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ORIGINAL RESEARCH

FOUR WEEKS OF ROLLER MASSAGE TRAINING DID NOT IMPACT RANGE OF MOTION, PAIN PRESSURE THRESHOLD, VOLUNTARY CONTRACTILE PROPERTIES OR JUMP PERFORMANCE

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ABSTRACT

Background: Roller massagers are popular devices that are used to improve range of motion (ROM), enhance recovery from muscle soreness, and reduce pain under acute conditions. However, the effects of roller massage training and training frequency are unknown.

Purpose: The objective was to compare two different roller massage training frequencies on muscle performance.

Study Design: Randomized controlled intervention study

Methods: Twenty-three recreationally active university students were randomly allocated to three groups: control (n = 8;), rolling three (3/W; n = 8;) and six (6/W; n = 7) times per week for four weeks. The roller massage training consisted of unilateral, dominant limb, quadriceps and hamstrings rolling (4 sets x 30 seconds). Both legs of participants were tested pre- and post-training for active and passive hamstrings and quadriceps range of motion (ROM), electromyography (EMG) activity during a lunge movement, unilateral countermovement jumps (CMJ), as well as quadriceps and hamstrings maximum voluntary isometric contraction (MVIC) forces and electromechanical delay. Finally, they were tested for pain pressure threshold at middle and distal segments of their quadriceps and hamstrings.

Results: There were no significant training interactions for any measure with the exception that 3/W group exhibited 6.2% ($p = 0.03$; Effect Size: 0.31) higher CMJ height from pre- (38.6 ± 7.1 cm) to post-testing (40.9 ± 8.1 cm) for the non-dominant limb.

Conclusions: Whereas the literature has demonstrated acute responses to roller massage, the results of the present study demonstrate no consistent significant training-induced changes. The absence of change may highlight a lack of muscle and myofascial morphological or semi-permanent neurophysiological changes with rolling.

Levels of Evidence: 2c

Key Words: self-myofascial release, foam rolling, massage, flexibility, strength,

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INTRODUCTION

Foam rollers and roller massagers are recent popular additions to training and recovery routines. Recently, researchers have demonstrated that an acute session of rolling can increase static hip flexors,[1-4] hip extensors,[4-7] and ankle[8,9] range of motion (ROM) as well as dynamic hip extensor ROM during a lunge.[10] Su et al.[11] found that an acute bout of foam rolling was more effective than static stretching for increasing hip flexor (modified Thomas test) ROM. The improved flexibility can have global effects since ROM was improved not only in the rolled limb but also the contralateral ankle,[12] as well as bilateral rolling of the soles of the feet improving the ROM of the hamstrings and lumbar spine.[13]

Not all studies demonstrate increases in ROM. Following foam rolling, the mobility of the thoracolumbar fascia significantly increased 1.79 mm (d = 0.756), but there was no significant effect on lumbar flexion.[14] Couture et al.[15] reported no significant improvement in hamstrings ROM with short (2 sets of 10s) and long (4 sets of 30s) durations of hamstrings rolling. Murray[16] indicated that the statistically significant increase in hip flexor (quadriceps) flexibility with 60 seconds of foam rolling was not clinically relevant while Vigotsky et al.[17] did not see an increase in passive hip extension or knee flexion ROM with 2 sets of 60 seconds of anterior thigh foam rolling. Hence, the literature is not consistent regarding the effects of rolling on subsequent measures of ROM. Furthermore, all the aforementioned studies were acute interventions that examined short term or acute outcomes.

There is also evidence that rolling can acutely increase pain pressure thresholds (PPT) by decreasing pain sensitivity[18] in the affected and contralateral limbs.[19-21] As Magnusson[22] has suggested that stretch (pain) tolerance can be an important factor with ROM improvements, rolling-induced increases in PPT could contribute to the rolling-induced improvements in flexibility for the stretched limb and non-stretched limbs. This decreased pain sensitivity with rolling before exercise might also be related to the improved function following exercise-induced muscle damage (EIMD).[23,24] Rolling improved recovery of muscle activation and vertical jump performance [24] as well as sprint, power (broad-jump distance), change of direction speed (T-test), and dynamic strength-endurance[23] after EIMD. In contrast, in another study by Casanova et al.,[25] roller massage did not alter the functional impairments, medial gastrocnemius morphology, or oxygenation kinetics after EIMD, however there were increases of ipsilateral (19%) and a trend toward increases in contralateral ($p = 0.095$) medial gastrocnemius PPT. Once again, the PPT studies are all acute protocols and it is unknown if the changes in PPT are apparent with more chronic rolling application.

