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Research article

Vibration Rolling, Non-Vibration Rolling, and Static Stretching for Delayed-Onset Muscle Soreness on Physiological Changes and Recovery of Athletic Performance in Runners

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Abstract
This study examined the effects of vibrating foam rollers (VR) on delayed-onset muscle soreness (DOMS), inflammatory response, and athletic performance. Eighteen experienced adult runners (average running experience: 6 years) participated in a crossover study with three recovery interventions: vibrating roller (VR), non-vibrating roller (NVR), and static stretching (SS). DOMS was induced through downhill treadmill running. Each intervention targeted four muscle groups bilaterally (gluteal, anterior/posterior thigh, anterior/posterior calf) for 30 seconds per group using a vibration frequency of 28 Hz for the VR condition. Blood samples were taken at baseline (T0), 24 hours (T24), and 48 hours (T48) post-exercise to assess creatine kinase (CK), C-reactive protein (CRP), and interleukin-6 (IL-6). Lower limb flexibility, muscle stiffness, vertical jump performance, and Y-balance test (YBT) were also measured. Eleven participants experienced DOMS and completed studies. No significant interaction effects were observed for any outcome variable. Hamstrings flexibility, YBT scores, and CK levels showed significant time effects, indicating natural recovery over 48 hours. Group differences in CK and YBT remained unchanged over time, indicating no intervention was more effective. In addition, muscle stiffness, jump performance, CRP, and IL-6 levels did not differ between interventions. VR, NVR, and SS produced similar short-term recovery outcomes, with no intervention showing clear superiority. Overall, the changes observed within 48 hours reflected general physiological recovery rather than distinct benefits from any specific intervention.

Key words: Eccentric exercise, exercise-induced muscle damage, creatine kinase, balance; vertical jump, self-myofascial release.

Introduction

Delayed-onset muscle soreness (DOMS) is muscle pain and stiffness that typically occurs 24 to 72 hours after intense or unfamiliar physical activity, particularly exercises involving eccentric muscle contractions (Smith, 1991). In runners, DOMS often results from activities like downhill running, sprinting, or increasing mileage or intensity too quickly (Braun and Dutto, 2003; Cheung et al., 2003). This soreness is caused by microtrauma to muscle fibers, leading to inflammation and temporary loss of strength (Lewis et al., 2012; Stozer et al., 2020). DOMS can lead to increased white blood cell counts and elevated levels of serum creatine kinase (CK), C-reactive protein (CRP), prostaglandins, histamine, and inflammatory cytokines (such as IL-1 and IL-6) (Bruunsgaard et al., 1997; Peake et al., 2005). For runners, DOMS can impair performance by reducing range of motion (Cheung et al., 2003), altering running mechanics (Dutto and Braun, 2004), and increasing the risk of injury if training continues without adequate recovery (Cheung et al., 2003). While DOMS is a natural part of the training adaptation process, minimizing its impact is essential for runners.

Although many methods exist to alleviate DOMS, including static stretching, heat therapy, cold therapy, medication, massage, low-intensity aerobic exercise, and vibration therapy, there is still no consensus on the most effective recovery strategy. Among these methods, whether performed before or after exercise, static stretching has been shown to be ineffective in protecting against DOMS or significantly reducing the risk of injury in a systematic review (Herbert and Gabriel, 2002).

In contrast, whole-body vibration (WBV) appears to be a more promising approach. Performing WBV before eccentric exercise has been found to help prevent the onset of DOMS, possibly by increasing blood flow (Aminian-Far et al., 2011), reducing IL-6 and lymphocyte levels, and decreasing macrophage activation and the associated inflammatory response (Broadbent et al., 2010). Additionally, WBV may improve joint flexibility, which can further help reduce pain perception (Aminian-Far et al., 2011). WBV applied after intense exercise has also been shown to alleviate muscle soreness within 48 hours (Bakhtiary et al., 2007).

Massage is another widely used and effective method for DOMS recovery (Nelson, 2013). Research indicates that performing a 30-minute massage on both legs within two hours after running can significantly reduce DOMS symptoms (Farr et al., 2002). Emerging evidence suggests that if the massage duration (or cumulative dose) is too short, it may not provide meaningful benefits for recovery from DOMS (Boguszewski et al., 2025; Li et al., 2025).

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Although both WBV and massage have been shown to reduce DOMS, each has practical limitations. WBV machines are often too large, difficult to transport, and extremely expensive, making them unsuitable for immediate post-exercise application at sports fields or training sites. Therefore, selecting a portable, field-appropriate exercise device that can deliver effective vibration is particularly important. Similarly, while massage is an effective method for alleviating DOMS, it requires sufficient application time (Boguszewski et al., 2025; Li et al., 2025). It often depends on the availability of licensed personnel, such as physical therapists, athletic trainers, or massage therapists. Consequently, developing accessible and practical solutions for reducing DOMS is crucial.

A vibrating foam roller (VR) has been proposed as a potential alternative for reducing DOMS, which may help overcome these barriers. Foam rolling alone has been shown to alleviate DOMS (Macdonald et al., 2014; Pearcey et al., 2015) through several mechanisms: increasing muscle blood flow (Mori et al., 2004), which helps reduce the production of inflammatory cells and associated inflammatory responses (e.g., serum creatine kinase) (Ye et al., 2024); activating mechanosensory signals (such as COX7B and ND1) to accelerate mitochondrial regeneration and tissue healing (Crane et al., 2012); and decreasing the activation of heat-shock proteins to mitigate inflammation further (Crane et al., 2012).

Incorporating vibration into the foam rolling process may enhance pain relief (Cheatham et al., 2019). However, only a limited number of studies have investigated the effects of vibrating rollers on joint range of motion (Cheatham et al., 2019), jump height (Su et al., 2017), flexibility (Su et al., 2017), muscle strength (Lee et al., 2018), balance (Lee et al., 2018), and pain reduction (Romero-Moraleda et al., 2019). Recent literature highlights that foam rolling studies targeting DOMS generally fall into two categories: (1) protocols applying foam rolling immediately after exercise to mitigate the development of muscle damage and inflammation, and (2) protocols applying foam rolling during the symptomatic DOMS period to alleviate existing soreness. For example, several post-exercise studies have shown reductions in creatine kinase and muscle stiffness when rolling is performed immediately following eccentric activity (Ali et al., 2023; Romero-Moraleda et al., 2019). In contrast, other investigations that applied foam rolling 24 - 48 hours after DOMS induction reported improvements in pain, range of motion, and performance during the recovery phase (Nakamura et al., 2022). Because timing appears to influence physiological and perceptual responses, clearly defining the application window is essential when interpreting foam-rolling efficacy. In the present study, vibration and non-vibration foam rolling were administered immediately after the downhill running protocol, before the onset of DOMS symptoms, placing this investigation within the post-exercise, DOMS-prevention category of the literature.

Therefore, this study aims to investigate whether VR could influence DOMS symptoms, inflammatory responses, and performance outcomes in runners. We hypothesized that VR might produce more favorable changes in inflammatory markers, muscle stiffness, balance, and jump performance compared with non-vibration rolling and static stretching.

Methods

All participants provided written informed consent for this study, which the Institutional Review Board of Kaohsiung Medical University Hospital approved (KMUHIRB-F(I)-20180006). Before the formal trial began, the examiners received comprehensive testing training. Each participant was familiarized with all experimental procedures and testing items.

