Impact of 10-Minute Interval Roller Massage on Performance and Active Range of Motion

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ABSTRACT

Hodgson, DD, Quigley, PJ, Whitten, JHD, Reid, JC, and Behm, DG. Impact of 10-minute interval roller massage on performance and active range of motion. J Strength Cond Res 33(6): 1512–1523, 2019—Roller massage (RM) has been shown to increase range of motion (ROM) without subsequent performance deficits. However, prolonged static stretching (SS) can induce performance impairments. The objective of this study was to examine the effects of combining SS and RM with and without subsequent RM on ROM and neuromuscular performance. Subjects (n = 12) participated in 5 sessions: (a) SS only (SS_rest), (b) SS + RM (SS + RM_rest), (c) SS with RM at 10 and 20 minutes after stretch (SS + RM), (d) SS + RM with RM at 10 and 20 minutes after stretch (SS + RM_RM), and (e) control. For the SS conditions, the quadriceps and hamstrings received passive SS for 2 × 30 seconds each. For the SS + RM conditions, SS was applied to the quadriceps and hamstrings for 30 seconds each, and RM was performed for 30 seconds per muscle. SS_RM and SS + RM_RM conditions received an additional 30-second RM at 10 and 20 minutes after warm-up, whereas sessions without additional RM rested for the same duration. Testing measures included hip flexion (HF) and knee flexion (KF) active and passive ROM, hurdle jump height, and contact time, countermovement jump height, and maximal voluntary isometric contraction force. Initial KF and HF ROM improvements provided by SS_RM and SS + RM_RM were sustained up to 30 minutes after intervention. Furthermore, SS_RM exhibited greater ROM compared with sessions lacking additional RM in active and passive HF as well as active and passive KF. Similarly, SS + RM_RM elicited greater KF and HF ROM improvements than SS_rest. In conclusion, active KF and HF ROM improvements after 3 minutes of both FR and SS (23.6%) than...
3 minutes of either on their own (FR: 6.9%; SS: 12.3%). Similar findings were reported by Škarabot et al. (39), who elicited greater ankle dorsiflexion ROM improvements with 90 seconds of both FR and SS (9.1%) than 90 seconds of either on their own (FR: no change; SS: 6.2%). In both studies, the total volume was doubled for the combined intervention, and neither study monitored changes in performance. Thus, it remains unknown how combining FR/RM and SS affects ROM and neuromuscular performance compared with the same volume of either intervention alone.

Further research is required to determine whether adding RM to a relatively short-duration stretching routine would augment stretch-induced ROM improvements. Furthermore, it is not known whether performing RM at intervals after the stretching routine would prolong the ROM increases. Maintaining improved ROM after a warm-up would benefit athletes such as basketball, soccer, and football players who substitute into the game from the bench. Prolonged rest periods may cause the positive effects of their warm-up to deteriorate, subjecting these athletes to a greater risk of injury and less than optimal performance. Hence, the first objective of this study was to compare similar volumes of an SS-only routine to a combined SS and RM protocol. A second objective was to examine the effects of adding additional RM at 10-minute intervals to the aforementioned routines on ROM and neuromuscular performance measures. It was hypothesized that combining SS and RM would provide similar ROM improvements as the same total volume of SS alone and that these enhancements would remain more evident after 30 minutes when additional RM was incorporated compared with sessions instead involving a rest period. Neuromuscular performance measures were not hypothesized to be affected by SS or by the inclusion of RM.

METHODS

Experimental Approach to the Problem

This research used a within-subject, repeated-measures design during which subjects completed 5 testing conditions on separate days, in a randomized order (Table 1). Experimental conditions included (a) SS only (SS_rest), (b) SS and RM (SS + RM_rest), (c) SS with additional RM after 10 and 20 minutes (SS_RM), (d) SS and RM with additional RM after 10 and 20 minutes (SS + RM_RM), and (e) control. Testing measures were performed before, as well as immediately, 10, 20, and 30 minutes after intervention (before additional RM in the SS_RM and SS + RM_RM conditions) and included hurdle jumps, countermovement jump (CMJ), and active (aROM) and passive (pROM) hip and knee flexion (KF) ROM in that order. Knee flexion and extension maximal voluntary isometric contractions (MVIC) were also measured after all other tests before, immediately after intervention, and 30 minutes after intervention. Each round of testing took approximately 2.5 minutes when MVICs were not included (post-10 and post-20), or 4.5 minutes when MVICs were included (pre, post, and post-30). Post-10 and post-20 measurements during sessions with additional RM lasted approximately 5 minutes (including the RM). After post, post-10, and post-20 measurements, the subject then rested in a comfortable seated position for the remainder of each 10-minute segment.