Unlike the performance impairments reported with prolonged static stretching,[26-28] acute bouts of rolling have been reported in some studies not to negatively affect subsequent strength[2,6,8] or power (i.e. vertical jump).[29] In contrast, Bradbury-Squires et al.[1] did find that the neuromuscular efficiency (amount of muscle activation [electromyography] needed to perform an activity) of a lunge was actually improved following rolling. Su[11] reported improved knee extension torques, while Monteiro et al.[30] showed an improvement in the performance of a functional movement screen overhead deep squat. In comparison to a total body dynamic warm-up, foam rolling was more effective at improving power, agility, strength, and speed.[31] On the other hand, whereas Healey et al.[32] reported a decrease in the sensation of post-exercise fatigue, Monteiro[33] countered that the number of knee extension repetitions was impaired when rolling was performed between knee extension sets. Furthermore, an acute session of rolling can also produce force deficits as evidenced by 9.5% - 19.1% decreases in the maximum voluntary isometric contraction (MVIC) force developed in the first 200 ms of the contraction when tested immediately and five minutes after rolling.[20] MacDonald et al.[24] reported that foam rolling negatively affected evoked muscle contractile properties. Furthermore, foam rolling of the quadriceps decreased biceps femoris activation.[34] Once again, the general findings of these acute studies are inconclusive with no roller training studies examining possible chronic training-induced changes in performance.

There is only one training study that involved rolling. Junker and Stoggl[35] reported similar increases in a stand and reach flexibility test for foam rolling and proprioceptive neuromuscular facilitation

(PNF) stretching over a three session per week, four-week training period of healthy adults. Thus, based on the lack of longer term rolling training studies, the objective of this study was to investigate the effects of two weekly frequencies (three versus six days per week) of a four-week roller massage training program on measures of ROM, PPT, voluntary contractile properties, and jump performance.

METHODS

Subjects

Twenty-three volunteers, including 13 males (25.1 ± 2.9 years, 180.4 ± 7.1 cm, 89.5 ± 16.4 kg) and 10 females (24.9 ± 4.3 years, 171 ± 7.8 cm, 69.1 ± 9.6 kg) were recruited from the university population. One female subject (six day/week group) withdrew from the study due to an unrelated injury. In order to meet entry criteria, subjects were between the ages of 18-35 years, were recreationally trained (participate in physical activity ≥ three times/week), had no experience of lower body injury or history of neurological conditions within the prior six-months, and reported no regular prior usage of roller massagers or foam rollers (defined as ≤ one time/week) within the past six months. After being briefed on study procedures all participants signed a consent form approved by the Health Research Ethics Authority at the University (file #:20180010-HK), in addition to completing the Physical Activity Readiness Questionnaire (Canadian Society for Exercise Physiology 2011). It was asked that participants avoid vigorous physical activity, foam rolling/roller massage, or stretching, and to refrain from alcohol consumption for 24-hours prior to testing sessions.

Experimental Design

The research questions were approached with a within subject, repeated measures, intervention design. Participants completed pre- and post-testing separated by a four-week intervention period involving either unilateral, dominant leg roller massage (RM) training (three or six times/week) or no RM training (control) (Table 1). Prior to each testing session, bipolar surface electrodes (Meditrace Pellet Ag/AgCl electrodes; Graphic Controls Ltd, Buffalo, NY) were placed over the midpoint of the participant's biceps femoris and rectus femoris on both legs. A ground electrode was also placed on the fibular head. The skin covering these areas was carefully shaved with reusable razors and cleansed with isopropyl alcohol swabs. The session then commenced with a dynamic warmup on a cycle ergometer (Monark; Ergomedic 828E; Sweden) at 60-70-rpm with a resistance of 1-kp (70 Watts) for five minutes. Participants then underwent testing measures, which included active and passive ROM, neuromuscular efficiency (as measured by EMG) during a dynamic lunge task, single-leg countermovement jumps (CMJs), maximal voluntary isometric contractions (MVICs) force and EMG for knee flexors

