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Research article

Effects of Percussive Massage Treatments on Symptoms Associated with Eccentric Exercise-Induced Muscle Damage

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Abstract

Percussive massage (PM) is an emerging recovery treatment despite the lack of research on its effects post-eccentric exercise (post-EE). This study investigated the effects of PM treatments (immediately, 24, 48, and 72 h post-EE) on the maximal isometric torque (MIT), range of motion (ROM), and an 11-point numerical rating scale (NRS) of soreness of the nondominant arm's biceps brachii from 24 - 72 h post-EE. Seventeen untrained, college-aged subjects performed 60 eccentric elbow flexion actions with their nondominant arms. Nine received 1 minute of PM, versus eight who rested quietly (control [CON]). In order, NRS, ROM, and MIT (relative to body mass) were collected pre-eccentric exercise (pre-EE) and after treatment (AT) at 24, 48, and 72 h post-EE. NRS was also collected before treatment (BT). Electromyographic (EMG) and mechanomyographic (MMG) amplitudes were collected during the MIT and normalized to pre-EE. There were no interactions for MIT, EMG, or MMG, but there were interactions for ROM and NRS. For ROM, the PM group had higher values than the CON 24-72 h by ~6-8°, a faster return to pre-EE (PM: 48 h, CON: 72 h), and exceeded their pre-EE at 72 h by ~4°. The groups' NRS values did not differ BT 24-72 h; however, the PM group lowered their NRS from BT to AT within every visit by ~1 point per visit, which resulted in them having lower values than the CON from 24-72 h by ~2-3 points. Additionally, the PM group returned their NRS to pre-EE faster than the CON (PM: BT 72 h, CON: never). In conclusion, PM treatments may improve ROM without affecting isometric strength or muscle activation 24 - 72 h post-EE. Although the PM treatments did not enhance the recovery from delayed onset muscle soreness until 72 h, they consistently provided immediate, temporary relief when used 24 - 72 h post-EE.

Key words: Percussion, massage gun, vibration, delayed onset muscle soreness, recovery, muscular strength.

Introduction

It is well understood that highly intense eccentric actions often result in exercise-induced muscle damage (Clarkson and Hubal, 2002). Delayed onset muscle soreness (DOMS), and decreased range of motion (ROM) and strength are common symptoms that may follow eccentric exercise (Cheung et al., 2003; Warren et al., 1999). Thus, researchers have investigated numerous passive (Cullen et al., 2021) and active (Fares et al., 2022) recovery strategies to help benefit athletes needing to maintain or improve performance levels following frequent training sessions and competitions (Kellmann et al., 2018) or individuals wanting a faster return to daily activities. Handheld percussive massage (PM) devices, such as the Hypervolt or Theragun, have recently gained popularity (Cheatham et al., 2021) and would be considered a passive recovery strategy (Cullen et al., 2021).

Despite the rise in popularity, only two peer-reviewed articles have investigated the effects of PM on symptoms associated with exercise-induced muscle damage (García-Sillero et al., 2021; Leabeater et al., 2023). García-Sillero et al. (2021) used a limb-to-limb design (i.e., treatment vs. control limb) with the gastrocnemius muscle to compare PM to three other treatment strategies. They concluded that PM, followed by 4 sets of 12 eccentric actions on a flywheel device, may help improve muscle recovery by potentially restoring muscle compliance and reducing stiffness. Leabeater et al. (2023) also used a limb-to-limb design with the gastrocnemius muscle and gave the PM post-exercise (3 sets of 20 double-leg calf raises). Their results indicated that the PM had no immediate post-exercise effects on muscular performance (range of motion, isometric strength, and dynamic endurance) or calf circumference, and it did not significantly affect perceived muscle soreness immediately, 4, 24, or 48 h post-exercise. The two studies' different research designs, such as their type of exercise or outcome measures, may be contributing factors as to why they had conflicting results. Additionally, investigating only a lower limb muscle (gastrocnemius) may be a potential limitation to these studies, because lower limb muscles are typically used more often than upper limb muscles during daily activities (Chen et al., 2011). Thus, it may be more difficult to control the amount of movement subjects undergo between testing sessions, which may in turn affect subjects' recovery rates.

Most of the literature on PM has been devoted to investigating its acute effects as a pre-exercise treatment. The majority of studies have indicated that PM may acutely increase the ROM of leg (Alvarado et al., 2022; Canbulut et al., 2023; Klimowska et al., 2023; Konrad et al., 2020; Park, 2020; Skinner et al., 2023) and shoulder joints (Jung and Ha, 2020) without affecting various performance measures, such as vertical jumping tasks (Alvarado et al., 2022; Canbulut et al., 2023; Szymczyk et al., 2022; Wang et al., 2022), change of direction performance (Canbulut et al., 2023; Wang et al., 2022), isometric strength (Konrad et al., 2020), dynamic balance (Wang et al., 2022), and lateral acceleration (Wang et al., 2022). One study observed that PM did not affect ROM (Yang et al., 2023); however, unlike the previously mentioned studies, which primarily targeted limb muscles, Yang et al. (2023) applied the PM on the erector spinae muscles and tested thoracolumbar ROM. Lastly, there has been one report of PM acutely decreasing muscular performance (anaerobic power output during a

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Wingate anaerobic cycling test) (Canbulut et al., 2023) and two reports of it acutely increasing muscular performance: (1) horizontal jumping performance, change of direction, and single leg balance performance with open and closed eyes (Menek and Menek, 2023), and (2) reactive strength during a drop jump (Wang et al., 2022). The conflicting results may be attributed to their varying PM parameters, research designs, or performance measures.

