

Comparison of Different Foam Rolling Protocols on Ankle Range of Motion, Strength, Muscle Activation, and Jump Performance

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ABSTRACT

Background: Foam rolling (FR) has been widely used as a means of acutely increasing range of motion (ROM) before strength and power activities. Presently, few studies have compared the effect of different FR intensities on changes in flexibility and neuromuscular function. **Purpose:** The aim was to compare the acute effect of different protocols of FR in the ankle range of motion, muscle strength, muscle activation, and jump performance. **Methods:** Ten recreationally trained male (28±4 years, 175±5 cm, 81±13 kg) and ten female (29±4 years, 163±5 cm, 66±10 kg) performed two sessions of data collection that compared four different protocols of FR: unilateral smooth roller (US), bilateral smooth roller (BS), unilateral grid roller (UG), and bilateral grid roller (BG). During all protocols, the triceps surae was rolled for 2 sets of 60 s with 60 s of rest between sets. Rating of perceived pain (RPP) after the rolling protocol; peak force (PF) during a maximal voluntary isometric contraction (MVIC), muscle activation during a MVIC, and single-leg drop jump (SLDJ) performance were measured before and after each condition. **Results:** The greatest RPP was reported in UG condition and the lowest RPP was reported in BS condition. All conditions increased ankle ROM to a similar extent without subsequent effect on PF, muscle activity, and SLDJ height. UG condition

caused an increase on SLDJ contact time. Our data indicate that FR using different combinations of surface pattern and rolling techniques increased ankle ROM without a subsequent effect on drop jump performance, triceps surae strength, and activation. **Conclusion:** In conclusion, practitioners could be encouraged to perform FR with mild discomfort and use a bilateral technique to save time.

Keywords: Flexibility, self-myofascial release, electromyography, force.

INTRODUCTION

Foam rolling (FR) has been widely used in the athletic community with the aim of increasing range of motion (ROM) before sports practices, especially strength and power activities [1-6]. It is likely that the pressure applied during the technique causes mechanical changes in the musculotendinous unit (MTU) and neurophysiological alterations to muscle tone that subsequently increases ROM without impairing strength and power performance [1-4].

The level of pressure/intensity during FR may be practically controlled by the roller surface [7, 8], the foam density [9, 10], and the technique employed (i.e., bilateral or unilateral weight-bearing over the

foam roller). Although the type of the roller may affect the exerted pressure [10], Cheatham et al. [9] reported similar increases to knee ROM and quadriceps pressure pain threshold (PPT) after performing a bout of rolling using soft, medium, and high-density foam rollers. However, in a subsequent study, Cheatham et al. [7] reported that a grid and a multilevel surface roller caused greater increases to knee ROM and quadriceps PPT compared to a smooth surface roller. It is suggested that the nodules on the grid roller simulate the thumbs of a masseuse and thus cause a deeper tissue deformation [8]. Another practical strategy to manipulate the pressure while performing FR is to perform the movement unilaterally (rather than bilaterally) over the roller. Performing the exercises unilaterally instead of bilaterally would increase the exerted pressure by simultaneously increasing the force and decreasing the contact area with the massaged muscle.

To the authors' knowledge, there are a limited number of studies investigating the effect of rolling pressure/intensity on ROM [7-11], and only one study has investigated the effects on strength, muscle activation, and jump performance [11]. Grabow et al. [11] compared the effects of low, moderate, and high roller massage forces on ROM, strength, and jump parameters. The forces exerted during the rolling protocol corresponded to 50, 70, and 90% of subjects' maximum rate of perceived pain. All intensities increased active and passive knee ROM without impairing knee flexion and extension peak force, force at 200 ms, drop jump height, and drop jump contact time. One important observation in the study by Grabow et al. [11] is that the intensity was precisely controlled by a custom device specially designed to exert constant force during the roller massage. Despite this approach increase the internal validity of the study, this may not be a practical and accessible approach to manipulate foam rolling intensity/pressure.