Subjects

A previous statistical power analysis to determine sample size was conducted based on similar studies (1,5,37) measuring ROM and MVIC force. Based on this analysis, it was determined that between 4 and 30 subjects would be needed to achieve an alpha level of 0.05 and a statistical power of 0.8. Thus, 12 volunteers, including 7 men (27 years, 180.6 cm, and 89.8 kg) and 5 women (26 years, 165.3 cm, and 60.8 kg) from the university population, were recruited to participate in this study. Subjects were between the ages of 18 and 30 years, reported to be recreationally trained (participate in physical activity ≥3 times wk⁻¹), and had no neurological conditions or history of lower-body injury during the past 6 months. Subject characteristics were measured mean ± SD. Subjects signed a consent form approved by the Health Research Ethics Authority at Memorial University of Newfoundland (file no. 20170222), in addition to completing the Physical Activity Readiness Questionnaire (Canadian Society for Exercise Physiology 2011). Before any testing session, subjects were asked to avoid vigorous physical activity and refrain from alcohol consumption for 24 hours. All testing sessions were completed, with consistent temperate conditions within the laboratory (−22° C; 35% relative humidity).

Procedures

All subjects completed a dynamic warm-up on a cycle ergometer (Ergomedic 828E; Monark, St. Eustache, Quebec, Canada) at 60–70 rpm with a resistance of 1 kp (70 W) for 5 minutes. After pretest measurements, subjects completed 1 of 5 additional warm-up protocols,
selected randomly by rolling a standard 6-sided dice until a session number (1–5) was rolled which the subject had not yet completed.

All warm-up interventions other than control included SS of the hamstrings and quadriceps. The SS condition only involved SS with no RM either in conjunction with or subsequent to the stretching. Hamstring stretches were performed with the subject lying supine with both knees fully extended. The researcher then passively raised 1 limb to increase the ROM until the subject indicated that the POD had been reached. The quadriiceps stretch was performed with the subject in a lounge position with the front limb fixed at 90° HF, KF, and ankle flexion. The rear hip was extended as far as possible with the knee resting on a foam pad. A metal frame was provided to hang onto for stability. The researcher then flexed the knee joint, raising the rear foot, until the POD was reached. Subjects were asked to provide feedback during all stretches, allowing the researcher to adapt to changes in the POD. All stretches were held for 2 repetitions of 30 seconds in a randomized order for the hamstrings and quadriceps of each limb. This duration is supported by recent reviews, suggesting that SS ≤60 seconds per muscle group can be performed before activity without compromising neuromuscular performance (4,26).

Two interventions included both SS and RM of the hamstrings and quadriiceps during the warm-up (SS + RM rest and SS + RM RM). The previously described SS protocol preceded the RM protocol except with only 1.
rather than two 30-second SS bouts per muscle group. Roller massage was then performed passively by the researcher using the Roller Massager by TheraBand, a portable rolling device wrapped with dense ridged foam. With 1 set of SS and RM each in the combined conditions (SS + RM_rest and SS + RM_RM), the intervention volume durations were equal (60 seconds) in all experimental conditions. Subjects were positioned prone (for hamstring RM) or seated on the edge of a chair (for quadriceps RM) with their knees fully extended while RM was applied over the full length of the intended muscles, without crossing any joint. All RM was performed for 1 repetition of 30 seconds per muscle group (to match the total volume of the SS-only conditions) in a randomized order to a cadence of 60 b·min⁻¹. This cadence allowed 1 full cycle to be completed every 2 seconds (1 second from distal to proximal, 1 second returning from proximal to distal). The researcher applied pressure eliciting a perceived pain of 7/10 on the visual analog scale (VAS-10) as indicated by the subject.

Two conditions applied additional RM after SS only (SS_RM) and SS and RM (SS + RM_RM) at 10 and 20 minutes after intervention. This interval was selected to ensure that a sufficient rest period would be provided after each round of testing and additional RM. These supplementary bouts were performed by the researcher as previously described, for 30 seconds per muscle group at 60 b·min⁻¹, and were always performed after the completion of other tests and measurements.

The control condition consisted of a 5-minute rest period between pretest and posttest measurements and then proceeded with additional measurements at 10, 20, and 30 minutes with no SS or RM at any point.

Countermovement Jump. A Vertec measuring device was used to assess CMJ height (Vertec; Sports Imports, Hilliard, OH, USA). The height of the device was adjusted until the fingertips of the subject’s dominant arm extended overhead and brushed against the bottom vane. Subjects were instructed to leap vertically from a 2-foot stance as high as possible, reaching with 1 arm to slap the Vertec at their peak. Although no steps were permitted before the leap, it was acceptable for subjects to squat (countermovement without pausing at the bottom) and swing their arms during the movement, thus making the task as natural as possible. The highest vane displaced (measured in ½'' intervals) was counted as their CMJ height.