Research on the mechanisms by which PM may affect recovery or performance is limited. Since there were no studies at the time, Cheatham et al. (2021) surveyed 425 healthcare and fitness professionals to investigate their beliefs on PM's potential clinical benefits. Most of the respondents (86%) believed that it has therapeutic effects, and of those 86%, more than half believed it may increase blood flow (69%), modulate pain (65%), enhance myofascial mobility (62%), and reduce myofascial restrictions (i.e., "break up myofascial trigger points") (54%). A recent study has confirmed that PM may acutely increase blood flow (Needs et al., 2023), which some speculate may help support muscle recovery (Needs et al., 2023; Percival et al., 2022). Furthermore, recent reports of PM reducing muscle tissue stiffness (Skinner et al., 2023), increasing skin temperature (Yang et al., 2023), and reducing echo intensity, which may represent a decrease in viscosity of loose connective tissue (i.e., decreased resistance to movement) (Yang et al., 2023), may provide evidence to why most investigators have seen acute improvements in ROM. Lastly, Yang et al. (2023) reported that PM immediately reduced perceived stiffness without affecting thoracolumbar fascial thickness.

In summary, PM is growing in popularity, but the literature on how it may affect symptoms associated with eccentric exercise-induced muscle damage is lacking. Specifically, researchers have yet to investigate the effects of PM treatments on maximal isometric torque (MIT) and ROM 24 to 72 h post-EE. Warren et al. (1999) suggested that those two measures are among the most valid and reliable for quantifying the effects of exercise-induced muscle damage. Therefore, this study aimed to investigate the effects of PM treatments (immediately, 24, 48, and 72 h post-EE) on the MIT, ROM, and DOMS (via an 11-point numerical rating scale [NRS] of soreness) of the nondominant arm's biceps brachii at 24, 48, and 72 h post-EE. The biceps brachii was selected as it has been shown to be more susceptible to symptoms associated with exercise-induced muscle damage than lower limb muscles (Chen et al., 2011) and may help reduce outside factors affecting recovery due to the likelihood of upper limb muscles being used less often than lower limb muscles during daily activities. Electromyographic (EMG) and mechanomyographic (MMG) amplitude responses were collected during the MIT to assess muscle activation characteristics. Additionally, the NRS of soreness was collected before the treatment intervention on the post-EE visits. The authors hypothesized that the PM would improve MIT and ROM while reducing NRS of soreness values at all post-EE times, and the PM would immediately reduce NRS of soreness values from before to after the treatment intervention within every post-EE visit.

Methods

Experimental approach to the problem

Participants visited the laboratory on five separate visits. A between-subjects design (PM group [n = 9] vs. control group [n = 8]) with repeated measures was used to assess the effects of PM on symptoms associated with eccentric exercise-induced muscle damage of the nondominant arm's biceps brachii at 24, 48, and 72 h post-EE (Figure 1). A between-subjects design was selected since other forms of massage, such as foam rolling or roller massage, have been suggested to affect the central nervous system via reports of unilateral limb massage affecting the contralateral (i.e., non-massaged) limb's pain (Aboodarda et al., 2015), soreness (Jay et al., 2014), or ROM (Konrad et al., 2023). The nondominant arm was identified as the arm corresponding to the participant's non-preferred writing hand, and it was selected to help further decrease the potential outside factors affecting muscle recovery as it would presumably be used less often than the dominant arm during daily activities.

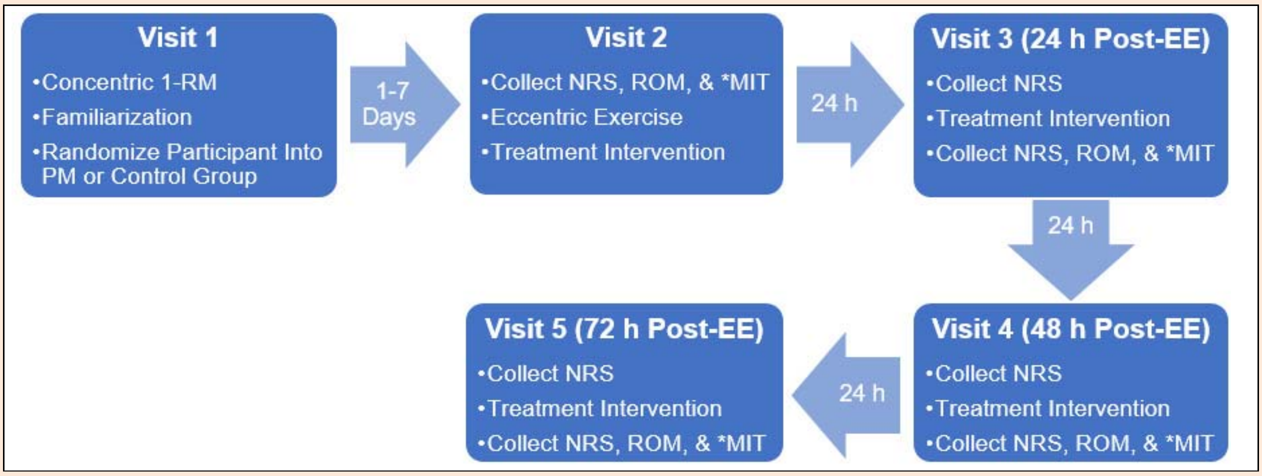

Figure 1. Research design (between-subjects with repeated measures). The bullet points within each box represent the sequence of procedures for that visit. Abbreviations: MIT: maximal isometric torque, NRS: numerical rating scale, Post-EE: post-eccentric exercise, PM: percussive massage, RM: repetition maximum, ROM: range of motion. *Electromyographic and mechanomyographic amplitudes were collected during the MIT.