Participants

A total of 18 experienced adult runners (age was restricted to 20 - 40 years) were recruited. Experienced runners were defined as individuals who have experience in finishing a half-marathon. Exclusion criteria: (1) Less than 3 times of regular exercise per week; (2) History of cardiovascular or neurological disorders; (3) History of asthma; (4) Musculoskeletal injury within 6 months; (5) History of fractures or surgeries involving the hip, knee, ankle, or foot; (6) Taking anti-inflammatory drugs, medications for hypertension and diabetes; (7) Smoking and excessive drinking alcohol; (8) Unable to comply with time for testing (including high-intensity training during the experimental process).

Given the crossover design of this study, the required sample size was determined using G*Power software. The calculation was based on a repeated-measures ANOVA (within-subject factors). An effect size of d = 0.66, an alpha level of 0.05, and a statistical power of 0.80 were applied to estimate the minimum sample size. The assumed moderate effect size was based on a previous VR study reporting a significant reduction in CK compared with control conditions after DOMS induction (Cheng et al., 2022). The analysis indicated that at least ten participants were required to achieve adequate statistical power for the present study. Considering a potential 20% dropout rate and aiming to increase the statistical power further, we ultimately recruited eighteen participants for this investigation.

Experimental Procedure

This study employed a crossover design with pre- and post-intervention assessments (Figure 1). A licensed physical therapist, certified as a basic emergency medical technician, oversaw all testing sessions and delivered the intervention protocols in a one-on-one format to ensure proper technique, monitor exercise performance, target areas for the vibrating foam roller (VR), non-vibrating foam roller (NVR), or static stretching (SS), and ensure participant safety. Participants completed a familiarization session one week before the initiation of data collection.

During the data collection session, after a 5-minute dynamic warm-up, participants completed a maximal oxygen uptake (VO_2 max) test using the Bruce protocol (Bires et al., 2013), followed by a treadmill downhill running protocol designed to induce DOMS (Broadbent et al., 2010). Each participant then underwent a 20-minute intervention targeting the gluteal muscles, quadriceps, hamstrings, and the anterior and posterior compartments of the lower leg bilaterally.

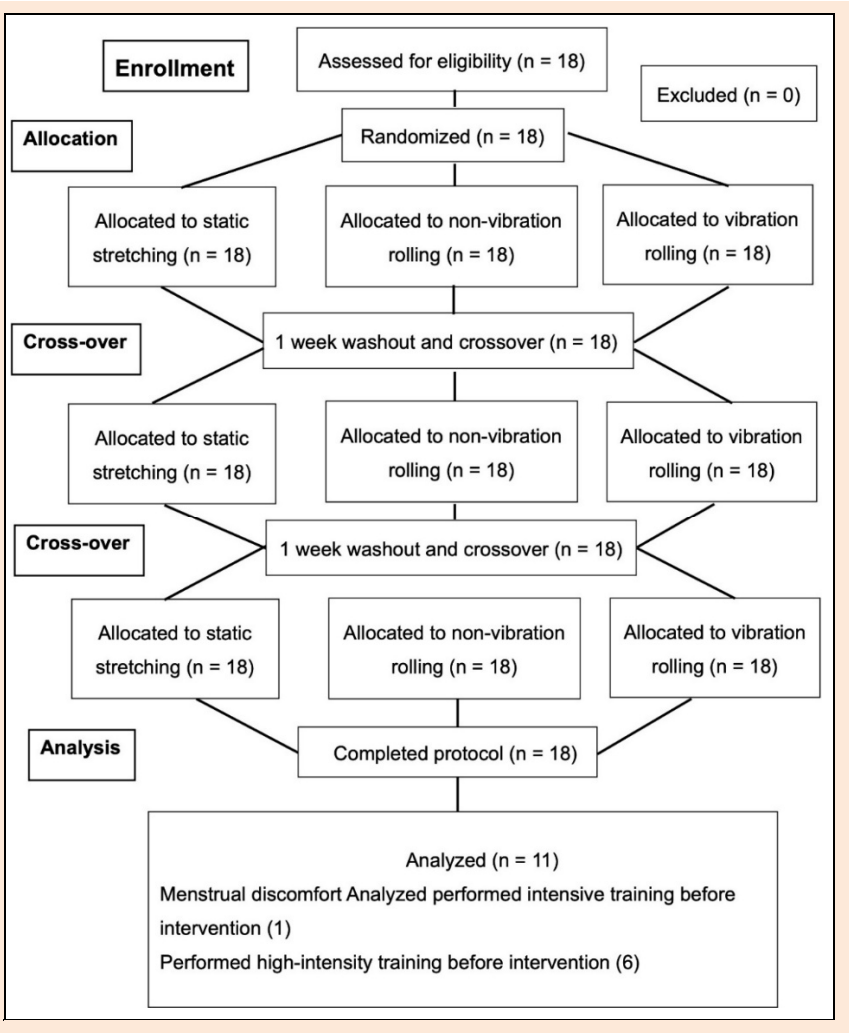

Figure 1. Study flow diagram.

To clarify intervention timing relative to DOMS onset, all recovery conditions (VR, NVR, and SS) were applied immediately after the downhill running protocol designed to induce muscle damage. This timing was selected to match studies evaluating foam rolling as an early, post-exercise recovery strategy rather than as a treatment for muscles already experiencing delayed-onset soreness. Participants completed the rolling or stretching protocol within minutes of the treadmill protocol, prior to the emergence of measurable DOMS symptoms, which typically appear 12 - 24 hours after eccentric exercise.

Outcome measures were collected at three time points: pre-intervention (baseline) (T0), 24 hours (T24), and 48 hours (T48) post-intervention. These measures included blood biomarkers, lower limb flexibility, muscle stiffness, vertical jump performance, and Y-balance test scores. Participants were instructed to refrain from engaging in moderate-to-high-intensity physical activity during the study period to prevent confounding effects. Licensed nursing professionals conducted blood drawing and the handling of biohazardous waste.

Interventions

Vibrating foam roller (VR)

Participants utilized a Vyper vibrating foam roller (Hyperice, California, USA), which consists of an outer polypropylene foam shell and an internal vibration-generating motor. The intervention targeted major lower limb muscle groups, including the gluteal region (primarily the gluteus maximus), anterior thigh (rectus femoris, vastus medialis, vastus lateralis, vastus intermedius), posterior thigh (semimembranosus, semitendinosus, and biceps femoris), anterior lower leg (tibialis anterior and extensor digitorum), and posterior lower leg (gastrocnemius and soleus) (Figure 2A). Each muscle group on both limbs received localized vibration treatment for 30 seconds per set, with four sets per muscle group (30 s/set × 4 sets × 5 muscle groups × 2 limbs). Vibration was applied at a fixed frequency of 28 Hz (Lin et al., 2020), resulting in a total intervention time of 20 minutes.

Non-vibrating foam roller (NVR)

The targeted muscle groups and treatment protocol for the NVR intervention were identical to those used in the vibrating foam roller condition, with the only difference being that the vibration function is turned off. The same foam roller model was selected for both VR and NVR to eliminate potential experimental bias that could arise from differences in outer foam hardness, material composition, or other design features between devices.