Hurdle Jump. The hurdle jump is a modified version of the test first described by Cavanaugh et al. (8). The test requires the subject’s maximum CMJ height to be established. This was measured immediately after the dynamic warm-up at the beginning of each testing session using a Vertec measuring device while subjects performed 2 CMJs, the better of which was used. A hurdle was then set to 75% of the maximum value and placed 6'' away from a force plate.

### Table 3. Condition × time interactions with range of motion (ROM) significantly increased over pretest values at 30 minutes.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hip flexion active ROM</th>
<th>Hip flexion passive ROM</th>
<th>Knee flexion active ROM</th>
<th>Knee flexion passive ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS_RM</td>
<td>$p = 0.001$, ES: 0.344, 6.5%</td>
<td>$p = 0.001$, ES: 0.470, 9.2%</td>
<td>$p = 0.002$, ES: 0.792, 7.7%</td>
<td>$p = 0.002$, ES: 0.608, 10.8%</td>
</tr>
<tr>
<td>SS + RM_RM</td>
<td>$p = 0.001$, ES: 0.316, 7.9%</td>
<td>$p = 0.001$, ES: 0.453, 8.9%</td>
<td>$p = 0.003$, ES: 0.792, 9.9%</td>
<td>$p = 0.009$, ES: 0.394, 6.2%</td>
</tr>
<tr>
<td>SS_rest</td>
<td>$p = 0.008$, ES: 0.344, 6.7%</td>
<td>$p = 0.001$, ES: 0.470, 9.2%</td>
<td>$p = 0.003$, ES: 0.608, 10.8%</td>
<td>$p = 0.001$, ES: 0.470, 9.2%</td>
</tr>
<tr>
<td>SS + RM_rest</td>
<td>$p = 0.001$, ES: 0.316, 7.9%</td>
<td>$p = 0.001$, ES: 0.453, 8.9%</td>
<td>$p = 0.003$, ES: 0.792, 9.9%</td>
<td>$p = 0.009$, ES: 0.394, 6.2%</td>
</tr>
</tbody>
</table>

*RM = roller massage; ROM = range of motion; SS = static stretching; ES = effect size.
†Additional rolling increased ROM for both passive and active measures, whereas the lack of additional rolling only increased passive ROM measures.
The hurdle jump required subjects to leap over the hurdle starting with a 2-foot stance from a distance of 6, land with both feet on the force plate, and immediately launch into a vertical CMJ, landing again on the force plate. Subjects were instructed to perform the task as quickly as possible while leaping as high as possible. Vertical jump height and contact time were assessed using force plate analysis. A sampling rate of 2,000 Hz and a gain of 1,000 were used for force plate data.

Range of Motion. Active and passive hip flexor ROM was measured using a large protractor designed on the wall of the laboratory. Subjects were positioned supine on the floor against the wall with their hip joint placed against the center of the protractor. During the initial measurement, tape was placed on the floor marking the heel position to ensure consistent positioning of the subject during subsequent measurements. All measurements were taken from the dominant limb while the nondominant hip and knee were held securely on the floor. For aROM, the subject was asked to raise their leg as far as possible without bending their knee. For pROM, the researcher passively raised the subject’s leg, maintaining neutral ankle flexion and a fully extended knee, until the end of the ROM was indicated by the subject. The maximum angle of HF achieved was recorded. Active and passive KF ROM was measured for the dominant limb with the subject placed in a lunge position as described in the SS protocol. Measurements were recorded using a handheld goniometer while the subject (aROM) or the researcher (pROM) raised the rear foot to the end of the ROM (16,36).

Maximal Voluntary Isometric Contraction. To perform MVICs, subjects were seated on the edge of a table with a backrest and a handle on either side. Their torso and upper legs were strapped securely in place, and the ankle of their dominant leg was inserted into a padded strap attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (LCCS 250; Omega Engineering, Inc.). The knee joint angle was fixed at 120° for KF and 90° for knee extension MVICs. Subjects were instructed to rapidly flex (KF) or extend (knee extension) their knee joint to achieve maximal force as quickly as possible. Each attempt was held for 3–5 seconds once an appropriate plateau in force was observed by the researcher. The greater of 2 attempts was accepted during pretesting, whereas 1 attempt was performed at post and 30 minutes after intervention. Data collected with the strain gauge were sampled at 2,000 Hz, amplified (DA 100, and analog to digital converter MP100WSW; Biopac Systems, Inc.), and analyzed using a commercially designed software program (Acq-Knowledge III; Biopac Systems, Inc.). Strain gauge data were used to measure peak force (PF) and the F100 (force generated in the first 100 ms of the contraction).

