high-intensity exercise. *Int J Sports Physiol Perform*. 2013;8(1):77–83.
36. Sanchez X, Boschker MS, Llewellyn DJ. Pre-performance psychological states and performance in an elite climbing competition. *Scand J Med Sci Sports*. 2010;20(2):356–363.
37. Kolt GS, Kirkby RJ. Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. *Br J Sports Med*. 1999;33(5):312–318.

Address correspondence to Natalia Romero-Franco, PhD, Nursing and Physiotherapy Department, University of the Balearic Islands, Road to Valldemossa, km 7.5, E-07122, Palma de Mallorca, Spain. Address e-mail to narf52@gmail.com.