Table 1. *Experimental Design.*

Pre-test measures	Four-week training intervention	Post-test
Active and passive hip flexion (hamstrings) ROM Neuromuscular efficiency during a lunge (EMG) Single leg CMJ Knee flexors and extensors MVIC Pain Pressure threshold of biceps femoris and rectus femoris	Roller massage 3 days per week Roller massage 6 days per week Control (no roller training)	Active and passive hip flexion (hamstrings) ROM Neuromuscular efficiency during a lung (EMG) Single leg CMJ Knee flexors and extensors MVIC Pain Pressure threshold of biceps femoris and rectus femoris

ROM: range of motion; EMG: electromyography; CMJ: countermovement jump; MVIC: maximum voluntary isometric contraction;

and extensors, and pain-pressure threshold (PPT) at the mid-muscle belly and distal muscle-tendon junction of the biceps femoris and rectus femoris. Electrodes were removed following MVICs to eliminate interference with testing locations for PPT trials. All measurements were performed on both legs, beginning with the dominant side.

Interventions

Immediately following their pre-test session, participants were randomly appointed to one of three intervention groups by having them roll a standard six-sided dice. The three (3/Wk: n = 8; when a 1 or 2 was rolled) and six (6/Wk: n = 7; when a 3 or 4 was rolled) RM sessions per week for four weeks consisted of RM over the quadriceps and hamstrings of the dominant leg for four sets of 30-seconds each. CONTROL (n = 8; when a 5 or 6 was rolled) involved no RM for four weeks.

Participants assigned to 3/Wk and 6/Wk groups were provided with a personal RM (TheraBand® Roller TH 11753: Performance Health: Akron Ohio, USA), that was a 24-cm long (plus protruding handles) dense rubber cylinder with longitudinal grooves designed for superficial and deep tissue mobilization. The researchers described and demonstrated proper RM application. Subjects were instructed to assume a seated position on the edge of a chair while resting the foot of their extended dominant leg on another surface of similar height (i.e. another chair). RM was then applied manually by the participant by manipulating the roller over the full length of the quadriceps (by pressing the roller downwards over the top of the thigh) and hamstrings (by pulling the roller up along the bottom of the thigh) without crossing any joints. Participants were asked to maintain an approximate cadence of 60-beats per minute, or one-second intervals rolling from the distal to proximal end and vice versa, while eliciting a perceived pain of 7/10 on a visual analogue scale (VAS-10). RM was performed for the dominant limb only, and each 30-second bout was alternated between the quadriceps and hamstrings until four sets had been completed for each.

All intervention groups were instructed to maintain their existing activity and lifestyle routines for this study; however, 3/Wk and 6/Wk were to add their prescribed RM, while CONTROL was asked to refrain from any RM or foam rolling. Members of 3/Wk and 6/Wk were also given a checklist to monitor diligence for daily RM completion. The checklist required participants to document the date and time of day of each rolling session, and to sign that it had been completed. Weekly email reminders were also sent to 3/Wk and 6/Wk groups to minimize the occurrence of missed training sessions. Post-testing was performed for each participant as close to the final day of their four-week intervention period as possible.

Measurements

Range of motion (ROM)

A large protractor designed on the wall of the laboratory was used to measure active and passive hip flexion ROM.[5] Subjects were positioned supine on the floor against the wall with their hip joint placed against the centre of the protractor (Figure 1). The contralateral knee and hip were held securely in place by the researcher. Active ROM was assessed by instructing the participant to explosively kick their foot as high as possible, holding the position briefly at the end of the movement. They were urged to contract their quadriceps and maintain a fully extended knee joint. Passive ROM testing was then conducted with the researcher raising the participant's relaxed limb while preventing knee flexion and sustaining neutral ankle flexion throughout the movement.