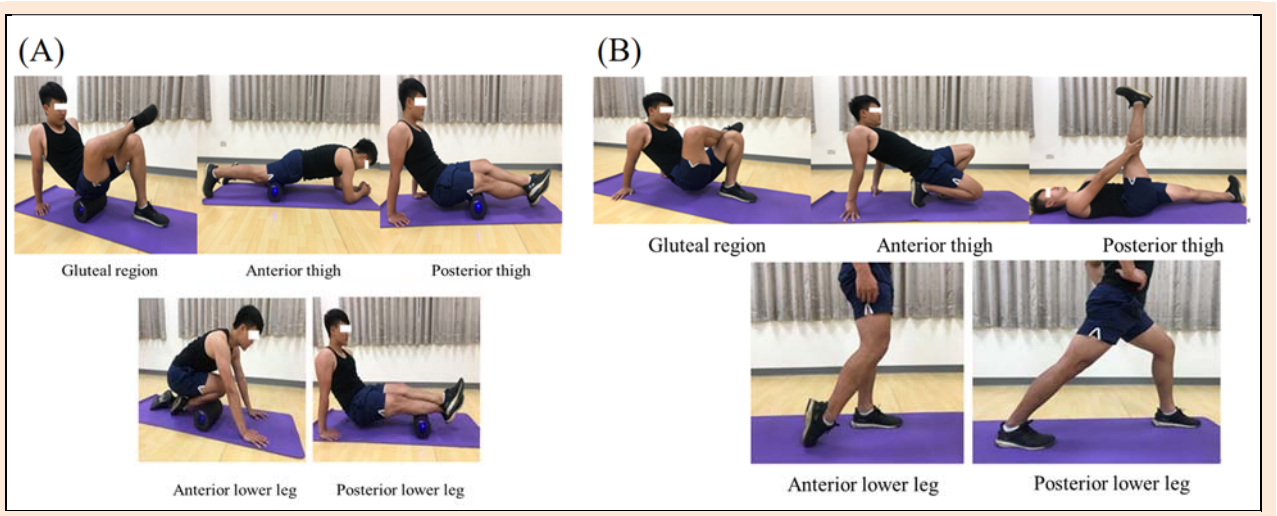

Figure 2. (A) Foam rolling with or without vibration intervention. (B) static stretching.

Static stretching (SS)

The static stretching protocol targeted five major lower limb muscle groups (Figure 2B), with each stretch performed bilaterally for four sets of 30 seconds, held to the point of mild discomfort. The specific stretches were as follows:

Gluteal muscles: Participants sat on the mat with both hands placed behind the body for support. The ankle of the stretching leg was crossed over the opposite knee, and the participant gently leaned forward while lifting the chest to apply tension to the gluteus maximus.

Anterior thigh: Participants performed a kneeling lunge stretch with the rear leg positioned behind the body and the front knee bent. The pelvis was gently pressed forward while keeping the trunk upright to lengthen the rectus femoris and quadriceps group.

Posterior thigh: While lying supine, participants lifted one leg upward with the knee extended and used both hands to hold the posterior thigh or calf. The leg was pulled toward the torso to stretch the hamstrings.

Anterior lower leg: Participants stood with the stretching leg placed slightly behind the body, with the foot gently pointed downward so that the dorsal surface of the toes contacted the ground. Slight backward pressure was applied to stretch the tibialis anterior.

Posterior lower leg: Participants performed a standing calf stretch by stepping one leg forward and keeping the rear heel firmly on the ground. For gastrocnemius, the rear knee remained extended; for soleus, the rear knee was slightly flexed while maintaining the same forward-lean posture.

A licensed physical therapist supervised all static stretches to ensure correct technique and consistent stretching intensity among participants.

Outcome measures

Blood biomarkers (Creatine kinase, CK; C-reactive protein, CRP; interleukin-6, IL-6)

Each participant underwent blood sampling three times (pre-intervention, 24-, and 48-hours post-intervention) per experimental condition, totaling nine blood draws per participant. While seated, blood was drawn from the antecubital vein following disinfection with an alcohol swab. Approximately 12 mL of blood was collected at each time point. Of this, 4 mL was placed into vacuum tubes without adding anticoagulant for hematological analysis, including white blood cell and lymphocyte counts. The remaining 8 mL was collected in gel-containing tubes to accelerate coagulation (approximately 30 minutes). After centrifugation, the gel separated serum from the blood clot, and the resulting serum was used to analyze inflammatory markers, including serum creatine kinase (CK), C-reactive protein (CRP), and interleukin-6 (IL-6). Serum samples were aliquoted into 2 mL centrifuge tubes and stored at -80°C until analysis. IL-6 was quantified by using an enzyme-linked immunosorbent assay. A Chemical Analyzer 16000 (Toshiba, Tokyo, Japan) was used to analyze CK and CRP.

Lower limb flexibility

The Popliteus angle test was used to assess the flexibility of the lower limb, specifically the hamstrings. The participant lay in a supine position with the hip and trunk maintained at a 90° angle. The knee was flexed to 90°, forming an L-shaped position. A goniometer was used to measure the angle, with the fulcrum placed at the lateral epicondyle of the femur. The proximal arm of the goniometer was aligned with the femoral shaft, and the distal arm was aligned with the tibial shaft. In this position, the participant was instructed to extend the knee voluntarily. The measured angle, formed at the posterior aspect of the knee - reflects hamstrings flexibility. In this study, the intraclass correlation coefficient (ICC) of this assessment was 0.94, indicating excellent test–retest reliability.

Muscle stiffness

Muscle stiffness was assessed using the Myoton PRO (Myoton AS, Tallinn, Estonia) before and after the experimental intervention (Lettner et al., 2024). The Myoton PRO device measures the natural oscillation of soft biological tissues in response to a brief mechanical impulse, recording acceleration signals to evaluate tissue damping and frequency response. Muscle stiffness was then quantified based on oscillation frequency. The measurements were taken at the following anatomical landmarks: the midpoint of the quadriceps femoris (Kong et al., 2018), the midpoint of the hamstrings (Kong et al., 2018), the midpoint of the

gastrocnemius muscle (Huang et al., 2018; Kong et al., 2018), and the midpoint of the tibialis anterior muscle (Huang et al., 2018; Kong et al., 2018). In this study, the ICC for this assessment was 0.94 for the quadriceps femoris, 0.96 for the hamstrings, 0.93 for the tibialis anterior, and 0.95 for the gastrocnemius, indicating excellent test–retest reliability.

Vertical jump height

My Jump 2 mobile application was used to measure countermovement jump performance in this study (Cruvinel-Cabral et al., 2018; Gallardo-Fuentes et al., 2016; Haynes et al., 2019; Yingling et al., 2018). Participants performed vertical jumps from a hands-on-hips position, ensuring that the knees remain extended during flight. Jump height was calculated based on the time interval between toe-off and landing, measured under bodyweight-only conditions (i.e., no external load). Participants performed the CMJ at a self-selected pace. They were instructed to perform a rapid, maximal-effort jump. Each participant performed three trials, and the highest value was used for the analysis. In this study, the ICC of this assessment was 0.92, indicating excellent test–retest reliability.