Therefore, the present study aimed to compare the acute effect of different protocols of FR in the ankle range of motion, muscle strength, muscle activation, and jump performance. Specifically, we compared four combinations of roller surface pattern (smooth roller, and grid roller) and rolling technique (unilateral, and bilateral). Based on the current literature [7-11], it was hypothesized that all FR protocols would increase ankle ROM, but the greater increase might occur by using the grid roller. However, it was not expected that significant changes would be observed in isometric peak force, triceps surae activation, and drop jump performance.

METHODS

Experimental approach to the problem

This quasi-randomized-cross-over study was conducted in three sessions that were each separated by 48-72 hours. In the first session, participants' anthropometric data were collected and familiarization with the experimental procedures was conducted. Specifically, the same procedures conducted in the second and third sessions of data collection were performed. The only difference occurred in the FR protocol; each one of the 2 sets of 60" were performed with a different foam roller. If the FR technique was not considered satisfactory additional sets were performed. The second and third sessions started with a warm-up on a cycle ergometer (5 minutes at 70-80 W with self-selected cadence) and were used to compare effects of four conditions of FR massage of the triceps surae on passive ankle range of motion; jump height and contact time during a single-leg drop jump; peak force and electromyographic activity (gastrocnemius lateralis and soleus) during a maximal voluntary isometric contraction (Figure 1). The conditions were as follows: unilateral smooth roller (US), bilateral smooth roller (BS), unilateral grid roller (UG), and bilateral grid roller (BG) (Figure 2B-E). The type of roller was randomized and counterbalanced across participants in the second and third sessions, however, the unilateral condition was always performed first and separated by 30 min to the bilateral condition to maintain the volume of rolling massage constant between conditions and to avoid any contralateral effect in the tested leg [12].

Participants

A convenience sample of twenty recreationally resistance-trained participants (10 males, 28±4 years, 175±5 cm, 81±13 kg, and 10 females, 29±4 years, 163±5 cm, 66±10 kg) were recruited to participate in this study. All participants had experience in resistance training for at least 1 year (minimum 3 sessions/week) but did not report to use FR regularly in the training routine. Moreover, participants were free from any existing musculoskeletal disorders; history of injury (with residual symptoms of pain, or feeling weakness) in the trunk and lower limbs within the last year. The participants were informed of the risks and benefits of the study before any data collection and then read and signed an institutionally approved informed consent document (Research Ethics Committee of the Nove de Julho University – São Paulo, Brazil