Table 4. Table illustrates between condition × time effects with additional rolling (top row) that had significantly greater ROM than those without additional rolling (first column) with the identified measures at 20 and 30 minutes after test.*

<table>
<thead>
<tr>
<th>ROM measures (N = 12)</th>
<th>SS_RM (post-20 min)</th>
<th>SS + RM_RM (post-30 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active hip flexion SS_rest</td>
<td>p = 0.055, ES: 0.146, 2.4%</td>
<td>p = 0.004, ES: 0.218, 3.4%</td>
</tr>
<tr>
<td>Passive hip flexion SS_rest</td>
<td>p = 0.017, ES: 0.152, 2.4%</td>
<td>p = 0.004, ES: 0.152, 2.4%</td>
</tr>
<tr>
<td>Active knee flexion SS + RM_rest</td>
<td>p = 0.003, ES: 1.04, 16.8%</td>
<td>p = 0.003, ES: 1.04, 16.8%</td>
</tr>
<tr>
<td>Passive knee flexion SS + RM_rest</td>
<td>p = 0.011, ES: 1.26, 16.8%</td>
<td>p = 0.011, ES: 1.26, 16.8%</td>
</tr>
</tbody>
</table>
| *RM = roller massage; SS = static stretching; ES = effect size.
Statistical Analyses

Statistical analyses were computed using SPSS software (version 22.0; SPSS, Inc., Chicago, IL, USA). Dependent variables underwent assumption of normality (Shapiro-Wilk test) and sphericity (Mauchly’s test), and if violated, the corrected value for nonsphericity with Greenhouse-Geisser Epsilon was reported. A 2-way analysis of variance (ANOVA) was conducted (5 x 5) to determine the existence of significant differences between the 4 warm-up conditions and the control condition (SS_rest, SS + RM_rest, SS_RM, SS + RM_RM, and control) and the 5 time periods (pre, post, 10-post, 20-post, and 30-post). To determine whether adding RM to SS augmented ROM immediately after the warm-up, the 2 conditions using SS only (SS_rest and SS_RM) were combined and compared with conditions using a combination of SS and RM (SS + RM_rest and SS + RM_RM) and the control condition. A 2-way repeated-measures ANOVA (3 warm-up conditions x 2 times [pre vs. post]) was performed. An alpha level of p = 0.05 was considered statistically significant. If significant main effects were demonstrated, Bonferroni post hoc analysis was conducted. The magnitude of change was calculated and reported as trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), or large (≥0.8) effect sizes (ES) (Cohen, 1988). Reliability was calculated with Cronbach’s alpha interclass correlation coefficient. Descriptive statistics include mean ± SD and SEM. Minimally clinically important or meaningful differences can be observed by examining the SEM or whether the difference is classified as a trivial ES (<0.2). Because the SEM is the variation in scores due to unreliability of the measure, a change that is less than the SEM is likely due to measurement error rather than a true observed change (11).

RESULTS

Range of Motion

Active and passive KF, and HF ROM improvements were prolonged by additional RM. Within-condition x time interactions showed that initial improvements provided by SS_RM and SS + RM_RM were sustained up to 30 minutes after intervention for all measures after additional RM.

| Table 5. Table illustrates significant improvements in range of motion (ROM) with main effects for initial warm-ups of either SS only (SS_rest and SS_RM) or SS + RM (SS + RM_rest and SS + RM_RM).*† |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| ROM measures (N = 12) | Static stretching (SS) only (SS_rest and SS_RM) | SS and roller massage (RM) | SS + RM_rest and SS + RM_RM |
| Active hip flexion | p = 0.045, ES: 0.076, 1.2% | P = 0.025, ES: 0.093, 1.6% |
| Passive hip flexion | p < 0.0001, ES: 0.211, 4.8% | p < 0.0001, ES: 0.282, 6.5% |
| Active knee flexion | p < 0.0001, ES: 0.588, 6.5% | p = 0.007, ES: 0.450, 5.9% |
| Passive knee flexion | p < 0.0001, ES: 1.008, 17.4% | p < 0.0001, ES: 0.755, 12.6% |

*ES = effect size.
†Both initial warm-up conditions (SS only and SS + RM) improved ROM with no significant difference between SS only and SS + RM.
Meanwhile, ROM improvements were evident only for KF passive and HF passive ROM after 30 minutes of rest compared with respective pretest values with SS_rest and SS + RM_rest conditions (Tables 2 and 3).

Between-condition × time interactions revealed significantly greater ROM improvements for SS_RM compared with sessions lacking additional RM in active and passive HF as well as active and passive HF. Similarly, SS + RM_RM elicited greater ROM improvements than SS_rest in active HF and passive KF (Tables 2 and 4).