In sequential order, the first visit consisted of participants performing a concentric 1-repetition maximum (1-RM) to determine the eccentric exercise weight, becoming familiarized with every procedure to minimize learning effects, and being randomly assigned to the PM or control (CON) group. The second visit was 1 to 7 days after the first visit and consisted of the following in order: pre-eccentric exercise (pre-EE) measurements (i.e., baseline measurements), eccentric exercise, and treatment intervention. The pre-EE measurements were collected in the following order: NRS of soreness, ROM, and MIT. EMG and MMG amplitudes were collected during the MIT testing. Visits three, four, and five were the sessions where NRS of soreness, ROM, and MIT were measured 24, 48, and 72 h post-EE. All of these visits were identical and started with collecting participants' NRS of soreness scores. Then, the appropriate treatment intervention was given to the participant. Afterward, they completed the same order of procedures described for the pre-EE measurements. Throughout the study, participants were instructed to refrain from strenuous physical activity, maintain their same diet and hydration habits, and avoid other forms of treatment (e.g., supplements, medications, massage, icing, etc.).

Subjects

The study consisted of 17 volunteers who were apparently healthy, untrained, and university-age (14 females [age 23.4 ± 2.8 years; height 161.7 ± 8.4 cm; body mass 68 ± 17.6 kg] and 3 males [age 26.33 ± 1.2 years; height 173.6 ± 3.8 cm; body mass 81.3 ± 10.1 kg]). The PM group consisted of 7 females and 2 males, and the CON group consisted of 7 females and 1 male. Both sexes were included since a meta-analysis revealed that displays of strength loss (relative to body mass) and DOMS after an intense eccentric exercise are similar between males and females (Morawetz et al., 2020). The sample size was determined using an a priori analysis (ANOVA: repeated measures, between factors) on G*Power software (Version 3.1), which revealed that at least 12 total subjects were needed for the study based on an effect size of 0.74, an alpha level of 0.05, and a power of 0.8. The effect size was determined from a previous local vibration therapy study that used a similar research design (i.e., between-subjects with repeated measures) (Percival et al., 2022). Untrained was defined as not having performed upper body resistance training for more than one time per week for the past six months. Participants were excluded from the study if they had any upper limb injuries in the past six months. Participants with prior PM experience within the past six months were also excluded to limit the possibility of participants having differences in sensitization to the treatment. Before participating, all subjects were required to read and sign an Informed Consent. The study was approved by the University Institutional Review Board.

Procedures

Concentric 1-Repetition Maximum (RM)

To determine the dumbbell weight for the eccentric exercise, participants completed a single-arm concentric 1-RM for their nondominant arm's elbow flexors. A dumbbell set increasing in 1.13 kg and Rogue Add-On Change Plates (0.22, 0.45, and 0.68 kg pairs) (Rogue, Columbus, Ohio) were used to increase the accuracy of identifying participants' 1-RMs and selecting their weight for the eccentric exercise. Participants were seated on a preacher curl machine with their nondominant elbow on the support pad in front of them and their dominant arm resting to their side. Participants started by extending their nondominant elbow on the pad with a slight bend (~2 to 5° of elbow flexion) and supinated forearm. An investigator placed a dumbbell in the participant's hand, and the participant was instructed to lift the dumbbell to a maximally flexed position while maintaining their elbow on the pad, a supinated forearm, and a neutral wrist position. To initiate the next repetition attempt, the investigator grabbed the dumbbell from the participant's hand so the participant could extend their elbow back to the starting position without loading the eccentric action. Participants performed multiple trials (~5), with 3 min of rest between trials, until they completed a trial where they could only lift the weight successfully for a single repetition. A repetition was considered successful when the participant curled the dumbbell into a maximally flexed position while maintaining proper form.

Eccentric exercise

Participants performed a single-arm eccentric exercise with a dumbbell to evoke symptoms associated with exercise-induced muscle damage. The protocol was adapted from a previous study (Tseng et al., 2013) and adjusted after pilot testing. Participants were positioned in the same preacher curl machine and used the same dumbbell equipment as the concentric 1-RM procedure. They performed 6 sets of 10 eccentric repetitions for the nondominant arm's elbow flexors through a full range of motion with a dumbbell that weighed approximately 85% of their concentric 1-RM. Two minutes of rest were given between sets. Participants started in a maximally flexed position with a supinated forearm. An investigator placed the dumbbell in the participant's nondominant hand, and the participant was instructed to lower the dumbbell to a maximally extended position in 7 s while maintaining their elbow on the pad, a supinated forearm, and a neutral wrist position. A metronome was used to assist the investigator in verbally counting the time to the participant (i.e., 0 [start], 1, 2, 3, 4, 5, 6, 7 [maximally extended]). After every eccentric repetition, the investigator lifted the dumbbell back to the starting position to eliminate loading the concentric action.

Treatment intervention

The PM group received 1 min of PM via a Hypervolt 2 (Hyperice, Irvine, California) on their nondominant arm's biceps brachii immediately, 24, 48, and 72 h post-EE, whereas the CON group rested quietly in a supine position for an equal amount of time. For the PM intervention, the round ball attachment and moderate speed level, or frequency of 40 Hz, were selected for the PM device. The device has an amplitude of approximately 12 mm. During the PM treatment, participants were relaxed in a supine position. The first 30 s of the PM targeted the lateral portion of the biceps brachii (i.e., long head), and the last 30 s targeted the medial portion (i.e., short head). The device's attachment head was applied directly on the skin and glided parallel with the muscle fibers at a pace of 5 s down and back from origin to insertion. The same investigator administered the PM throughout the study and attempted to apply equal pressure for every participant and treatment session. The PM parameters (attachment, duration, frequency, and pacing) were based on the most frequent responses from the survey by Cheatham et al. (2021). Additionally, the specific duration was determined from the Hyperice App's multiple upper body guided sessions ("upper body flush," "activate your upper body," and "upper body refresh"), whereby the biceps brachii was targeted for 1 min per arm.