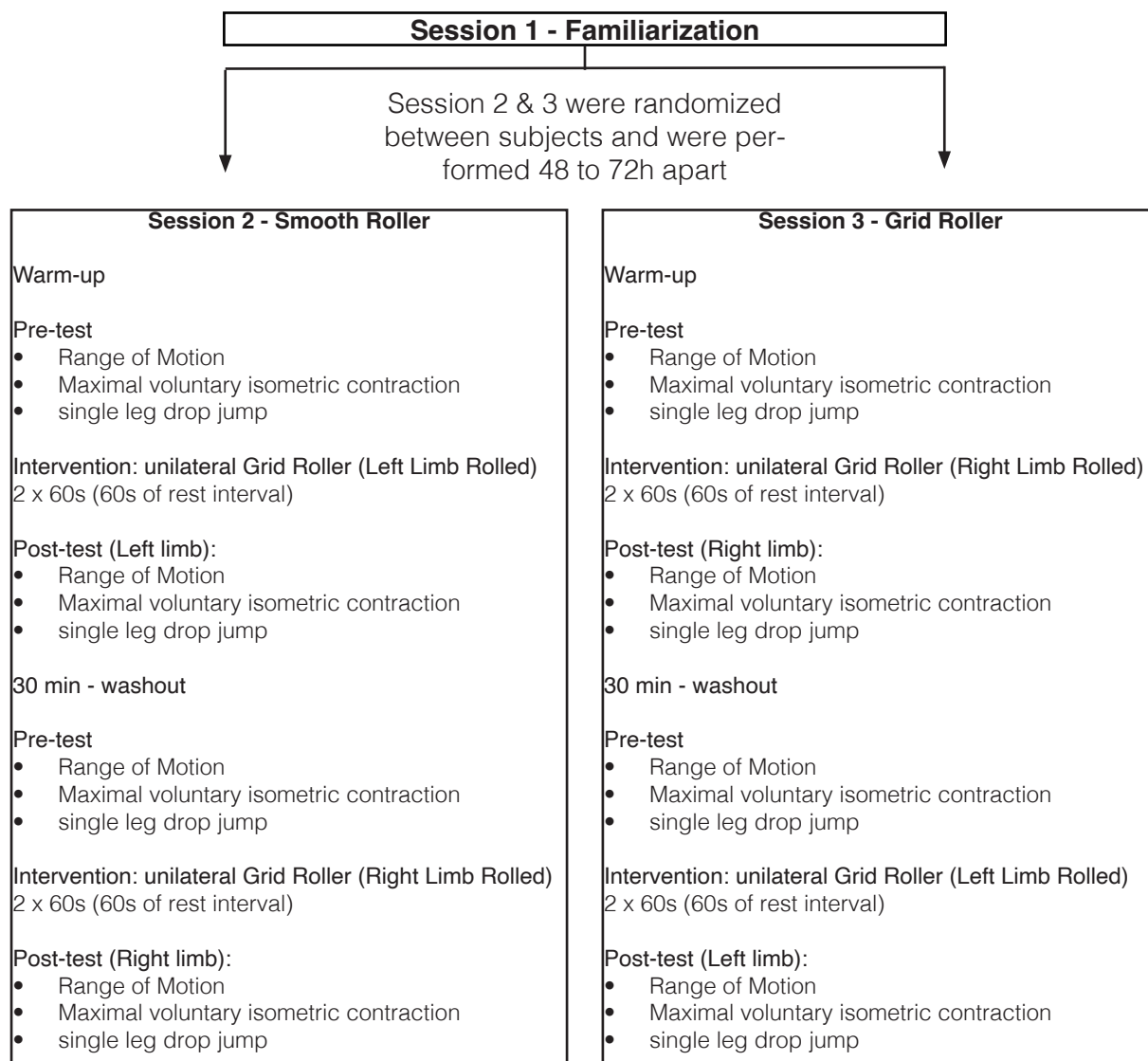


Figure 1. Experimental design. ROM – range of motion, MVIC – maximal voluntary isometric contraction, SLDJ – single-leg drop jump.

- Protocol #2.551.060). All procedures were in accordance with the Declaration of Helsinki.

Rolling protocol

Two types of rollers were used in this study: Smooth Roller (Six Plus Brazil, Model: Foam roller PRO 30, Dimensions: 30x15x15cm) and Grid Roller (Proaction Brasil, Model: Deep relief, Dimensions: 36x10x10cm) (Figure 2A). Participants rolled from the popliteal fossa to the calcaneus tendon in 3 stages of 20 s (proximal, medial, and distal regions of the triceps surae). Two sets of 60 s of rolling massage separated by 60 s of passive rest were performed. The cadence of rolling was self-determined but participants were instructed to support as much weight as possible on the roller.

Rating of perceived pain (RPP)

Subjects were asked to report the perceived pain immediately after each rolling protocol, based on an imaginary scale of 0 to 10, where 0 represents no discomfort/pain at all, and 10 represents the maximum tolerable discomfort/pain.

Ankle Range of Motion (ROM)

The weight-bearing lunge test was used to access the ankle dorsiflexion ROM following the recommendations of Konor et al. [13]. Briefly, participants stood barefoot with hands placed on the wall shoulder-width apart. They were instructed to lunge forward until the patella touched the wall. The feet started 10 cm from the wall and the participant was instructed to progressively move away until they were unable to touch the wall without raising the heel from the ground. The dorsiflexion ROM