Balance

The Y-balance test (YBT) was used to assess lower limb stability and dynamic balance control. This test is highly reliable, with an intraclass correlation coefficient (ICC) of 0.99 - 1.00 (Linek et al., 2017). Participants were instructed to perform the YBT barefoot to eliminate any potential influence of footwear on lower limb stability and balance. To measure dynamic lower limb stability, the dominant leg was used as the representative limb for each participant.

The procedure began with the participant positioning the toes of their dominant foot on the center of the intersection of the three lines on the YBT grid. Participants then placed their hands on their hips and, using their non-dominant foot, were instructed to reach as far as possible in three directions: anterior, posterior-medial, and posterior-lateral. During the test, participants were required to maintain balance while lightly tapping the ground with their toes. They were asked to hold this position for 3 seconds before returning to the starting point, maintaining balance for 2 seconds, and then placing their foot back on the ground (Butler et al., 2012).

For data analysis, the distance reached in each direction was measured in centimeters. The average distance in each direction across the three trials was calculated to determine the composite YBT score. Results were then normalized by the participant's leg length and multiplied by 100 to standardize the outcomes. In this study, the ICC for this assessment was 0.97.

Statistical analysis

Statistical analysis was conducted using SPSS 20.0 (IBM, Armonk, USA) with a significance level set at $p < 0.05$. Descriptive statistics were used to establish basic information for each group (VR, NVR, SS), including age, height, weight, gender, and running experience. Data normality was assessed using the Shapiro–Wilk test. For each outcome, a two-way repeated-measures ANOVA (group × time) was conducted. When a significant interaction effect was detected, Bonferroni-adjusted post hoc tests were applied for pairwise comparisons as appropriate.

Results

A total of 18 runners were initially enrolled in this study; however, 7 participants were excluded from the analysis. One participant was excluded due to menstrual discomfort, and 6 participants performed high-intensity training during the experimental period. Therefore, the final analysis included 11 participants (3 females: age 20.7 ± 1.5 years, height 158.3 ± 4.7 cm, weight 51.0 ± 2.6 kg, running experience 3.7 ± 0.6 years; 8 males: age 27.0 ± 8.4 years, height 175.4 ± 6.4 cm, weight 75.6 ± 10.7 kg, running experience 7.0 ± 4.9 years).

Blood biomarkers

CK showed no significant interaction effect ($p = 0.50$), but both a significant time effect ($p < 0.01$) and a significant group effect ($p < 0.001$). CK levels increased at 24 hours across all groups compared with baseline. By 48 hours, CK values began to decline (Figure 3).

CRP demonstrated no significant interaction ($p = 0.41$), no time effect ($p = 0.83$), and no group effect ($p = 0.41$). CRP values remained similar across time points and interventions.

IL-6 showed no significant interaction effect ($p = 0.49$), no time effect ($p = 0.41$), and no group effect ($p = 0.62$). IL-6 levels did not differ among groups at any time point.

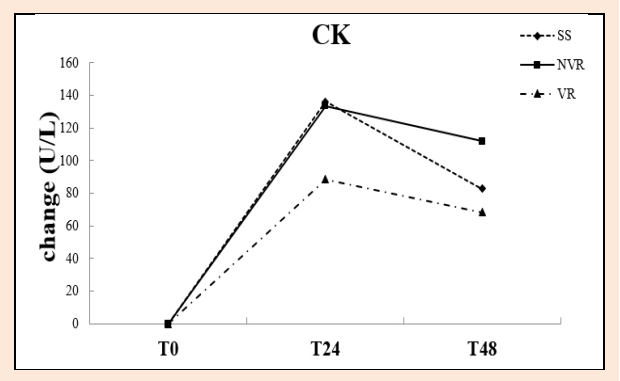

Figure 3. Changes in creatine kinase levels over time following interventions.

Lower limb flexibility

The popliteus angle test showed no significant interaction effect ($p = 0.16$) and no group effect ($p = 0.06$). A significant time effect was observed ($p = 0.03$), indicating that knee joint flexibility improved over the 48-hour period across all interventions (Figure 4).

Muscle stiffness

No significant interaction effects were observed for the quadriceps ($p = 0.97$), hamstrings ($p = 0.25$, Figure 5), tibialis anterior ($p = 0.76$), or calf muscles ($p = 0.22$, Figure 6). In addition, no significant time or group effects were detected for any muscle group (all $p > 0.05$), indicating that stiffness did not change over the 48-hour period regardless of intervention.

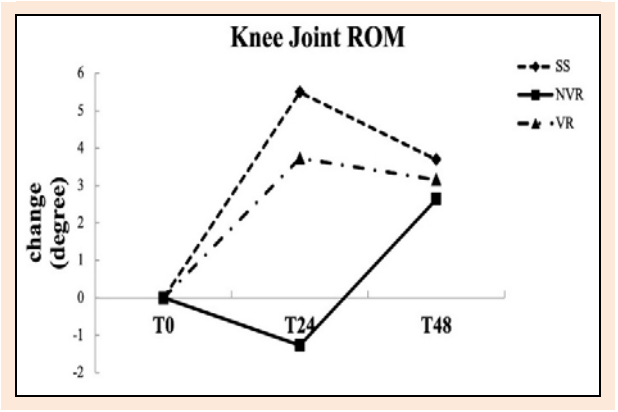

Figure 4. Changes in knee joint range of motion over time following interventions.

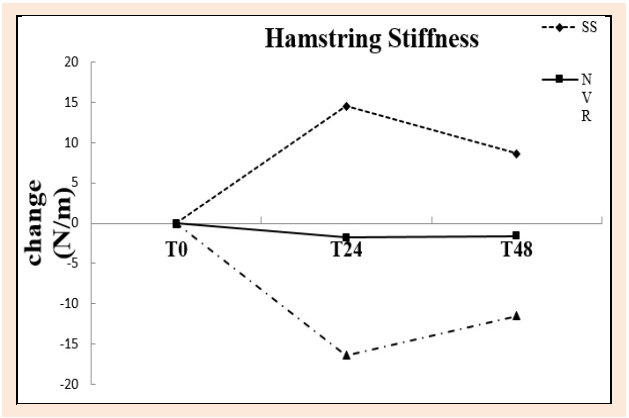

Figure 5. Changes in hamstrings stiffness over time following interventions.

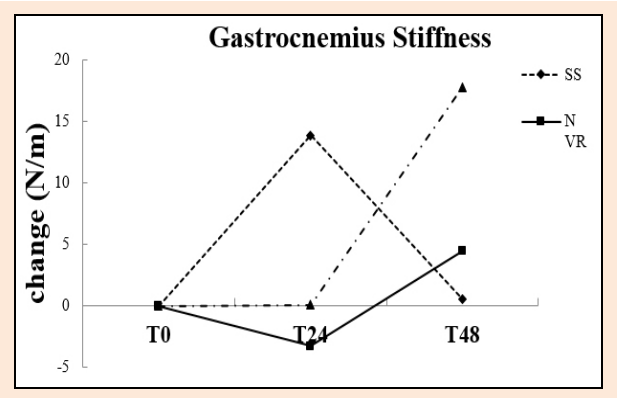

Figure 6. Changes in gastrocnemius stiffness over time following interventions.

Vertical jump height

Jump performance showed no significant interaction effect ($p = 0.51$), no group effect ($p = 0.55$), and no time effect ($p = 0.35$) (Figure 7).