Delayed Onset Muscle Soreness (DOMS)

The magnitude of DOMS was assessed with a NRS (Iodice et al., 2019; Leabeater et al., 2023), which ranged from 0 (no soreness) to 10 (worst possible soreness). Using a NRS with adults has been reported to be reliable and valid via systematic reviews (Hjermstad et al., 2011; Karcioglu et al., 2018). Before participants verbalized their scores, they were instructed to perform two tasks: (1) palpate their nondominant arm's biceps brachii from origin to insertion while relaxing their arm to their side and (2) maximally flex and extend their elbow joint. The NRS of soreness was collected before and after the participant received their treatment intervention at 24, 48, and 72 h post-EE. When collecting the NRS of soreness after the treatment intervention, an investigator always led with the following before participants verbalized their scores to limit those in the PM group expecting soreness to decrease: "Do you feel the same, worse, or better? Please be honest."

Range of Motion (ROM)

The ROM of the elbow joint was determined by measuring relaxed (RANG) and flexed (FANG) elbow joint angles with a standard plastic goniometer. The protocol was adapted from a previous study (Chen and Nosaka, 2006). Throughout the test, participants were standing and instructed to maintain a supinated forearm so that their nondominant palms were pointed forward. The RANG was determined by instructing participants to relax (i.e., "hang") their arm to their side, whereas the FANG was determined by instructing participants to maximally flex their elbow by attempting to touch their ipsilateral shoulder with their palm while maintaining their elbow to their side. The anatomical landmarks for the goniometer's stationary arm, axis, and moving arm were the lateral midpoint of the humerus, lateral axis of the elbow joint, and lateral midpoint of the radius, respectively. These landmarks were marked with a permanent marker before the pre-EE testing to maximize consistency throughout the study. The FANG and RANG were both measured three times, and an average was calculated for each angle. The ROM of the elbow joint was calculated by subtracting the mean RANG from the mean FANG.

Maximal isometric torque

An isokinetic dynamometer (HUMAC NORM CSMI, Stoughton, MA, USA) was used for assessing the MIT of the nondominant arm's elbow flexors. Participants were supine and positioned in accordance with the HUMAC NORM Testing and Rehabilitation System User's Guide. The lever arm of the dynamometer was set to 65° of elbow flexion (Trevino et al., 2015). Before the MIT trial, participants warmed up by performing three submaximal isometric contractions at 50% of their perceived maximal effort. After two min of rest, the MIT trial was conducted, which consisted of three maximal isometric contractions. Each isometric contraction was held for 6 s, and 30 s of rest was given between contractions. Similar verbal encouragement was given to all participants. The highest torque value of the three maximal isometric contractions was selected as the MIT for analysis.

Electromyographic and mechanomyographic measurements and signal processing

During the MIT testing, surface EMG signals were recorded using a bipolar surface electrode arrangement (approximately 5 cm center-to-center) placed over the muscle belly of the nondominant arm's bicep brachii. The electrodes were positioned approximately midway between the axillary fold and the midpoint of the cubital fossa. A reference electrode was placed over the anterior end of the forearm between the styloid processes of the ulna and radius. The electrodes were traced with a permanent marker before the pre-EE trial to ensure identical placements for the subsequent visits. Before placing the electrodes, the skin was lightly abraded and sterilized with an isopropyl alcohol wipe to reduce interelectrode impedance. The EMG signals were pre-amplified (gain 1000×) via a differential amplifier (EMG 100C, BIOPAC Systems Inc., Santa Barbara, CA; bandwidth = 1 - 500 Hz). MMG signals were also recorded during the MIT testing via an accelerometer (EGAS-FT-10/V05; Entran, Fairfield, NJ, USA) placed between the two surface EMG electrodes. Double-sided foam tape was placed on the skin to secure the accelerometer.

The raw EMG and MMG signals were obtained and stored on a personal computer (AcqKnowledge 5.0, BIOPAC Systems Inc., Santa Barbara, CA). The EMG and MMG signals were collected at 1000 Hz and band-pass filtered (fourth-order Butterworth filter) at 10 to 500 Hz and 5 to 100 Hz, respectively. The middle 2 s of the 6 s MIT contractions were used for analyzing the EMG and MMG amplitudes. The EMG and MMG amplitudes were expressed as root mean square values (EMG_{RMS} and MMG_{RMS}).

Statistical analyses

Five separate two-way (group × time) mixed factorial ANOVAs were used to analyze NRS of soreness, ROM, MIT, EMG_{RMS}, and MMG_{RMS}. MIT was made relative to body mass to reduce differences in strength loss between sexes (Morawetz et al., 2020). EMG_{RMS} and MMG_{RMS} were normalized to the participants' pre-EE values that were collected during the MIT testing. An α level of $p < 0.05$ was used to determine statistical significance, and post hoc tests with Bonferroni corrections were used when appropriate. All descriptive statistics were presented as mean ± standard deviation (*SD*). Cohen's *d* was used to determine the magnitude of pairwise comparisons, and it was interpreted with a modified classification system (trivial: ≤ 0.2, small: ≤ 0.6, moderate: ≤ 1.2, large: ≤ 2.0, very large:

> 2.0) (Batterham and Hopkins, 2006). Additionally, the reliability of the ROM and MIT testing was assessed via separate intraclass correlations coefficients (ICC). All of the data were analyzed with IBM SPSS Statistics (Version 29).