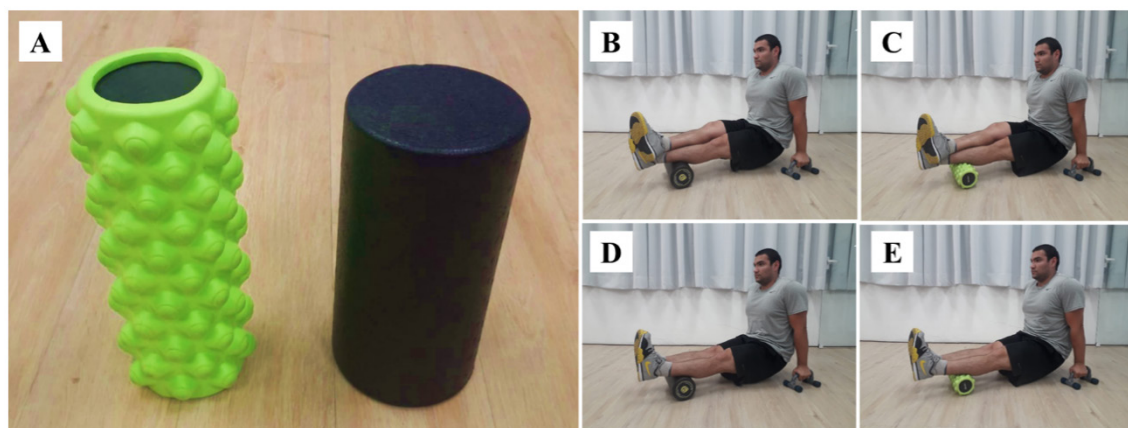


Figure 2. Grid roller (left) and smooth roller (right) (A), unilateral smooth roller (B), unilateral grid roller (C), bilateral smooth roller (D), and bilateral grid roller (E).

was measured using a smartphone (Samsung J6) placed at the tibial tuberosity by using the mobile application Climometer + Bubble Level (Plain Code, Inc.). Three trials, separated by 1 min, for each condition/moment were performed and the mean value was used in statistical analysis. The test-retest intraclass correlation coefficient (ICC) assessed in the familiarization session was 0.989.

Maximal Voluntary Isometric Contraction (MVIC)

Participants were placed on a seated calf raise device (Portico Brazil, Model: BD1009) with the knee and ankle joint of the tested limb flexed at 90 degrees. A load cell sampling at 2000 Hz (EMG832C, EMG system Brazil, Brazil) was fixed to the weight support of the seated calf raise device. To avoid extraneous movement of the upper body, participants were instructed to keep their arms crossed in front of the chest. Participants were instructed to produce force as quickly as possible and sustain a MVIC for 5 s. Strong verbal encouragement was given during the MVIC. Three trials separated by 1 min of rest interval were performed. Force-time data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). Force-time data were low-pass filtered at 10 Hz using a fourth-order Butterworth filter with a zero lag, then, the peak force (PF) was defined as the highest value in the range of 1-4 s. PF was quantified in kilogram-force (kgf). The mean value of three MVIC trials was used in further analysis. The test-retest intraclass correlation coefficient (ICC) assessed in the familiarization session was 0.981.

Integrated Electromyography (iEMG)

Surface electromyographic (sEMG) signals were recorded from the gastrocnemius lateralis and soleus during the MVIC test. Participants' skin was

prepared before placement of the sEMG electrodes. Hair at the site of electrode placement was shaved, abraded, and the skin was cleaned with alcohol. Bipolar active disposable dual Ag/AgCl snap electrodes were used which were 1-cm in diameter for each circular conductive area with 2-cm center-to-center spacing. Electrode placement was oriented accordingly to Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guidelines [14]. For the gastrocnemius lateralis, the pair of electrodes were placed at one third distance from the head of the fibula and the Achilles tendon insertion, oriented in the direction of the line between the head of the fibula and the Achilles tendon insertion. For the soleus, the pair of electrodes were placed at two-thirds distance between the medial condyle of the femur to the medial malleolus, oriented in the direction of the line between the medial condyle to the medial malleolus. A ground electrode was placed on the right-side clavicle. The electrode placement was marked with semi-permanent ink to avoid differences in electrode placement between sessions. The sEMG signals were recorded by an electromyographic acquisition system (EMG832C, EMG system Brazil, Brazil) with a sampling rate of 2000 Hz using a commercially designed software program (EMG System Brazil, São José dos Campos, Brazil). sEMG activity was amplified (bipolar differential amplifier, input impedance = 2M Ω , common-mode rejection ratio > 100 dB min (60 Hz), gain \times 20, noise > 5 μ V), and analog-to-digital converted (12 bit). sEMG data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). The digitized sEMG data were processed according to the following order: the sEMG was band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time-domain analysis, RMS (200 ms moving window) was calculated in the range of 1-4 s to avoid effects of body adjustments and

3.62]; BS vs. UG: $p < 0.001$, 95% CI [1.73, 5.36]). The UG condition caused greater RPP than the other conditions (UG vs. US: $p = 0.007$, 95% CI [0.44, 3.45]; UG vs. BG: $p < 0.001$, 95% CI [0.77, 2.51]). There was no significant difference between US and BG conditions ($p = 1.000$, 95% CI [-1.78, 1.18]).