Figure 1. *Measurement of passive hip flexion range of motion. Participant actively raised their own leg to evaluate active hip flexion range of motion.*

The subject was asked to indicate when the end of the ROM had been reached, defined as the maximal point of discomfort (POD). The maximum angle of hip flexion was recorded. Reliability intraclass correlation coefficients (ICC) of 0.91-0.93 have been reported from this laboratory for this ROM test.[36]

As published from this laboratory and others,[1,31,37,38] active and passive knee flexion was assessed by placing the subject in a lunge position and extending the hip to slide the rear knee as far back as possible, while maintaining a 90° angle in the front knee and hip. A metal frame was provided for the subject to maximize stability during the measurement. A handheld goniometer was used to measure the degree of knee flexion while the subject (for active ROM) or the researcher (passive ROM) raised the rear foot, flexing the knee joint, until the end of the ROM (maximum POD) was reached (Figure 2). The authors' have previously reported reliability ICC's of 0.964-0.993 for this test.[37]

Neuromuscular efficiency

A lunging task, similar to that previously demonstrated in this laboratory,[1] was used to determine the neuromuscular efficiency of the rectus femoris and biceps femoris during a submaximal dynamic activity. In order to standardize lunge lengths, the distance from the participant's iliac crest to their lateral malleolus was measured, recorded, and marked on the floor using tape. This distance was used to measure lunge length during pre- and post-testing sessions to ensure inter-session consistency. Subjects were instructed to step forward to their individual tape marking with their hands on their hips and gaze fixed forward, and lower their rear knee into a lunge with a cadence of two-seconds down, and two-seconds up. Electromyography (EMG) of the rectus femoris and biceps femoris was monitored throughout, and was analyzed for the concentric portion (two-seconds) of the movement. Following the skin preparation, bipolar Ag/AgCl electrodes (Ag/AgCl; Kendall MediTrace foam electrodes, Holliston, Massachusetts, USA) were placed over the mid-belly (half the distance between the anterior superior iliac spine and the patella) of the rectus femoris The reference electrode was placed over the head of the radius. The inter-electrode spacing was 20 mm. All the EMG signals were collected by the Biopac data acquisition system (Hardware: Biopac Systems Inc., DA 100, and analog to digital converter MP100WSW; Hilliston, MA., Software: AcqKnowledge III, Biopac System Inc. Holliston MA. USA) at a sample rate of 2000 Hz (impedance = 2 MΩ, common mode rejection ratio >110 dB min (50/60 Hz), noise >5 μV). A bandpass filter (10–500 Hz) was applied prior to digital conversion.

Figure 2. *Kneeling lunge position for measurement of passive (researcher assisted shown in figure) and active (no assistance) knee flexion range of motion (ROM).*

Single-leg countermovement jumps (CMJs)

Unilateral CMJ height was assessed using a Vertec measuring device (Vertec, Sports Imports, Hilliard, OH).[23,24] The height of the device was adjusted until the fingertips of the subject's dominant arm, extended overhead, brushed against the bottom vane. Subject performed the test using a single-leg stance, leaping as high as possible and reaching with their dominant hand to slap the Vertec at the peak of their jump. Subjects were encouraged to make the task as natural as possible by allowing them to squat down and swing their arms for momentum. Three attempts were granted, and the highest vane displaced (measured in ½" intervals) was recorded as their CMJ height. EMG was also recorded and analyzed for the concentric portion of the task. ICCs for CMJ have exceeded 0.9 in testing from this laboratory.[23,24,38]

Maximal voluntary isometric contractions (MVICs)