Results

Maximal isometric torque

There was no significant interaction (p = 0.22, η_p^2 = 0.09) for relative (to body mass) MIT, but there was a significant main effect for time (p < 0.001, η_p^2 = 0.41) (Table 1). MIT was significantly reduced (p = 0.02, d = 0.33) from pre-EE to 24 h post-EE by approximately 12%. Then, there was an approximately 8% significant increase (p = 0.02) from 24 to 48 h post-EE, which resulted in no difference (p = 0.47) between pre-EE and 48 h. At 72 h post-EE, MIT remained significantly higher (p = 0.01) than the values at 24 h, and there were no significant differences from pre-EE (p = 1.00) or 48 h post-EE (p = 0.16). The two groups did not differ (p = 0.67) at pre-EE, and the ICC (r = 0.99) for the MIT trials taken at pre-EE revealed a high reliability.

Electromyographic and mechanomyographic amplitude

There was no significant interaction (p = 0.55, η_p^2 = 0.04) or main effect of time (p = 0.47, η_p^2 = 0.047) for EMG_{RMS} (pre-EE: PM = 100 ± 0%, CON = 100 ± 0%; 24 h post-EE: PM = 106.3 ± 36.5%, CON = 88.2 ± 25.1%; 48 h post-EE: PM = 110.6 ± 44.8%, CON = 92.2 ± 49.6%; 72 h post-EE: PM = 113.9 ± 40.8%, CON = 103.7 ± 40.1%). There was also no significant interaction (p = 0.20, η_p^2 = 0.10) for MMG_{RMS}, but there was a significant main effect for time (p = 0.001, η_p^2 = 0.37), revealing an approximately 50% increase (p = 0.006, d = 0.99) from pre-EE at 72 h post-EE (Table 1).

Range of Motion

A significant interaction (p < 0.001, η_p^2 = 0.45) was found for ROM (Figure 2). The groups did not significantly differ (p = 0.66) at pre-EE, but the PM group had significantly higher ROM than the CON at 24 (p = 0.01, d = 1.24), 48 (p = 0.01, d = 1.14), and 72 h (p = 0.04, d = 0.89) post-EE by approximately 8, 6, and 6°, respectively (Table 2). The CON group's ROM was significantly lower than their pre-EE at 24 (p < 0.001) and 48 h (p = 0.02) by approximately 10° and 4°, respectively, but it returned to pre-EE (p = 1.00) by 72 h. The PM group's ROM was significantly lowered (p = 0.002) at 24 h compared to pre-EE by approximately 4°, returned to pre-EE (p = 1.00) by 48 h, and then significantly exceeded (p < 0.001, d = 0.58) their pre-EE at 72 h by approximately 4°. The ICC (r = 0.99) for the FANG and RANG measurements taken at pre-EE revealed a high reliability.

Table 1. Mean ± SD values for relative (N·m·kg^{-1}) maximal isometric torque (MIT) and normalized (% of pre-eccentric exercise [pre-EE]) mechanomyographic root mean square (MMG_{RMS}) from the main effect of time during pre-EE and 24, 48, and 72 h post-eccentric exercise (post-EE).

	pre-EE	24 h post-EE	48 h post-EE	72 h post-EE
MIT	0.60 ± 0.22	0.53 ± 0.24†	0.57 ± 0.24‡	0.60 ± 0.23‡
MMG_{RMS}	100 ± 0%	114.6 ± 26.3%	114 ± 37.1%	150.1 ± 50.7%†

†p < 0.05 vs. pre-EE, ‡p < 0.05 vs. 24 h p-EE

Table 2. Mean ± SD values for the degrees (°) of range of motion from the percussive massage (PM) and control (CON) group during pre-eccentric exercise (pre-EE) and 24, 48, and 72 h post-eccentric exercise (post-EE).

	pre-EE	24 h post-EE	48 h post-EE	72 h post-EE
PM	119.6 ± 3.9°	115.6 ± 3.5°*†	120.9 ± 3.7°*	123.3 ± 4.1°*†
CON	118.4 ± 6.3°	108 ± 6.1°†	114.8 ± 5.4°†	117.6 ± 6.4°

*p < 0.05 vs. CON, †p < 0.05 vs. pre-EE

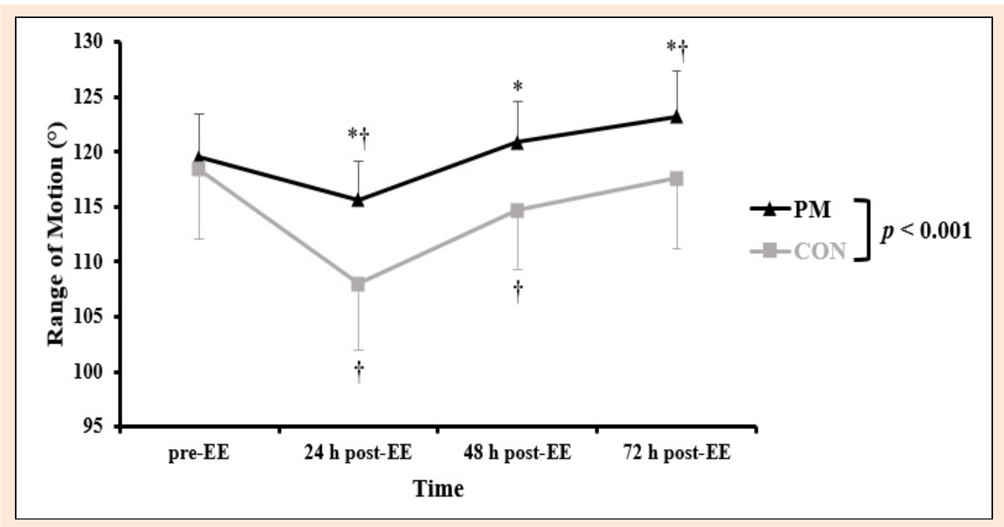

Figure 2. Mean ± SD changes in the degrees (°) of range of motion from the percussive massage (PM) and control (CON) group during pre-eccentric exercise (pre-EE) and 24, 48, and 72 h post-eccentric exercise (post-EE). p < 0.001: significant interaction. *p < 0.05 vs. CON; †p < 0.05 vs. pre-EE.