Range of Motion (ROM)

The repeated measures ANOVA revealed a significant effect of time ($F_{1,19} = 41.412$, $p < 0.001$, $\eta^2_p = 0.728$) but not condition*time ($F_{1,773,33.687} = 0.324$, $p = 0.699$, $\eta^2_p = 0.017$) on ROM. The ROM increased from pre to post-test in BS condition ($p = 0.004$, 95% CI [0.41, 1.93]), US condition ($p < 0.001$, 95% CI [0.82, 1.57]), BG condition ($p = 0.034$, 95% CI [0.07, 1.68]), and UG condition ($p = 0.029$, 95% CI [0.09, 1.54]) (Table 1).

Peak Force (PF)

The repeated measures ANOVA revealed no significant effect of time ($F_{1,19} = 4.618$, $p = 0.065$, $\eta^2_p = 0.196$) and condition*time ($F_{3,57} = 0.424$, $p = 0.737$, $\eta^2_p = 0.196$) on PF (Table 1).

Integrated Electromyography (iEMG)

The repeated measures ANOVA revealed no significant effect of time ($F_{1,19} = 0.222$, $p = 0.643$, $\eta^2_p = 0.012$) nor condition*time ($F_{3,57} = 0.830$, $p = 0.483$, $\eta^2_p = 0.042$) on gastrocnemius lateralis IEMG. Additionally, the repeated measures ANOVA revealed no significant effect of time ($F_{1,19} = 0.998$, $p = 0.330$, $\eta^2_p = 0.050$) and condition*time ($F_{3,57} = 0.435$, $p = 0.615$, $\eta^2_p = 0.022$) on soleus IEMG (Table 1).

Single-leg drop jump (SLDJ)

The repeated measures ANOVA revealed no significant effect of time ($F_{1,19} = 3.249$, $p = 0.090$, $\eta^2_p = 0.144$) and condition*time ($F_{1,19} = 0.880$, $p = 0.457$, $\eta^2_p = 0.044$) on jump height. The repeated measures ANOVA revealed a significant effect of time ($F_{1,19} = 7.585$, $p = 0.013$, $\eta^2_p = 0.285$) but not condition*time ($F_{3,57} = 1.214$, $p = 0.313$, $\eta^2_p = 0.060$) on contact time. Post-hoc analysis revealed that contact time increased from pre- to post-test in UG condition only ($p = 0.018$, 95% CI [4.71, 44.92]) (Table 1).

DISCUSSION

The aim of the present study was to compare the acute effect of different protocols of FR in the ankle range of motion, muscle strength, muscle activation, and jump performance. Specifically, we compared four combinations of roller surface pattern (smooth roller, and grid roller) and rolling technique (unilateral, and bilateral). Despite the differences in the rate of perceived pain (GU > GB ≈ SU > SB), all conditions similarly increased the ankle ROM without a subsequent effect in peak force, muscle activation, and jump height.

Ankle ROM increased to a similar extent (~1°) after all rolling conditions despite the differences in rolling technique, surface pattern, and the rate of perceived pain. Previous studies have also reported a small but significant increase in ankle ROM following bouts of FR [12, 15-17] and roller massager [18]. Apparently, the triceps surae muscle is less susceptible to the acute effects of FR [19]. The meta-analysis by Wilk et al. [19] observed stronger effect of FR of the hamstrings in comparison to the triceps surae muscles in joint-specific tests of ROM. The above-mentioned studies [12, 15, 18] reported mean increases on ROM in the weight bearing lunge that ranged from 0.4 cm to 1.2 cm. Such increase can be considered small/trivial to the healthy population but might be considered clinically relevant to individuals with limited ankle ROM (e.g., while squatting) [20] and in a rehabilitation setting.