Balance

For the Y-balance test (YBT), no significant interaction effect was observed ($p = 0.55$). Significant group ($p < 0.01$) and time effects ($p = 0.02$) were found, indicating overall differences in YBT scores among groups and improvements over time (Figure 8).

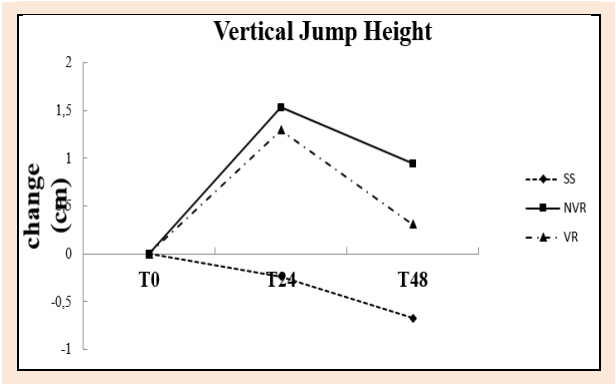

Figure 7. Changes in vertical jump height over time following interventions.

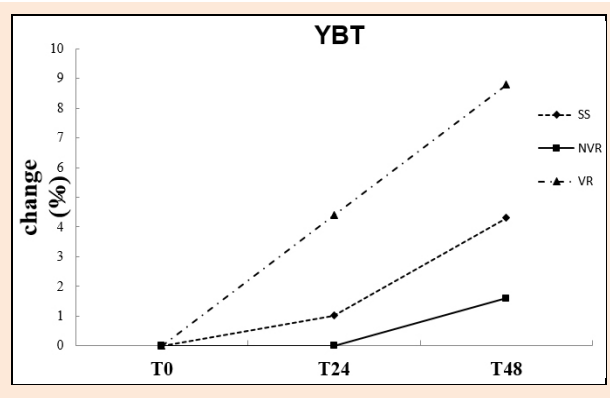

Figure 8. Changes in YBT scores over time following interventions.

Discussion

The purpose of this study was to examine the effects of VR, NVR, and SS on DOMS-related symptoms, inflammatory responses, and performance outcomes in trained runners. Across the 48-hour period, CK, flexibility, and YBT performance demonstrated significant time effects, whereas CRP, IL-6, muscle stiffness, and jump height did not show statistically significant improvements. Furthermore, no interaction effects were detected for any variable, indicating that the improvements observed over time reflected the natural resolution of DOMS rather than modality-specific treatment effects.

The downhill running protocol successfully induced DOMS, as reflected by CK elevations meeting established diagnostic thresholds (Nardin et al., 2009). The presence of muscle soreness alone is not a sufficient diagnostic criterion for DOMS (Lewis et al., 2012). Instead, biochemical markers, in particular CK, remain among the most informative indicators of muscle membrane disruption and exercise-induced muscle damage (Lewis et al., 2012). Among these, CK is recognized as an indirect but robust marker of muscle injury, reflecting disruptions in muscle fiber membrane integrity following its release into circulation, potentially due to alterations in osmotic balance (Hotfiel et al., 2018). In this study, CK increased at 24 hours in all groups and returned to baseline only in the VR group by 48 hours. However, the absence of a significant interaction effect suggests that these temporal changes represent the natural resolution of muscle damage rather than a modality-specific treatment effect. This pattern suggests a typical time

course of exercise-induced muscle damage and recovery, but does not support a modality-specific acceleration of systemic recovery. In addition, neither IL-6 nor CRP markers changed significantly in the present study. Previous studies on DOMS and non-pharmacological recovery strategies showed that systemic inflammatory markers may remain unchanged after moderate muscle-damaging exercise or after certain recovery modalities (Akinci et al., 2020; Park and Kim, 2025; Szajkowski et al., 2025; Tanabe et al., 2015). Biomarker clearance is a systemic process involving the liver and spleen (Chalchat et al., 2022). The reticuloendothelial system relies on specific uptake mechanisms that operate at biologically determined rates. While either foam rolling with or without vibration and stretching might transiently increase local perfusion or lymphatic uptake at the site of injury, it cannot upregulate the systemic enzymatic activity of the reticuloendothelial system (Muslimovic et al., 2020). Consequently, systemic inflammatory biomarkers may not be sensitive to moderate degrees of localized muscle damage (ie, DOMS) in all experimental treatments.

With regard to stretching, our findings are consistent with evidences indicating that post-exercise stretching, when used as a standalone recovery intervention, does not meaningfully improve soreness, strength, performance, flexibility, or pain threshold when compared with no stretching (Afonso et al., 2021; Zhang et al., 2025). Afonso et al. concluded that stretching should not be relied upon as a primary recovery technique. Zhang et al. reported trivial, non-significant standardized mean differences across all key outcome domains, suggesting that stretching is physiologically safe but has limited efficacy as a primary recovery strategy. Similarly, a randomized trial on different intensities of passive static stretching found only modest benefits and no clear advantages in the recovery of muscle function or soreness compared with control (Apostolopoulos et al., 2018). In line with this study, SS did not produce superior outcomes for inflammatory markers, muscle stiffness, flexibility, or jump performance. Athletes may feel “comfort” because pain signals are dampened via gate control mechanisms after external stimulation (e.g., VR, FR, SS), while the underlying physiological status remains essentially unchanged.

No statistically significant differences were observed among the VR, NVR, and SS groups in overall muscle stiffness across the quadriceps, hamstrings, tibialis anterior, and calf muscles. However, previous research has shown that VR acutely reduced passive stiffness (Nakamura et al., 2022), potentially through mechanoreceptor-mediated modulation of sympathetic tone (Behm and Wilke, 2019). However, other studies have failed to demonstrate clear superiority of VR or NVR over other strategies in modifying mechanical properties or neuromuscular function during recovery (Akinci et al., 2020; de Benito et al., 2019). A recent meta-analysis indicated that NVR's effects on performance and recovery are relatively minor and largely negligible (Warneke et al., 2024). Although VR increased skin blood flow more than NVR, without statistically significant between-condition differences in perfusion (Lai et al., 2020), highlighting that physiological changes do not necessarily translate into clear functional gain. A recent systematic review found that VR may reduce subjective fatigue and DOMS. However, findings across studies were inconsistent, particularly in physiological markers, where statistically significant differences were not always observed (Park and Kim, 2025). These findings support emerging evidence that most recovery modalities exert minimal influence on muscle mechanical properties following DOMS. In addition, Cheng et al. suggested that low-frequency stimulation at 25 Hz (3-mm amplitude) had poorer effects than high-frequency stimulation at 50 Hz (Cheng et al., 2022). In the present study, we chose VR of 28 Hz based on a previous study indicating reduced muscle stiffness in athletes (Lin et al., 2020). However, that study primarily examined warm-up effects (pre-rolling), which may not directly translate to recovery effects (post-rolling) after a DOMS-inducing protocol.