Delayed Onset Muscle Soreness

A significant interaction (p = 0.01, η_p^2 = 0.22) was observed for the NRS of soreness (Figure 3). There were no significant differences between the PM and CON group when NRS was collected before the treatment intervention at 24 (p = 0.11) , 48 (p = 0.052), and 72 h (p = 0.10) post-EE; however, after the treatment intervention, the PM group had significantly lower (p < 0.001) NRS values than the CON at 24 (d = 3.04), 48 (d = 1.77), and 72 h (d = 1.61) by approximately 3, 3, and 2 points, respectively (Table 3). The CON group's NRS remained significantly higher (p < 0.001) than their pre-EE from 24 to 72 h post-EE (before and after treatment), whereas the PM group was only significantly higher (p < 0.001) than their pre-EE from 24 to 48 h (before and after treatment). The PM group returned to their pre-EE by 72 h post-EE (before treatment, p = 0.08; after treatment, p = 1.00). The CON group had no significant differences (p = 1.00) from before to after treatment within every post-EE visit, but the PM group's values were reduced from before to after treatment at 24 (p < 0.001, d = 1.6), 48 (p < 0.001, d = 0.87), and 72 h (p = 0.01, d = 0.69) post-EE by approximately 1 point per visit.

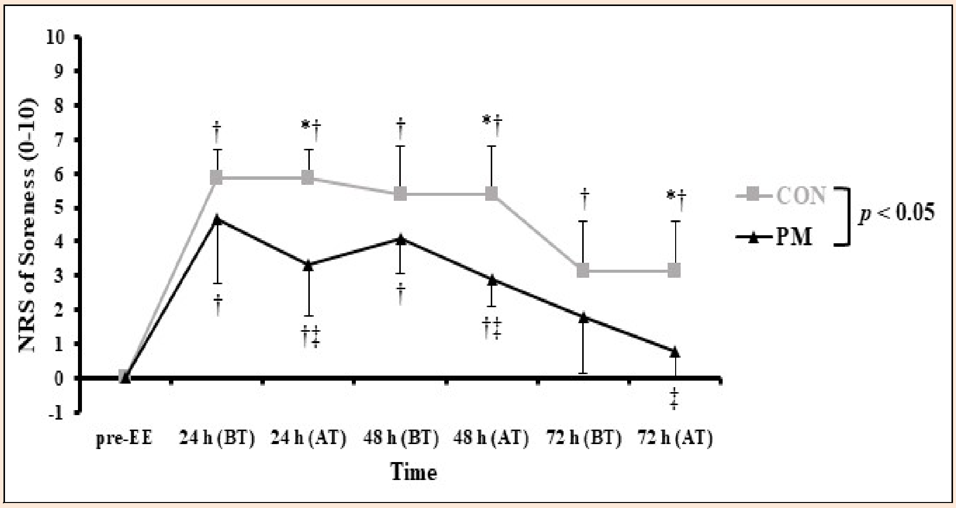

Figure 3. Mean ± SD changes in the numerical rating scale (NRS) of soreness from the percussive massage (PM) and control (CON) group during pre-eccentric exercise (pre-EE) and 24, 48, and 72 h post-eccentric exercise. On the post-eccentric exercise visits, values were collected before treatment (BT) and after treatment (AT). p < 0.05: significant interaction. *p < 0.05 vs. CON. †p < 0.05 vs. pre-EE. ‡p < 0.05 vs. BT (same day visit).

Table 3. Mean ± SD values for the numerical rating scale of soreness (0-10) from the percussive massage (PM) and control (CON) group during pre-eccentric exercise (pre-EE) and 24, 48, and 72 h post-eccentric exercise. On the post-eccentric exercise visits, values were collected before treatment (BT) and after treatment (AT).

	pre-EE	24 h (BT)	24 h (AT)	48 h (BT)	48 h (AT)	72 h (BT)	72 h (AT)
PM	0 ± 0	4.7 ± 1.9†	3.3 ± 1.5*†‡	4.1 ± 1.1†	2.9 ± 0.8*†‡	1.8 ± 1.6	0.8 ± 0.8*‡
CON	0 ± 0	5.9 ± 0.8†	5.9 ± 0.8†	5.4 ± 1.4†	5.4 ± 1.4†	3.1 ± 1.5†	3.1 ± 1.5†

*p < 0.05 vs. CON, †p < 0.05 vs. pre-EE, ‡p < 0.05 vs. BT (same day visit).

Discussion

The present study aimed to investigate if PM treatments on the nondominant arm's biceps brachii immediately and daily 24 to 72 h post-EE could improve MIT, ROM, and DOMS (NRS of soreness) at 24, 48, and 72 h post-EE. There are a few key takeaways. The PM did not affect MIT or neuromuscular activation (EMG_{RMS} and MMG_{RMS}) but moderately improved ROM from 24 to 72 h post-EE by approximately 6 to 8°. Additionally, the PM did not improve the recovery from DOMS until 72 h post-EE; however, it consistently provided an immediate, moderate-to-large decrease in perceived muscle soreness from before to after the treatment intervention within the 24, 48, and 72 h post-EE visits by approximately 1 point per visit.