Main effects for warm-up combinations (initial SS only vs. combined SS + RM) demonstrated that with both initial SS-only conditions (SS_rest and SS_RM) or SS + RM combined (SS + RM_rest and SS + RM_RM), HF active and passive and KF active and passive ROM were all improved (Table 5; Figures 1–3). Significant warm-up combination × time interactions revealed that sessions with initial warm-ups including SS only (aROM: \( p = 0.019 \), pROM: \( p = 0.001 \) ) and SS + RM (pROM: \( p = 0.010 \) ) improved KF ROM, whereas no differences emerged between SS and SS + RM (Figures 1 and 2).

Significant main effects for time indicate improved post-test ROM compared with pretest for HF (aROM: \( p = 0.014 \), pROM: \( p < 0.001 \) ) and KF (aROM: \( p = 0.001 \), pROM: \( p < 0.001 \) ), whereas there were no main effects for condition.

**Jump Measures**

With the initial 2-way ANOVA, a significant main effect for the 5 conditions demonstrated that CMJ height was compromised in SS_rest (\( p = 0.05 \), ES: 0.309, -3.9%)
compared with control. Significant main effects for time revealed that CMJ height was impaired at post ($p = 0.005$, ES: 0.218, -2.6%), post-10 ($p < 0.0001$, ES: 0.259, -3.1%), post-20 ($p < 0.0001$, ES: 0.288, -3.5%), and post-30 ($p = 0.006$, ES: 0.318, -3.9%) compared with pretest. There were significant but small magnitude differences between pretest measures for SS_rest ($p = 0.036$, ES: 0.260, -3.3%), SS + RM_rest ($p = 0.025$, ES: 0.344, -4.3%), and SS_RM ($p = 0.023$, ES: 0.389, -4.7%) compared with control. Condition × time interactions illustrated that jump performance was impaired at post, post-10, post-20, and post-30 compared with pretest for all conditions with the exception of SS + RM_RM during which no significant CMJ differences were found at posttest or post-30 (Table 6).

With the second 2-way ANOVA for SS-only vs. SS + RM combined and control warm-up conditions, significant condition effects indicate reduced posttest CMJ height compared with control for sessions containing SS only (SS_rest

| Table 6. Jump performance reported at 5 time points relative to the intervention.†

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>Post-10</th>
<th>Post-20</th>
<th>Post-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS_rest</td>
<td>18.125 ± 2.2</td>
<td>17.750 ± 1.9</td>
<td>17.458 ± 2.0</td>
<td>17.625 ± 2.0</td>
<td>17.375 ± 1.8</td>
</tr>
<tr>
<td>SS + RM_rest</td>
<td>17.942 ± 2.1</td>
<td>17.375 ± 2.2</td>
<td>17.542 ± 2.4</td>
<td>17.167 ± 2.1</td>
<td>17.208 ± 2.4</td>
</tr>
<tr>
<td>SS_RM</td>
<td>17.875 ± 1.9</td>
<td>17.417 ± 1.9</td>
<td>17.250 ± 2.0</td>
<td>17.250 ± 2.1</td>
<td>17.333 ± 2.2</td>
</tr>
<tr>
<td>SS + RM_RM</td>
<td>18.208 ± 2.1</td>
<td>17.917 ± 2.3</td>
<td>17.708 ± 2.3</td>
<td>17.625 ± 2.5</td>
<td>17.792 ± 2.7</td>
</tr>
<tr>
<td>Control</td>
<td>18.750 ± 2.6</td>
<td>18.125 ± 2.1</td>
<td>18.083 ± 2.3</td>
<td>18.083 ± 2.3</td>
<td>17.667 ± 2.3</td>
</tr>
<tr>
<td>Hurdle jump height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS_rest</td>
<td>0.244 ± 0.060</td>
<td>0.220 ± 0.054</td>
<td>0.235 ± 0.059</td>
<td>0.224 ± 0.055</td>
<td>0.233 ± 0.069</td>
</tr>
<tr>
<td>SS + RM_rest</td>
<td>0.233 ± 0.054</td>
<td>0.220 ± 0.063</td>
<td>0.219 ± 0.065</td>
<td>0.217 ± 0.049</td>
<td>0.231 ± 0.062</td>
</tr>
<tr>
<td>SS_RM</td>
<td>0.245 ± 0.061</td>
<td>0.227 ± 0.068</td>
<td>0.231 ± 0.063</td>
<td>0.228 ± 0.045</td>
<td>0.222 ± 0.052</td>
</tr>
<tr>
<td>SS + RM_RM</td>
<td>0.246 ± 0.065</td>
<td>0.233 ± 0.064</td>
<td>0.229 ± 0.067</td>
<td>0.224 ± 0.072</td>
<td>0.232 ± 0.073</td>
</tr>
<tr>
<td>Control</td>
<td>0.246 ± 0.066</td>
<td>0.231 ± 0.081</td>
<td>0.233 ± 0.073</td>
<td>0.243 ± 0.073</td>
<td>0.231 ± 0.072</td>
</tr>
<tr>
<td>Hurdle jump contact time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS_rest</td>
<td>0.236 ± 0.049</td>
<td>0.229 ± 0.048</td>
<td>0.249 ± 0.048</td>
<td>0.226 ± 0.038</td>
<td>0.230 ± 0.039</td>
</tr>
<tr>
<td>SS + RM_rest</td>
<td>0.224 ± 0.033</td>
<td>0.236 ± 0.044</td>
<td>0.228 ± 0.034</td>
<td>0.228 ± 0.030</td>
<td>0.235 ± 0.023</td>
</tr>
<tr>
<td>SS_RM</td>
<td>0.221 ± 0.031</td>
<td>0.231 ± 0.039</td>
<td>0.232 ± 0.038</td>
<td>0.231 ± 0.030</td>
<td>0.224 ± 0.026</td>
</tr>
<tr>
<td>SS + RM_RM</td>
<td>0.226 ± 0.049</td>
<td>0.249 ± 0.042</td>
<td>0.244 ± 0.033</td>
<td>0.233 ± 0.036</td>
<td>0.246 ± 0.035</td>
</tr>
<tr>
<td>Control</td>
<td>0.240 ± 0.045</td>
<td>0.231 ± 0.035</td>
<td>0.243 ± 0.034</td>
<td>0.249 ± 0.031</td>
<td>0.238 ± 0.033</td>
</tr>
</tbody>
</table>