Furthermore, the increase in ROM appears to be similar when different intensities of roller massager [11] and different densities of the foam roller are used [9]. Grabow et al. [11] used a custom-made device to constantly apply pressure during the roller massager. They observed a similar increase in knee ROM (kneeling lunge test) after three sets of 60 s of roller massage of the quadriceps at intensities corresponding to $3.9/10 \pm 0.64$ (low), $6.2/10 \pm 0.64$ (moderate), and $8.2/10 \pm 0.44$ (high) of subjects' RPP. Additionally, they observed small correlations between subjects' RPP and the increase in ROM ($0.29 < r < 0.321$). Cheatham and Stull [9] observed a similar increase in knee ROM (prone knee flexion test) after two minutes of foam rolling of the quadriceps with three different density type foam rollers (soft, medium, and hard). However, in the following study using similar procedures (rolling time and ROM test) Cheatham and Stull [7] observed a greater increase in knee ROM when rolling was performed with a grid (+5.9°) and a multilevel (+5.5°) foam roller than a smooth roller (+2.9°). On the contrary, the present

Table 1. Mean \pm SD of the measurements. US - unilateral smooth roller, BS - bilateral smooth roller, UG - unilateral grid roller, and BG - bilateral grid roller.

Variables	Pre-Test	Post-Test	MD (95% CI)	Time p	Time*Group p
Range of motion (°)					
BS	50 \pm 6	51 \pm 6*	1.1 (0.411-1.932)	>0.001	0.699
US	50 \pm 7	51 \pm 8*	1.1 (0.820-1.577)	0.004	
BG	50 \pm 7	51 \pm 7*	0.9 (0.074-1.683)	0.034	
UG	50 \pm 6	51 \pm 7*	0.8 (0.96-1.547)	0.029	
Peak force (kgf)					
BS	36.2 \pm 13.5	35.8 \pm 13.3	0.35 (-1.896-1.194)	0.640	0.737
US	35.2 \pm 12.5	33.5 \pm 12.3	1.72 (-0.192-3.634)	0.075	
BG	38.1 \pm 14.6	37.3 \pm 15.4	0.73 (-1.023-2.487)	0.393	
UG	36.5 \pm 12.6	35.7 \pm 12.5	0.78 (-1.323-2.890)	0.446	
Gastrocnemius lateralis IEMG (V.s)					
BS	0.75 \pm 0.26	0.76 \pm 0.27	0.009 (-0.041-0.022)	0.546	0.483
US	0.67 \pm 0.21	0.65 \pm 0.22	0.016 (-0.023-0.055)	0.397	
BG	0.71 \pm 0.23	0.71 \pm 0.25	0.002 (-0.033-0.029)	0.906	
UG	0.72 \pm 0.27	0.74 \pm 0.29	0.020 (-0.055-0.015)	0.252	
Soleus IEMG (V.s)					
BS	0.62 \pm 0.19	0.65 \pm 0.31	0.030 (-0.114-0.055)	0.470	0.615
US	0.65 \pm 0.24	0.69 \pm 0.36	0.044 (-0.117-0.089)	0.498	
BG	0.66 \pm 0.26	0.64 \pm 0.27	0.016 (-0.019-0.051)	0.345	
UG	0.59 \pm 0.20	0.61 \pm 0.20	0.019 (0.037-0.002)	0.340	
Single-leg drop jump height (cm)					
BS	13.0 \pm 5.7	12.5 \pm 4.9	0.49 (-0.100-1.083)	0.098	0.457
US	11.8 \pm 4.4	11.8 \pm 4.3	0.13 (-0.562-0.589)	0.962	
BG	12.2 \pm 5.4	11.8 \pm 5.3	0.39 (-0.085-0.872)	0.102	
UG	12.2 \pm 4.2	11.9 \pm 4.0	0.24 (-0.668-0.185)	0.250	
Single-leg drop jump contact time (ms)					
BS	383 \pm 82	399 \pm 77	15 (-2.549-33.082)	0.089	0.313
US	375 \pm 73	385 \pm 66	9 (-5.520-23.753)	0.208	
BG	383 \pm 97	392 \pm 89	8 (-4.743-21.337)	0.198	
UG	369 \pm 78	394 \pm 88*	24 (4.713-44.921)	0.018	

* Significant difference from pre to post-test ($p < 0.05$).

study observed a similar increase in the ROM irrespective of the type of surface of the foam roller. Collectively, the present and the previous studies indicate that ROM increases following a bout of foam rolling or roller massager, however, the manipulation of rolling intensity by different strategies (i.e., rolling force, roller density, and roller surface) needs to be further investigated.