Similar to a number of other studies from this laboratory,[6,38-40] participants assumed a seated position on the edge of a table with a backrest adjusted to allow 1″ between their popliteal space and the edge of the table. They were strapped securely in position across the shoulders and upper legs. The ankle of the testing leg was then inserted into a padded cuff secured to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCS 250, Don Mills, Ontario, Canada) by a high-tension wire. Knee joint angles were adjusted to 60° from full knee extension when performing knee flexion and 90° for knee extension MVICs, during which subjects were instructed to contract their quadriceps (knee extension) or hamstrings (knee flexion) as forcefully and rapidly as possible by pushing or pulling against the immobile ankle cuff. Attempts were held for three to five seconds until an appropriate plateau of force had been achieved, and was accompanied by repeated shouts of verbal encouragement. Two attempts were performed (with a third attempt if the second was ≥5% than the first), and the effort with the greatest peak force was used for analysis. Data collected with the strain gauge was sampled at 2000-Hz, amplified (Biopac Systems Inc., DA 100, and analog to digital converter MP100WSW; Hilliston, MA.), and analyzed using a commercially designed software program (Acq-Knowledge III, Biopac Systems Inc., Hilliston, MA.). Peak force (PF) and F100 (force generated in the first 100-ms) were assessed with strain gauge data, while muscle activation (EMG) was recorded during the MVIC (see neuromuscular efficiency paragraph for electrode and system details). Prior published ICCs for MVIC measures from this laboratory have all exceeded 0.9.[8,34,38,40]

Pain-pressure threshold (PPT)

PPT was incorporated similar to other studies from this laboratory.[19,20] PPT was evaluated at the mid-muscle belly and distal muscle-tendon junction of the rectus femoris and biceps femoris. A hand-held algometer (Lafayette Manual Muscle Test System™, Model 01163, Lafayette Instrument Company, Indiana, USA) with a range of 0–136.1 kg was used to apply pressure to the muscle tissue with the subject lying supine (rectus femoris measurements) or prone (biceps femoris measurements). The researcher performed three consecutive tests for each target area by exerting pressure in an incremental manner until the subject verbally indicated that the POD (defined as the onset of pain) had been reached. The mean of the three trials was recorded as the PPT. Prior use of this procedure from our laboratory has provided reliability ICC of 0.93.[19]

Statistical Analysis

Statistical analyses were computed using SPSS software (Version 23.0, SPSS, Inc., Chicago, IL). Dependent variables underwent assumption of normality (Shapiro-Wilk test) and sphericity (Mauchley test), and if violated, the corrected value for non-sphericity with Greenhouse-Geisser Epsilon was reported. Three-way analyses of variance (ANOVAs) [Three groups (CONTROL, 3/Wk and 6/Wk) × 2 times (pre- and post-training) x 2 legs (dominant and non-dominant] were used to analyze quadriceps and hamstrings MVICs, ROM, unilateral CMJ, CMJ rectus femoris and biceps femoris EMG activity, quadriceps and hamstrings electromechanical delay, lunges, rectus femoris and biceps femoris EMG and PPT at all positions. Post hoc LSD analyses were used to examine main effect pairwise differences with t-tests employed to detect the location of specific significant interactions. Statistical significance was accepted with an alpha level of $p = 0.05$. Descriptive statistics include means ± standard deviation (SD).

RESULTS

There were no significant training interactions for any measures except for CMJ height, which presented an interaction between group, time and leg. Post-hoc analysis found an interaction between time and leg only for 3/Wk group ($p = 0.01$), showing that the non-dominant leg pre-test (15.18 ± 2.84 cm) was lower than post-test (16.12 ± 3.24 cm, $p = 0.03$).

Main effects for time were evident with pre- to post-training decreases in active and passive hamstrings ROM, hamstrings and quadriceps MVIC, CMJ rectus femoris and biceps femoris EMG (Table 2). Main effects for limb dominance were apparent with the dominant leg exceeding the non-dominant leg for hamstrings (approaching a significant difference) and quadriceps passive ROM and quadriceps electromechanical delay, whereas the non-dominant limb exhibited higher scores for quadriceps MVIC force (Table 3).

DISCUSSION

The major findings in the present study were that four weeks of roller massage training with either three or six sessions per week did not induce physiological (i.e. MVIC force and EMG, electromechanical delay, neuromuscular efficiency with a lunge) or performance (i.e. ROM, CMJ) training adaptations in the rolled or untrained, contralateral limbs with the exception that 3/Wk group exhibited higher CMJ height pre- to post-testing for the contralateral, untrained, non-dominant limb.