Vertical jump height remained unchanged across time and intervention groups, consistent with reports that acute VR or NVR interventions do not enhance explosive performance following DOMS (Afonso et al., 2021; Alonso-Calvete et al., 2022). This contrasts with studies reporting performance improvements following chronic vibration training (Rosenberger et al., 2017). That study emphasized the importance of chronic vibration exposure and load progression in eliciting neuromuscular adaptations. In contrast, the present study utilized a single post-DOMS recovery session, which may have been insufficient to produce measurable gains in power-based performance. Y-balance test scores demonstrated significant time and group effects, with VR showing higher mean values at 24 and 48 hours. While these differences suggest that VR may confer benefits in dynamic balance, the absence of an interaction effect prevents attributing these improvements directly to the intervention. Previous research has demonstrated acute YBT enhancements following 3 × 60 seconds static squats on a vibration platform (Cloak et al., 2016). Still, the present findings indicate that all three interventions followed a similar recovery trajectory. A previous study reported that both VR and NVR improved YBT reach distances, but there were no additional benefits of VR, implying only trivial-to-small incremental effects of adding vibration (de Benito et al., 2019).

Overall, when considering symptom attenuation, restoration of muscle function, and resolution of inflammatory responses, DOMS appears largely self-limiting, and the added value of short-term interventions beyond the body’s intrinsic healing processes seems limited. Several limitations should be considered when interpreting the results of this study. First, this real-world crossover trial in experienced runners resulted in a modest final sample size because six participants were excluded due to unavoidable high-intensity training and competition commitments, which may have reduced the statistical power to detect between-condition differences. In future studies with larger samples, it would be valuable to investigate potential responders and non-responders further. Second, the study included only healthy young runners with limited variability in physical conditioning and in their responses to DOMS, which may limit the generalizability of the findings to

broader populations, such as older adults, clinical populations, or elite athletes. Third, this study examined only "a single bout" of each intervention; therefore, the effects of repeated applications remain unclear. Future work should investigate the "repeated bout effect" of continued daily use over consecutive days beyond 48 hours. Fourth, the study did not include a true control group without intervention, which limits the ability to isolate the treatment effects from natural recovery fully. Fifth, while the study measured outcomes related to flexibility, muscle stiffness, and performance, it did not assess underlying neuromuscular mechanisms (e.g., electromyography and proprioception) that could explain the observed differences. Lastly, the post-intervention follow-up was limited to 48 hours, which may not capture longer-term recovery patterns or delayed responses beyond this timeframe. Future research with larger and more diverse samples, longer follow-up durations, and physiological measurements, as well as monitoring sleep and nutrition conditions, is warranted to better understand the mechanisms and long-term efficacy of vibration-based recovery interventions.

Conclusion

VR, NVR, and SS produced similar short-term recovery outcomes, with no intervention showing clear superiority. Overall, the changes observed within 48 hours reflected general physiological recovery rather than distinct benefits from any specific intervention. For practical applications, VR, NVR, and SS produce equivalent short-term recovery profiles following DOMS in trained runners. Since recovery beyond 48 hours appears to be primarily driven by natural physiological processes, these techniques may be used as adjuncts rather than primary treatments, chosen based on the athlete's preferences, comfort, time availability, and equipment access. VR, NVR, and SS may help some athletes feel subjectively "looser or relaxed", and current evidence does not show harmful effects on performance; however, expected benefits in terms of ROM, stiffness, or biochemical markers should be considered modest. Clinicians and coaches should therefore be cautious about promoting any of these modalities as a physiological recovery accelerator for DOMS-related symptoms.

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References

Afonso, J., Clemente, F.M., Nakamura, F.Y., Morouço, P., Sarmento, H., Inman, R.A. and Ramirez-Campillo, R. (2021) The effectiveness of post-exercise stretching in short-term and delayed recovery of strength, range of motion and delayed onset muscle soreness: A systematic review and meta-analysis of randomized controlled trials. *Frontiers in Physiology* **12**, 677581. https://doi.org/10.3389/fphys.2021.677581

Akinci, B., Zenginler Yazgan, Y. and Altinoluk, T. (2020) The effectiveness of three different recovery methods on blood lactate, acute muscle performance, and delayed-onset muscle soreness: a randomized comparative study. *Journal of Sports Medicine and Physical Fitness* **60**, 345-354. https://doi.org/10.23736/S0022-4707.19.10142-9

Ali, M., Pangestu, B., Rahayu, S., Anggita, G.M., Kurniawati, D., Noer, E. and Mohamed, A. (2023) Foam rolling reduced total creatine kinase in acute muscle inflammation following long-distance running. *Journal of Sport Area* **8**, 117-122. https://doi.org/10.25299/sportarea.2023.vol8(1).12144

Alonso-Calvete, A., Lorenzo-Martínez, M., Padrón-Cabo, A., Pérez-Ferreirós, A., Kalén, A., Abelairas-Gómez, C. and Rey, E. (2022) Does vibration foam roller influence performance and recovery? A systematic review and meta-analysis. *Sports Medicine - Open* **8**, 32. https://doi.org/10.1186/s40798-022-00421-2

Aminian-Far, A., Hadian, M.R., Olyaei, G., Talebian, S. and Bakhtiary, A.H. (2011) Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. *Journal of Athletic Training* **46**, 43-49. https://doi.org/10.4085/1062-6050-46.1.43

Apostolopoulos, N.C., Lahart, I.M., Plyley, M.J., Taunton, J., Nevill, A.M., Koutedakis, Y., Wyon, M. and Metsios, G.S. (2018) The effects of different passive static stretching intensities on recovery from unaccustomed eccentric exercise: a randomized controlled trial. *Applied Physiology, Nutrition, and Metabolism* **43**, 806-815. https://doi.org/10.1139/apnm-2017-0841

Bakhtiary, A.H., Safavi-Farokhi, Z. and Aminian-Far, A. (2007) Influence of vibration on delayed onset of muscle soreness following eccentric exercise. *British Journal of Sports Medicine* **41**, 145-148. https://doi.org/10.1136/bjsm.2006.031278

Behm, D.G. and Wilke, J. (2019) Do self-myofascial release devices release myofascia? Rolling mechanisms: A narrative review. *Sports Medicine* **49**, 1173-1181. https://doi.org/10.1007/s40279-019-01149-y

Bires, A.M., Lawson, D., Wasser, T.E. and Raber-Baer, D. (2013) Comparison of Bruce treadmill exercise test protocols: is ramped Bruce equal or superior to standard Bruce in producing clinically valid studies for patients presenting for evaluation of cardiac ischemia or arrhythmia with body mass index equal to or greater than 30? *Journal of Nuclear Medicine Technology* **41**, 274-278. https://doi.org/10.2967/jnmt.113.124727

Boguszewski, D., Kaaroud, C. and Adamczyk, J. (2025) Assessment of the effect of classic sports massage on the reduction of delayed onset muscle soreness in the rectus abdominis. *Baltic Journal of Health and Physical Activity* **17**, 9-9. https://doi.org/10.29359/BJHPA.17.1.09

Braun, W.A. and Dutto, D.J. (2003) The effects of a single bout of downhill running and ensuing delayed onset of muscle soreness on running economy performed 48 h later. *European Journal of Applied Physiology* **90**, 29-34. https://doi.org/10.1007/s00421-003-0857-8

Broadbent, S., Rousseau, J.J., Thorp, R.M., Choate, S.L., Jackson, F.S. and Rowlands, D.S. (2010) Vibration therapy reduces plasma IL6 and muscle soreness after downhill running. *British Journal of Sports Medicine* **44**, 888-894. https://doi.org/10.1136/bjsm.2008.052100