*CMJ = countermovement jump; RM = roller massage; SS = static stretching.
†CMJ and hurdle jump height reported in inches, hurdle jump contact time reported in seconds. N = 12.
‡Values are significantly different from prevalue.

Figure 4. Pre-post countermovement jump (CMJ) height with conditions pooled for initial warm-ups of static stretching (SS) only (SS_rest and SS_RM) vs. SS + RM (SS + RM_rest and SS + RM_RM). N = 12. *Value is significantly different from prevalue. RM = roller massage.
and SS_RM) \( (p = 0.012, ES: 0.275, -3.5\%) \) and SS + RM (SS + RM_rest and SS + RM_RM) \( (p = 0.017, ES: 0.224, -3.4\%) \) in the initial warm-up. However, there were no interactions between SS only and SS + RM (Figure 4). The combined condition analysis revealed interactive effects for conditions \( \times \) time with SS only (SS_rest and SS_RM), SS + RM (SS + RM_rest and SS + RM_RM), and CONTROL CMJ height (SS: \( p = 0.001, ES: 0.215, -2.3\% \); SS + RM: \( p < 0.0001, ES: 0.202, -2.4\% \); CONTROL: \( p < 0.0001, ES: 0.272, -3.3\% \)) demonstrating impairments after test (Figure 4). Main time effects demonstrated a reduction in CMJ height from pretest to posttest \( (p < 0.001, ES: 0.231, -2.7\%) \).

There were also significant main effects for time-revealing deficits in hurdle jump height at posttest \( (p = 0.009, ES: 0.267, -7.0\%) \) and post-20 \( (p = 0.034, ES: 0.266, -6.6\%) \) only, whereas there were no significant changes in contact time (Table 6).

**Knee Extension and Flexion Maximal Voluntary Isometric Contraction Force Measures**

Significant main effects for time indicate a reduction in knee extension PF at posttest \( (p = 0.002, ES: 0.152, -3.8\%) \) and post-30 \( (p = 0.024, ES: 0.170, -4.3\%) \) only. There were no significant differences found in KF PF and f100, or in knee extension f100.

**Reliability Coefficients**

Interclass correlation coefficient reliability coefficients for hamstrings active \( (0.98; 3.18 \text{ SEM}) \) and passive \( (0.993; 4.51 \text{ SEM}) \) ROM, CMJ \( (0.98; 0.45 \text{ SEM}) \), quadriceps MVIC \( (0.98; 3.05 \text{ SEM}) \) and F100 \( (0.92; 2.49 \text{ SEM}) \), hamstrings MVIC \( (0.97; 1.71 \text{ SEM}) \) and F100 \( (0.91; 1.08 \text{ SEM}) \), hurdle jump height \( (0.96; 0.012 \text{ SEM}) \), and contact time \( (0.91; 0.0085 \text{ SEM}) \) were all categorized as excellent. Moderate reliability correlations were found for quadriceps active \( (0.68; 1.56 \text{ SEM}) \) and passive \( (0.74; 1.72 \text{ SEM}) \) ROM.