Prior publications have demonstrated that the acute implementation of RM has increased static ROM of the hip flexors,[1-4,11] hip extensors,[4-7] and ankle plantar flexors[8,9] as well as dynamic hip extensor ROM during a lunge.[10] There has only been one rolling training study, which reported similar increases in a stand and reach flexibility test with foam rolling and PNF stretching after a three session per week, four-week training period of healthy adults.[35] There were only minor differences between the Junker and Stoggl training study and the present study. While the frequency and duration (four weeks) of the rolling training was similar as was the duration of rolling repetitions (30 vs. 30-40s), the participants in the present study were on average six years younger

Table 2. *Main Effects for Time.*

Main Effects for Time	Pre-training	Post-training	p-value ES
Hamstrings Active ROM (^{0})	95.66 ± 2.73	91.87 ± 2.47	$p = 0.002$ ES=1.45
Hamstrings Passive ROM (^{0})	98.92 ± 4.04	92.40 ± 3.36	$p = 0.001$ ES=1.76
Hamstrings MVC (kg)	35.73 ± 1.89	33.54 ± 1.64	$p = 0.04$ ES=1.24
Quadriceps MVC (kg)	62.07 ± 4.02	57.84 ± 3.73	$p = 0.001$ ES=1.09
CMJ Rectus Femoris EMG (mV)	0.69 ± 0.04	0.60 ± 0.03	$p = 0.04$ ES=2.57
CMJ Biceps Femoris EMG (mV)	0.43 ± 0.05	0.32 ± 0.03,	$p = 0.06$ ES=2.75

ROM: range of motion in degrees; MVC, maximal voluntary isometric contraction; CMJ: countermovement jump; EMG: electromyography; ES: Effect size
Note: ES descriptor: large magnitude of change = ≥ 0.80

Table 3. *Main Effects for Leg Dominance.*

Main Effects for Leg Dominance	Dominant	Non-dominant	P value
Hamstrings Passive ROM (^{0})	97.08 ± 3.69	94.24 ± 3.69	$p = 0.1$ ES=0.76
Quadriceps Passive ROM (^{0})	53.29 ± 2.35	45.83 ± 2.06	$p = 0.003$ ES=3.39
Quadriceps MVC (kg)	57.97 ± 3.53	61.93 ± 4.25	$p = .008$ ES=1.01
Quadriceps EMD (ms)	78.17 ± 3.70	68.87 ± 3.63	$p = 0.04$ ES=2.56

ROM: range of motion in degrees; MVC, maximal voluntary isometric contraction; EMD: electromechanical delay; ES: Effect size
Note: ES descriptors: moderate magnitude of change = ≥ 0.5 – 0.79, large magnitude of change = ≥ 0.80

(25 vs 31 years), and used a roller massager rather than a foam roller possibly with different intensities of rolling (7/10 VAS scale vs. body mass load when foam rolling). Furthermore, the ROM test with the Junker and Stoggl study was a stand and reach test whereas the present study used active and passive supine straight leg hip flexion. While the small age difference was probably not a significant factor, the possibility of differing intensity or pressure of rolling should also not have played a role. Grabow et al.[41] reported that acute rolling massage at 4/10, 6/10/ or 8/10 on a VAS scale did not provide significant differences in post-rolling ROM or induce performance decrements. Hence the discrepancy might be attributed to the use of a foam roller versus a roller massage. In the present study, with the 3/Wk and 6/Wk groups combined (n = 15), there was actually a significant decrease in ROM after the four weeks of training. Whereas roller massage involves just the upper limbs to move the roller, foam rolling involves the upper limbs to move the body segment over the roller and trunk or core muscle stabilization to maintain proper positioning. It might be possible that the core stabilization efforts with foam rolling strengthened this area allowing the subjects to actively reach farther down during the stand and reach test. If this was the case, then the effect was due more to a core strengthening effect than a change in leg muscle extensibility (compliance). However, as this rationale is speculative, further studies are necessary to delineate the effect of foam roller and roller massage training on ROM.