Bruunsgaard, H., Galbo, H., Halkjaer-Kristensen, J., Johansen, T.L., MacLean, D.A. and Pedersen, B.K. (1997) Exercise-induced increase in serum interleukin-6 in humans is related to muscle damage. *Journal of Physiology* **499**, 833-841. https://doi.org/10.1113/jphysiol.1997.sp021972

Butler, R.J., Southers, C., Gorman, P.P., Kiesel, K.B. and Plisky, P.J. (2012) Differences in soccer players' dynamic balance across levels of competition. *Journal of Athletic Training* **47**, 616-620. https://doi.org/10.4085/1062-6050-47.5.14

Chalchat, E., Gaston, A.F., Charlot, K., Peñailillo, L., Valdés, O., Tardo-Dino, P.E., Nosaka, K., Martin, V., Garcia-Vicencio, S. and Siracusa, J. (2022) Appropriateness of indirect markers of muscle damage following lower limbs eccentric-biased exercises: A systematic review with meta-analysis. *PLOS ONE* **17**, e0271233. https://doi.org/10.1371/journal.pone.0271233

Cheatham, S.W., Stull, K.R. and Kolber, M.J. (2019) Comparison of a vibration roller and a nonvibration roller intervention on knee range of motion and pressure pain threshold: A randomized controlled trial. *Journal of Sport Rehabilitation* **28**, 39-45. https://doi.org/10.1123/jsr.2017-0164

Cheng, L., Wang, K., He, B. and Yan, Y. (2022) Effect of vertical vibration stimulation at different frequencies on delayed muscle soreness in athletes: A randomized trial. *Frontiers in Public Health* **10**, 980454. https://doi.org/10.3389/fpubh.2022.980454

Cheung, K., Hume, P. and Maxwell, L. (2003) Delayed onset muscle soreness: treatment strategies and performance factors. *Sports Medicine* **33**, 145-164. https://doi.org/10.2165/00007256-200333020-00005

Cloak, R., Nevill, A. and Wyon, M. (2016) The acute effects of vibration training on balance and stability amongst soccer players. *European Journal of Sport Science* **16**, 20-26. https://doi.org/10.1080/17461391.2014.973912

Crane, J.D., Ogborn, D.I., Cupido, C., Melov, S., Hubbard, A., Bourgeois, J.M. and Tarnopolsky, M.A. (2012) Massage therapy attenuates inflammatory signaling after exercise-induced muscle damage. *Science Translational Medicine* **4**, 119ra13. https://doi.org/10.1126/scitranslmed.3002882

Cruvinel-Cabral, R. M., Oliveira-Silva, I., Medeiros, A. R., Claudino, J. G., Jiménez-Reyes, P. and Boullosa, D. A. (2018) The validity and reliability of the "My Jump App" for measuring jump height of the elderly. *PeerJ* **6**, e5804. https://doi.org/10.7717/peerj.5804

de Benito, A. M., Valldecabres, R., Ceca, D., Richards, J., Barrachina Igual, J. and Pablos, A. (2019) Effect of vibration vs non-vibration foam rolling techniques on flexibility, dynamic balance and perceived joint stability after fatigue. *PeerJ* **7**, e8000. https://doi.org/10.7717/peerj.8000

Dutto, D. J. and Braun, W. A. (2004) DOMS-associated changes in ankle and knee joint dynamics during running. *Medicine and Science in Sports and Exercise* **36**, 560-566. https://doi.org/10.1249/01.MSS.0000121957.83226.CC

Farr, T., Nottle, C., Nosaka, K. and Sacco, P. (2002) The effects of therapeutic massage on delayed onset muscle soreness and muscle function following downhill walking. *Journal of Science and Medicine in Sport* **5**, 297-306. https://doi.org/10.1016/S1440-2440(02)80018-4

Gallardo-Fuentes, F., Gallardo-Fuentes, J., Ramirez-Campillo, R., Balsalobre-Fernandez, C., Martinez, C., Caniuqueo, A., Canas, R., Banzer, W., Loturco, I., Nakamura, F. Y. and Izquierdo, M. (2016) Intersession and intrasession reliability and validity of the My Jump App for measuring different jump actions in trained male and female athletes. *Journal of Strength and Conditioning Research* **30**, 2049-2056. https://doi.org/10.1519/JSC.0000000000001304

Haynes, T., Bishop, C., Antrobus, M. and Brazier, J. (2019) The validity and reliability of the My Jump 2 app for measuring the reactive strength index and drop jump performance. *Journal of Sports Medicine and Physical Fitness* **59**, 253-258. https://doi.org/10.23736/S0022-4707.18.08195-1

Herbert, R. D. and Gabriel, M. (2002) Effects of stretching before and after exercising on muscle soreness and risk of injury: Systematic review. *BMJ* **325**, 468. https://doi.org/10.1136/bmj.325.7362.468

Hotfiel, T., Freiwald, J., Hoppe, M. W., Lutter, C., Forst, R., Grim, C., Bloch, W., Hüttel, M. and Heiss, R. (2018) Advances in delayed-onset muscle soreness (DOMS): Part I: Pathogenesis and diagnostics. *Sportverletz Sportschaden* **32**, 243-250. https://doi.org/10.1055/a-0753-1884

Huang, J., Qin, K., Tang, C., Zhu, Y., Klein, C. S., Zhang, Z. and Liu, C. (2018) Assessment of passive stiffness of medial and lateral heads of gastrocnemius muscle, Achilles tendon, and plantar fascia at different ankle and knee positions using the MyotonPRO. *Medical Science Monitor* **24**, 7570-7576. https://doi.org/10.12659/MSM.909550

Kong, P. W., Chua, Y. H., Kawabata, M., Burns, S. F. and Cai, C. (2018) Effect of post-exercise massage on passive muscle stiffness measured using myotonometry - a double-blind study. *Journal of Sports Science and Medicine* **17**, 599-606. https://pubmed.ncbi.nlm.nih.gov/30479528/

Lai, Y. H., Wang, A. Y., Yang, C. C. and Guo, L. Y. (2020) The recovery benefit on skin blood flow using vibrating foam rollers for postexercise muscle fatigue in runners. *International Journal of Environmental Research and Public Health* **17**, 9118. https://doi.org/10.3390/ijerph17239118

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

Lettner, J., Królikowska, A., Ramadanov, N., Oleksy, Ł., Hakam, H. T., Becker, R. and Prill, R. (2024) Evaluating the reliability of MyotonPRO in assessing muscle properties: A systematic review of diagnostic test accuracy. *Medicina* **60**. https://doi.org/10.3390/medicina60060851

Lewis, P. B., Ruby, D. and Bush-Joseph, C. A. (2012) Muscle soreness and delayed-onset muscle soreness. *Clinical Sports Medicine* **31**, 255-262. https://doi.org/10.1016/j.csm.2011.09.009

Li, H., Luo, L., Zhang, J., Cheng, P., Wu, Q. and Wen, X. (2025) The effect of percussion massage therapy on the recovery of delayed onset muscle soreness in physically active young men: A randomized controlled trial. *Frontiers in Public Health* **13**. https://doi.org/10.3389/fpubh.2025.1561970