Isometric muscular strength and activation

The PM did not affect MIT 24 to 72 h post-EE. Although there were no differences between the groups, the main effect for time revealed that MIT was reduced 24 h post-EE, which is a typical response to eccentric exercise (Cheung et al., 2003; Warren et al., 1999). To the authors' knowledge, this is the first study to investigate the effects of PM on strength, or any other physical performance measure, 24 to 72 h post-EE. The results confirm the findings of Konrad et al. (2020) but contradict García-Sillero et al. (2021) and Needs et al. (2023). In the present study, the PM was given prior to the MIT test; therefore, the present study's results confirm the results of Konrad et al. (2020) since they observed that a single PM treatment on the gastrocnemius muscle had no immediate effect on MIT. However, García-Sillero et al. (2021) suggested that 2 min of PM (29 Hz) on the gastrocnemius muscle could have the potential to improve muscle recovery via their observation of it restoring contraction time and radial displacement, which were measured via a tensiomyography, after 4 sets of 12 eccentric repetitions on a flywheel device with an individualized load (0.035 or 0.050 kg·m^{-2}). The contradicting findings may be attributed to the different PM parameters (duration and frequency [Hz]), targeted muscle, eccentric exercise protocol, or outcome variables. Furthermore, Needs et al. (2023) reported that PM improved blood flow and suggested the increase in blood flow may help improve muscle recovery. They reported that both 5 and 10 min of PM increased calf muscle blood flow, but 10 min was superior to 5 min. The present study's PM was only 1 min, which was within a range (30 s to 3 min) found to be the most popular among 425 surveyed practitioners for post-exercise treatment purposes (Cheatham et al., 2021); however, 1 min of PM may not be long enough to promote significant increases in blood flow that could potentially result in improved muscle recovery.

The present study's results of PM having no effect on EMG_{RMS} corroborates the MIT results. Additionally, this is the first study to investigate the acute effects of PM on EMG_{RMS}; however, other studies utilizing different methods of localized vibration have also reported no acute changes in EMG_{RMS} (Bosco et al., 1999; Cochrane, 2015, 2016). Pamukoff et al. (2014) reported that local vibration increased EMG_{RMS} for up to 5 min, which may be attributed to the tonic vibration reflex (Burke et al., 1976; Eklund and Hagbarth, 1966), but the present study's MIT testing occurred more than 5 min after the PM treatment.

Similar to EMG_{RMS}, there was no interaction for MMG_{RMS}; however, there was a main effect for time, revealing a moderate increase from pre-EE at 72 h post-EE. Since the MMG signal was recorded with an accelerometer, the increase at 72 h post-EE likely occurred from mechanical changes in the biceps brachii in response to eccentric exercise-induced muscle damage. To illustrate, previous studies (Bajaj et al., 2002; Kawczyński et al., 2007) have observed increased MMG_{RMS} without changes in EMG activity post-EE. As a result, it is perhaps more likely that the increase in MMG_{RMS} was from changes in the mechanical properties of the muscle due to eccentric exercise-induced muscle damage, such as edema or changes in muscle compliance and stiffness, rather than changes in neural activation patterns.

Range of Motion

Although MIT and muscle activation were unaffected by PM, the PM group's ROM was moderately higher than the CON at 24, 48, and 72 h post-EE by approximately 8, 6, and 6°, respectively. A decrement in ROM is a typical response to eccentric exercise (Cheung et al., 2003; Warren et al., 1999), which was seen with both groups in the present study; however, the PM group had a faster return to their pre-EE values than the CON group (PM: 48 h, CON: 72 h). Lastly, at 72 h post-EE, the PM group had a small increase in ROM from their pre-EE values by approximately 4°.

No study has yet investigated the effects of PM on ROM 24 to 72 h post-EE. However, studies have investigated the acute effects of PM on ROM (Park, 2020; Jung and Ha,; Konrad et al., 2020; Alvarado et al., 2022; Klimowska et al., 2023; Canbulut et al., 2023; Skinner et al., 2023). These studies may relate to the present study since the PM treatments preceded the ROM testing. Based on the previous studies' results, the present study's findings of improved ROM with PM were not surprising given the multitude of PM studies that targeted a limb muscle and observed an acute increase in ROM (Park, 2020; Jung and Ha, 2020; Konrad et al., 2020; Alvarado et al., 2022; Klimowska et al., 2023; Canbulut et al., 2023; Skinner et al., 2023).

There are a few reasons why PM may acutely increase ROM. For example, Yang et al. (2023) indicated that PM reduced the echo intensity of the thoracolumbar fascia in healthy men. The authors speculated that a decrease in echo intensity might suggest PM reduced the viscosity of hyaluronic acid in loose connective tissue, which could decrease the resistance to movement (i.e., increase ROM). Yang et al. (2023) suggested the decrease in echo intensity may have come from the PM squeezing hyaluronic acid toward the fascial rim region (Roman et al., 2013) or from an increase in temperature (Tadmor et al., 2002). Yang et al. (2023) confirmed the latter via their results of increased skin temperature. Furthermore, Skinner et al. (2023) observed a decrease in muscle tissue stiffness with PM and suggested it may have occurred from the mechanical forces increasing muscle-tendon compliance (Imtiyaz et al., 2014) or thixotropic effects (i.e., a viscous fluid becoming less viscous when agitated, sheared, or stressed) (Behm and Wilke, 2019). These results and suggestions coincide with results of Yang et al. (2023). Lastly, specifically for the present study, it may be possible that the PM group was able to move through a greater active ROM due to less discomfort (i.e., increased stretch tolerance), because the PM group had lower NRS of soreness values leading into the ROM testing (i.e., "after treatment" values). An increase to the tolerance of stretch has been observed with stretching (Magnusson et al., 1996) and massage (Akazawa et al., 2016); thus, future PM studies may want to examine if stretch tolerance also plays a role in improving ROM alongside the other potential mechanical mechanisms previously discussed.