Whereas the present study also did not show training related changes in PPT, acute rolling studies have reported increased PPT or decreased pain sensitivity in the rolled[18] and non-treated contralateral limbs.[19-21] The proposed mechanisms for the pain modulation was postulated to be a central pain modulation system[19,20] such as the gate control theory[42,43] or diffuse noxious inhibitory control.[44] Similarly, acute rolling-induced improvements in ROM have been attributed to central or neural responses. This central neural response of rolling was highlighted by increased ROM in the contralateral ankle,[12] as well as with the hamstrings and lumbar spine following bilateral rolling of the soles of the feet.[13] Although, contralateral increases in ROM were not evident in the present study, the 3/Wk group exhibited higher CMJ height following training for the non-dominant limb. As there were no significant changes in ROM or PPT in the present study, there was no significant evidence for training-related changes in ROM or PPT-related central neural responses. Young et al.[45] in an acute study reported decreased Hoffman (H) reflex activity during rolling, which returned to baseline immediately upon rolling cessation. Similarly, Aboodarda et al.[46] demonstrated reduced corticospinal excitability as measured with transcranial magnetic stimulation (TMS) during four sets of roller massage, which returned to baseline immediately following the rolling protocol. Hence, the neural effects of rolling may be quite transient.

Furthermore, as Magnusson[22] has suggested that stretch (pain) tolerance can be an important factor with ROM improvements. Improved stretch tolerance has been postulated to underpin ankle plantar flexor's[47] and hip extensor's[48,49] ROM improvements following static stretching training programs with similar treatment volume or duration to the rolling intervention in this study. The lack of rolling-induced increases in PPT and ROM in the present study would suggest that four weeks of roller massage did not significantly impact stretch (pain) tolerance.

The increased CMJ height of the contralateral, non-rolled limb with the 3/Wk group would argue for a training-related neurological adaptation. In light of the lack of any other ipsilateral or contralateral results, it is difficult to postulate a specific neurological adaptation. Single leg CMJ are not a common activity and thus there might have been a learning effect from pre- to post-training tests. Although the 3/Wk group showed a significant improvement, there were non-significant improvements that occurred in the 6/Wk (pre-test: 14.2 to post-test: 14.5 cm) and CONTROL (pre-test: 13.9 to post-test: 14.9 cm) groups. While it could also be a statistical anomaly (random effect), there is the possibility that a learning effect occurred to provide a significant, small effect size magnitude change[50] improvement in CMJ height with the 3/Wk group.

Limitations of the current study included the relatively small sample population (8, 7, and 8 per group respectively) and training duration (four weeks). With the exception of one finding (contralateral CMJ height), none of the other statistical interactions were anywhere near significance and thus even substantial increases (i.e. increase from 8 to 12 per group) would probably not be expected to alter the findings. However, similar studies with greater statistical power are always recommended. The four-week training duration has been shown to be effective for significantly increasing ROM with stretch training studies[26-28] and thus the present roller training duration demonstrates that rolling is not as effective as stretching for improving ROM over this time period.

Related to this point, there are a few acute studies that have combined rolling with stretching to determine if an additive effect was possible. Mohr et al.[3] reported greater hip flexion ROM improvements following three-minutes of combined foam rolling and static stretching (23.6%) versus three-minutes of either intervention (Foam rolling: 6.9%; static stretch: 12.3%). Similarly, Škarabot et al.[9] found greater ankle dorsiflexion ROM with 90-seconds of foam rolling and static stretching (9.1%) than rolling or stretching in isolation. However, there was no significant additive effect with 30 seconds of roller massage and static stretching.[38] As there are no training studies integrating both rolling and stretching, further research could be conducted on this question.

CONCLUSIONS

In summary, roller massage training performed either three or six days per week did not improve any of the physiological or performance measures with the rolled or contralateral limbs indicating that previously reported rolling-induced acute improvements may be transient. The increased unilateral CMJ height pre- to post-testing for the contralateral, untrained, limb might be ascribed to a learning effect with an unfamiliar task. Hence, roller massage may be a beneficial tool for increasing ROM and PPT during and soon after a warm-up session but its acute effects may not translate into chronic changes. Hence, the clinical relevance reveals that past and present evidence demonstrate that rolling massage can produce acute increases in ROM and pain pressure threshold, however, chronic rolling does not induce plastic (semi-permanent) adaptations.

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