Lin, W. C., Lee, C. L. and Chang, N. J. (2020) Acute effects of dynamic stretching followed by vibration foam rolling on sports performance of badminton athletes. *Journal of Sports Science and Medicine* **19**, 420-428. https://pubmed.ncbi.nlm.nih.gov/32390736/

Linek, P., Sikora, D., Wolny, T. and Saulicz, E. (2017) Reliability and number of trials of Y Balance Test in adolescent athletes. *Musculoskeletal Science and Practice* **31**, 72-75. https://doi.org/10.1016/j.msksp.2017.03.011

Macdonald, G. Z., Button, D. C., Drinkwater, E. J. and Behm, D. G. (2014) Foam rolling as a recovery tool after an intense bout of physical activity. *Medicine and Science in Sports and Exercise* **46**, 131-142. https://doi.org/10.1249/MSS.0b013e3182a123db

Mori, H., Ohsawa, H., Tanaka, T. H., Taniwaki, E., Leisman, G. and Nishijo, K. (2004) Effect of massage on blood flow and muscle fatigue following isometric lumbar exercise. *Medical Science Monitor* **10**, 173-178.

Muslimovic, A., Fridén, V., Starnberg, K., Tenstad, O., Espedal, H., Vukusic, K., Nyström, S., Wesén, E., Esbjörner, E. K., Granholm, K., Lindahl, B. and Hammarsten, O. (2020) Novel clearance of muscle proteins by muscle cells. *European Journal of Cell Biology* **99**, 151127. https://doi.org/10.1016/j.ejcb.2020.151127

Nakamura, M., Sato, S., Kiyono, R., Yoshida, R., Yasaka, K., Yahata, K. and Konrad, A. (2022) Comparison between foam rolling with and without vibration on passive and active plantar flexor muscle properties. *Journal of Strength and Conditioning Research* **36**, 3339-3344. https://doi.org/10.1519/JSC.0000000000004123

Nardin, R.A., Zarrin, A.R., Horowitz, G.L. and Tarulli, A.W. (2009) Effect of newly proposed CK reference limits on neuromuscular diagnosis. *Muscle & Nerve* **39**, 494-497. https://doi.org/10.1002/mus.21258

Nelson, N. (2013) Delayed onset muscle soreness: Is massage effective? *Journal of Bodywork and Movement Therapies* **17**, 475-482. https://doi.org/10.1016/j.jbmt.2013.03.002

Park, S. and Kim, B. (2025) Effects of vibration foam rolling on pain, fatigue, and range of motion in individuals with muscle fatigue: A systematic review. *Healthcare* **13**. https://doi.org/10.3390/healthcare13121391

Peake, J., Nosaka, K. and Suzuki, K. (2005) Characterization of inflammatory responses to eccentric exercise in humans. *Exercise Immunology Review* **11**, 64-85.

Pearcey, G.E., Bradbury-Squires, D.J., Kawamoto, J.E., Drinkwater, E.J., Behm, D.G. and Button, D.C. (2015) Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *Journal of Athletic Training* **50**, 5-13. https://doi.org/10.4085/1062-6050-50.1.01

Romero-Moraleda, B., González-García, J., Cuéllar-Rayo, Á., Balsalobre-Fernández, C., Muñoz-García, D. and Morencos, E. (2019) Effects of vibration and non-vibration foam rolling on recovery after exercise with induced muscle damage. *Journal of Sports Science and Medicine* **18**, 172-180. https://pubmed.ncbi.nlm.nih.gov/30787665/

Rosenberger, A., Beijer, Å., Johannes, B., Schoenau, E., Mester, J., Rittweger, J. and Zange, J. (2017) Changes in muscle cross-sectional area, muscle force, and jump performance during 6 weeks of progressive whole-body vibration combined with progressive, high intensity resistance training. *Journal of Musculoskeletal & Neuronal Interactions* **17**, 38-49.

Smith, L.L. (1991) Acute inflammation: The underlying mechanism in delayed onset muscle soreness? *Medicine & Science in Sports &*

Exercise **23**, 542-551. https://doi.org/10.1249/00005768-199105000-00006

Stozer, A., Vodopivc, P. and Krizancic Bombek, L. (2020) Pathophysiology of exercise-induced muscle damage and its structural, functional, metabolic, and clinical consequences. *Physiological Research* **69**, 565-598. https://doi.org/10.33549/physiolres.934371

Su, H., Chang, N.J., Wu, W.L., Guo, L.Y. and Chu, I.H. (2017) Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. *Journal of Sport Rehabilitation* **26**, 469-477. https://doi.org/10.1123/jsr.2016-0102

Szajkowski, S., Pasek, J. and Cieślar, G. (2025) Foam rolling or percussive massage for muscle recovery: Insights into delayed-onset muscle soreness (DOMS). *Journal of Functional Morphology and Kinesiology* **10**. https://doi.org/10.3390/jfmk10030249

Tanabe, Y., Maeda, S., Akazawa, N., Zempo-Miyaki, A., Choi, Y., Ra, S.G., Imaizumi, A., Otsuka, Y. and Nosaka, K. (2015) Attenuation of indirect markers of eccentric exercise-induced muscle damage by curcumin. *European Journal of Applied Physiology* **115**, 1949-1957. https://doi.org/10.1007/s00421-015-3170-4

Warneke, K., Plöschberger, G., Lohmann, L.H., Lichtenstein, E., Jochum, D., Siegel, S.D., Zech, A. and Behm, D.G. (2024) Foam rolling and stretching do not provide superior acute flexibility and stiffness improvements compared to any other warm-up intervention: A systematic review with meta-analysis. *Journal of Sport and Health Science* **13**, 509-520. https://doi.org/10.1016/j.jshs.2024.01.006

Ye, D., Kim, D., Kim, E., Byun, Y. and Yoon, S. (2024) Effect of the application of vibration foam rollers before and after resistance exercise on blood muscle injury markers and muscle stiffness. *Korean Journal of Health Promotion* **24**, 93-100. https://doi.org/10.15384/kjhp.2024.00094

Yingling, V.R., Castro, D.A., Duong, J.T., Malpartida, F.J., Usher, J.R. and O, J. (2018) The reliability of vertical jump tests between the Vertec and My Jump phone application. *PeerJ* **6**, e4669. https://doi.org/10.7717/peerj.4669

Zhang, P., Chen, J. and Xing, T. (2025) Effects of post-exercise stretching versus no stretching on lower limb muscle recovery and performance: A meta-analysis. *Frontiers in Physiology* **16**, 1674871. https://doi.org/10.3389/fphys.2025.1674871

Key points

- This was the first study to examine the effects of a single bout of vibrating foam rollers (VR) on delayed-onset muscle soreness (DOMS), inflammation, and performance recovery in experienced runners.
- Flexibility, balance performance, and creatine kinase levels improved over 48 hours, consistent with normal post-exercise recovery.
- Muscle stiffness, jump performance, C-reactive protein, and interleukin-6 did not show significant changes across the interventions.
- None of a single bout of three modalities demonstrated superior effects; VR, NVR, and SS resulted in comparable short-term recovery outcomes.
- These findings indicate that recovery from DOMS during the first 48 hours mainly follows the body's natural healing process, with no clear added benefit from any specific intervention.

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