**DISCUSSION**

The most important findings in this study were that applying RM 10 and 20 minutes after SS (SS_RM) or after a combination of SS + RM (SS + RM_RM) prolonged KF and HF aROM and pROM improvements up to 30 minutes. There were also passive but not active ROM improvements without additional rolling provided by SS (SS_rest) and combining SS and RM (SS + RM_rest) that persisted up to 30 minutes. However, all active and passive ROM enhancements provided by SS_RM and SS + RM_RM were maintained or augmented with additional RM. Main condition interactions demonstrated that SS_rest was the only condition to impair CMJ height, whereas conditions involving RM (SS + RM_rest, SS_RM, SS + RM_RM) did not adversely affect subsequent performance measures compared with control. Sessions grouped by initial warm-up (SS only or SS + RM) generated similar improvements in pretest to posttest ROM, while eliciting similar decrements to CMJ height.

Initial KF (18.3%) and HF (4.1%) pROM improvements brought about by SS_rest remained evident throughout the 30-minute recovery period (10.8 and 4.1%, respectively). Initial KF aROM improvements (6.0%) with SS_rest persisted for 10 minutes (3.4%) but returned to baseline before 20 minutes. Passive ROM has been demonstrated to persist for \( \leq 3 \) (12), \( \leq 5 \) (44), \( \leq 10 \) (6,39), \( \leq 30 \) (15,32,35), \( \leq 90 \) (27), and \( \leq 120 \) minutes (39) after acute SS; therefore, this study joins a relatively conflicting pool of literature. These variances are likely due to inconsistent protocols such as stretching duration and intensity or different muscle groups examined.

Similar to SS_rest, initial KF (10.9%) and HF (6.6%) passive ROM improvements elicited by SS + RM_rest remained significantly improved after 30 minutes of rest (8.2 and 5.9%, respectively). However, there were no significant improvements in active ROM throughout the postintervention testing periods when there was no additional rolling (SS_rest and SS + RM_rest). The effect of additional rolling may be to provide less reflexive activity during the dynamic muscle contractions allowing the muscles to achieve a greater active ROM. Previous massage (23) and roller (45) studies have shown decreased Hoffman reflex activity indicating a decreased afferent excitability of the spinal motoneurons (13). This is the first study monitoring the effects of combined SS and RM over time. These findings suggest that SS + RM may exhibit similar lasting effects on passive ROM to SS alone. The scant pool of research on this topic exposes a need to further probe into the time course of effects brought about by acute SS + RM. This information would be of particular interest to athletes who endure prolonged rest between warm-up and intense exercise.

Considering this uncertainty, a strategy to sustain acute active and passive ROM improvements after a warm-up may be beneficial for athletes entering a game from the bench. This study is the first to report on RM applied subsequent to an SS or SS + RM routine. Whereas sessions involving a postintervention rest period showed persistent improvements in passive ROM measurements over 30 minutes, sessions including RM at 10 and 20 minutes after intervention demonstrated maintained or greater passive and active ROM after 30 minutes (Table 2). Initial improvements in KF (aROM: 7.1%, pROM: 16.5%) and HF (aROM: 2.0%, pROM: 5.5%) ROM for SS_RM remained elevated at 30 minutes (KF aROM: 7.7%, pROM: 16.2%; HF aROM: 3.1%, pROM: 6.5%). Similarly, initial ROM improvements brought about by SS + RM_RM for KF (aROM: 7.7%, pROM: 14.1%) and HF (aROM: 2.0%, pROM: 6.4%) were sustained at 30 minutes (KF aROM: 9.9%, pROM: 20.8%; HF aROM: 2.8%, pROM: 7.9%). Thus, additional RM seems capable of prolonging or augmenting active and passive ROM improvements elicited during warm-ups involving SS and SS + RM. Roller massage (or FR) on its own has been reported to elicit enhancements to ROM that return to baseline (20) or remain to a smaller extent (29) after 10 minutes. These findings are in contrast to the current study, which indicates
that RM, when combined with SS (SS + RM_rest), or when performed at 10-minute intervals (SS_RM, SS + RM_Rm), can exhibit active and passive ROM improvements at 30 minutes. It remains unknown whether RM alone, with or without subsequent RM (e.g., RM_rest and RM_Rm), is capable of providing a similar warm-up effect to combined SS + RM routines. The optimal frequency of additional RM intervals to maximize ROM while minimizing impairments is also unclear. Therefore, future investigations should deploy warm-ups comparing SS, RM, and SS + RM with subsequent RM performed at varying intervals. Furthermore, it may be beneficial to investigate the effects of additional RM after intense dynamic exercise. This would simulate athletes resting during a game or at intermission and help determine whether ROM can be effectively maintained using RM while they wait to resume activity.