The acute increase in the ROM following a bout of foam rolling is typically explained by a combination of mechanical and neurophysiological mechanisms [2-5, 21]. At first, foam rolling was described in the literature as a practice of 'self-myofascial release' [5,

15, 21-23]. Previous studies have observed a decrease in musculotendinous unit (MTU) stiffness [24, 25] and elastic modulus [26]. For example, Chang et al. [25] observed an increase in ankle dorsiflexion ROM and a decrease in stiffness of gastrocnemius-achilles tendon complex following a similar rolling protocol (3 sets of 1 min of unilateral FR with grid surface) to the present study. On the other hand, other studies indicate that the MTU stiffness [27] and the fascicle length of the MTU remains unaffected [28] following a bout of FR. Therefore, it is possible that the term 'self-myofascial release' is misleading [2]. A more accepted explanation for the acute increase in ROM after a bout of foam rolling is a global increase

in stretch/pain tolerance combined with a global reduction in muscle tone [2-4].

None of the FR techniques used in the present study affected drop jump height, plantar flexion peak force, and triceps surae activation. The only difference observed in the present study was an increase on drop jump contact time after UG condition. However, there were no significant differences within conditions at the same time point neither effect of UG condition on jump height. The results are similar to previous studies that observed no meaningful changes in measures of strength, muscle activation, and jump performance following a bout of foam rolling [1, 6, 8, 29, 30]. Jones et al. [29], Baumgart et al. [31], and Smith et al. [32] did not observe changes in countermovement jump performance following one, two, and three sets of 30 s of FR to the major lower limb muscles, respectively. Behara and Jacobson [8], found no significant difference in peak and average isometric leg extension torque following 1 min of FR for the hamstrings, quadriceps, gluteus, and hamstrings. MacDonald et al., [33] found no significant difference in peak isometric leg extension force, rate of force development, and rectus femoris activity following 2 sets of 1 min of FR for the quadriceps. Finally, similarly to the findings of the present study, Grabow et al. [11] also observed no impairments in strength and jump performances after three sets of 60 s of FR massage at different levels of pain perception. On the other hand, FR may decrease strength endurance when performed between sets of resistance training. Monteiro and Corrêa Neto [34] observed a decrease in the maximum number of repetitions performed on seated knee extension machine when FR were performed between sets. FR may therefore exert a greater influence on strength endurance tasks such as repetitions to failure than single maximal tasks such as MVIC and jumps. This hypothesis needs further examination.

The generalization of the findings from the present study must account for its main limitations and delimitations. There is a possibility of a non-local/cross-over effect of the unilateral condition in the outcome of the bilateral condition [12, 16, 31, 35]. However, the quasi-randomized-cross-over design was selected to reduce the time and cost of the study [36]; additionally, the "washout" period of 30-min was deemed to be sufficient considering that the cross-over effect of FR in the ROM of the contralateral limb apparently dissipate within 10-15 min [12]. People of different ages, health conditions, and training levels may respond differently than the ones that composed our sample (healthy, resistance-trained

adults). Finally, the sEMG assessment, the isometric tests, and the SLDJ were performed at specific anatomical points, and joint positions, and drop heights. Possibly the results would diverge if different electrode locations were selected or different joint positions and drop heights were tested.

CONCLUSION

In conclusion, FR using different combinations of surface pattern and rolling techniques increase ankle ROM to a similar extent without a subsequent effect on drop jump performance, triceps surae strength, and activation. Therefore, it is reasonable to encourage practitioners to perform FR bilaterally and with a smooth roller to decrease discomfort and to save time.

FUTURE RECOMMENDATIONS

Future studies may examine the prolonged and chronic effects of FR (rather than immediately after FR) on ROM, strength, and power performance. Furthermore, it would be interesting to investigate the effects of different combinations of volume and intensity of FR (e.g., greater intensity with a lower duration of FR and vice versa).

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