Delayed Onset Muscle Soreness

Before the treatment intervention, the NRS of soreness values did not differ between groups from 24 to 72 h post-EE. However, the PM group had moderate-to-large decreases in their NRS values from before to after the treatment intervention within every post-EE visit by approximately 1 point per visit. As a result, after the treatment intervention, the PM group had lower values (large-to-very large differences) than the CON at 24, 48, and 72 h post-EE by approximately 3, 3, and 2 points, respectively. Additionally, the PM group recovered faster to their pre-EE values than the CON (PM: 72 h post-EE [before treatment]; CON: never recovered). Thus, the PM appeared to consistently provide immediate, temporary relief in perceived muscle soreness since it did not enhance recovery until 72 h post-EE.

To our knowledge, the present study is the first to administer PM treatments daily 24 to 72 h post-EE and observe its effects on perceived muscle soreness before and after the treatment intervention during those times. Leabeater et al. (2023) reported no significant differences in perceived muscle soreness with PM 24 and 48 h after three sets of 20 calf raises, but the PM was only given once after the exercise. Thus, these results may align with the present study's findings of PM having no effect on NRS of soreness before the treatment intervention at 24 and 48 h post-EE. However, the present study also collected NRS of soreness before the treatment intervention at 72 h post-EE and found that the PM group recovered to their pre-EE values, whereas the CON did not recover. Thus, daily PM treatments given over multiple post-EE days may have the potential to have positive effects on DOMS by 72 h post-EE. Lastly, despite the different types of perceived sensations, the present study's results of PM immediately reducing perceived soreness confirms the findings of Yang et al. (2023), which found that PM immediately reduced perceived stiffness in healthy males.

The mechanisms by which PM may help reduce perceived muscle soreness are not well understood since there are no studies on the topic. However, there are a few potential explanations based on research involving vibration. For example, vibration has been seen to activate sensory fibers in muscles (Burke et al., 1976), which may potentially affect the sensation of pain associated with group III and IV afferent fibers (Lau and Nosaka, 2011; Cochrane, 2017). Vibration may also stimulate Ruffini cylinders and Pacinian corpuscles, potentially resulting in muscle relaxation via inhibiting sympathetic activity (Behm et al., 2019). Since PM devices' parameters (e.g., frequencies [Hz] or amplitudes) may differ from other vibration devices, future research specifically utilizing PM is needed to provide insight on the mechanisms by which it may help reduce sensations of perceived muscle soreness.

Limitations

The present study is not without limitations. Firstly, the PM group was compared only to a CON group that received no treatment instead of a sham intervention or other treatment strategy. Additionally, the present study did not control for or track the female menstrual cycle. Certain phases within the female menstrual cycle, such as the early follicular phase, late follicular phase, and mid-luteal phase, may affect DOMS and strength losses associated with exercise-induced muscle damage (Romero-Parra et al., 2021). Furthermore, regarding the sample's characteristics, the subjects were untrained. The effects of PM seen within the present study may not have been as significant if trained individuals were selected as they may experience lesser symptoms of exercise-induced muscle damage than untrained individuals due to the repeated bout effect (Howatson and Van Someren, 2008).

There are also a few limitations within the procedures of the present study. For example, using dynamic constant external resistance (i.e., a dumbbell) for the eccentric exercise ensures that the load was consistent among participants (~85% 1-RM); however, there may have been slight variability in the participants' abilities to consistently lower the weight in exactly 7 seconds, which could have affected the amount of work between participants. Also, regarding variability between participants, the pressure in which the PM was applied to the participants' nondominant arms was not controlled for or tracked; thus, participants' treatments may have varied slightly due to human error of being unable to maintain precisely consistent pressure. Lastly, the present study did not collect MIT, EMG, MMG, and ROM immediately after the eccentric exercise and before the treatment intervention on the 24 to 72 h post-EE visits, all of which could have provided more insight into monitoring the recovery process. Specifically, with not measuring before the treatment intervention on the 24 to 72 h post-EE visits, it remains unknown if the PM in the present study accelerated the recovery of ROM or only provided an immediate, temporary increase in ROM similar to the response seen with NRS of soreness at 24 and 48 h post-EE.

Conclusion

This study was the first to analyze the effects of PM treatments (immediately, 24, 48, and 72 h post-EE) on the MIT, ROM, and DOMS (via an 11-point NRS of soreness) of the nondominant arm's biceps brachii at 24, 48, and 72 h post-EE. The PM did not affect MIT or muscle activation; however, it moderately improved ROM from 24 to 72 h post-EE and resulted in a faster return to pre-EE. Additionally, the PM did not enhance the recovery from DOMS until 72 h post-EE, but it consistently provided immediate, temporary relief when given daily from 24 to 72 h post-EE. Thus, after an intense eccentric elbow flexion exercise, PM may acutely reduce perceived muscle soreness and increase ROM without affecting maximal isometric strength performance or muscle activation from 24 to 72 h post-EE in apparently healthy, untrained, college-aged individuals.

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There is no conflict of interest. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

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Key points

- Seventeen apparently healthy, untrained, college-aged subjects performed 60 eccentric elbow flexion actions with their nondominant arms
- Nine subjects received 1 minute of percussive massage on their nondominant arm's biceps brachii immediately, 24, 48, and 72 h post-eccentric exercise, versus eight subjects rested quietly (i.e., control group)
- Percussive massage improved range of motion without affecting isometric muscular strength or activation from 24-72 h post-eccentric exercise
- Percussive massage did not accelerate the recovery from delayed onset muscle soreness until 72 h post-eccentric exercise
- Percussive massage provided immediate, temporary relief in perceived muscle soreness when given 24, 48, and 72 h post-eccentric exercise

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