In addition to ROM measurements, neuromuscular performance was also monitored. According to a main condition effect, SS_rest exhibited significantly impaired CMJ height (–3.9%) compared with control. This is the lone intervention (SS_rest) containing no RM at any point, whereas the remaining 3 conditions were not significantly different than control. When warm-up conditions were combined to SS only (SS_rest and SS_Rm) and SS + RM (SS + RM_rest and SS + RM_Rm), control conditions had significantly less CMJ height impairment after test than the experimental conditions. Despite indications that performance deficits occur mainly with SS >60-second duration (4,25,26), the 60 seconds of SS performed in this study was enough to elicit minor impairments to CMJ height. The finding of jump impairments with 60 seconds or less of SS is not uncommon though, with deficits reported for squat jumps and CMJ (10,14,22,42). It is unclear if the inclusion of additional RM in other sessions was responsible for counterbalancing the negative effects of SS. Main time effects demonstrated impaired CMJ height at all times compared with pretest; however, the absence of condition effects or condition × time interactions suggests that impairments to CMJ height were primarily a result of testing effects or fatigue, rather than RM or SS. The SS + RM_RM condition demonstrated no impairments at posttest or post-30 (Table 2). This is the condition with the greatest volume of RM. It is possible that the larger volume of RM in SS + RM_RM was accountable for masking these testing effects, thus minimizing performance deficits for this condition. One previous study (36) reported improved performance (i.e., +7.8% vertical jump height) after 30 seconds of FR. Hence, it is not unreasonable to suggest that RM played a role in abating the impairments brought about by the SS routine. It would be beneficial for future investigations to further investigate whether RM can improve performance, or even simply mask the negative effects of SS.

Trivial deficits in hurdle jump height at posttest and post-20 and knee extension PF at posttest and post-30 were strictly main effects for time, and the lack of condition effects (Table 3) suggests that these reductions were a result of the testing procedure rather than the intervention. Furthermore, there were no significant changes in hurdle jump contact time, KF PF or f100, or knee extension f100. These findings are consistent with those of previous reports (2,20,21,29,31,40), illustrating no changes in maximal strength or power tasks after FR or RM.

Another research objective was to compare the immediate effects of SS and SS + RM. Sessions involving an initial intervention of SS + RM (30 seconds each), and those consisting of SS only (60 seconds total), each provoked HF and KF active and passive ROM improvements that were not significantly different (Table 5). This is in contrast to Mohr et al. (33) and Škarabot et al. (39), who reported greater improvements in KF and ankle dorsiflexion, respectively, after SS + FR/RM compared with SS alone. This discrepancy is likely due to differences in the total intervention volume. Both aforementioned studies combined their FR/ RM and SS protocols, thereby doubling the total volume, for the combined condition, whereas in the current study, the duration of SS was reduced by half to accommodate an equal volume of RM and maintain a consistent total volume compared with the SS-only conditions. This is the first study to directly compare equal volumes of SS to combined SS + FR/RM. The results suggest that both warm-ups provide similar ROM improvements, while neither produced adverse performance decrements. Whether longer duration combined with warm-up routines would counterbalance impairments from prolonged (e.g., >60 seconds) SS remains unclear. Thus, future research should aim to elicit significant performance impairments with prolonged SS and compare the effects to conditions with equal and double duration combined protocols and to RM on its own.

The small sample size (n = 12) may be a limiting factor for this study; however, it was determined that between 4 and 30 subjects were required to achieve an alpha level of 0.05 and a power of 0.8 based on similar previous studies (1,5,37). Furthermore, although all subjects reported being at least recreationally active, the findings of this study may be of interest to competitive athletes. The relationship of these effects between recreational and highly trained athletes is unclear. Another limitation to the current study is the absence of sessions including RM only (e.g., RM_rest and RM_Rm). Inclusion of these conditions would allow direct comparison of RM, SS, and SS + RM, and this concept may be ideal for future investigations. Finally, the control condition did provide increased ROM in 2 measures. Although the experimental conditions provided statistically significantly greater ROM improvements than control, the control improvements with active and passive HF indicate that the ROM testing played a small role for improving flexibility.

In summary, the current study suggests that although SS and SS + RM warm-up routines can elicit passive ROM increases lasting up to 30 minutes, the maintenance of active ROM can be maximized or augmented with additional RM
applied at 10-minute intervals. Furthermore, SS and combined SS + RM routines of equal total duration can provide similar ROM improvements. Finally, the combination of SS + RM, or the addition of subsequent RM to an SS or SS + RM routine, does not seem to exert adverse effects on neuromuscular performance.

**Practical Applications**

This research may be of benefit to athletes who are exposed to prolonged rest before entering (e.g., from the bench) a game after a warm-up. Because athletes need functional flexibility, the improvements in active ROM (ROM achieved while the muscles are contracting) would play a more important role than improved passive ROM during a sport activity. Athletes should periodically (at least every 10 minutes) roll the applicable muscles for at least 30 seconds each.

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**References**


