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# Whole-Body Vibration While Squatting and Delayed-Onset Muscle Soreness in Women

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***Context:*** Research into alleviating muscle pain and symptoms in individuals after delayed-onset muscle soreness (DOMS) has been inconsistent and unsuccessful in demonstrating a useful recovery modality.

***Objective:*** To investigate the effects of short-term whole-body vibration (WBV) on DOMS over a 72-hour period after a high-intensity exercise protocol.

***Design:*** Randomized controlled clinical trial.

***Setting:*** University laboratory.

***Patients or Other Participants:*** Thirty women volunteered to participate in 4 testing sessions and were assigned randomly to a WBV group (n = 16; age = 21.0 ± 1.9 years, height = 164.86 ± 6.73 cm, mass = 58.58 ± 9.32 kg) or a control group (n = 14; age = 22.00 ± 1.97 years, height = 166.65 ± 8.04 cm, mass = 58.69 ± 12.92 kg).

***Intervention(s):*** Participants performed 4 sets to failure of single-legged split squats with 40% of their body weight to induce muscle soreness in the quadriceps. The WBV or control treatment was administered each day after DOMS.

***Main Outcome Measure(s):*** Unilateral pressure-pain threshold (PPT), range of motion (ROM), thigh circumference, and muscle-pain ratings of the quadriceps were collected before and for 3 days after high-intensity exercise. Each day, we collected 3 sets of measures, consisting of 1 measure before the WBV or control treatment protocol (pretreatment) and 2 sets of posttreatment measures.

***Results:*** We observed no interactions for PPT, thigh circumference, and muscle pain ($P > .05$). An interaction was found for active ROM ($P = .01$), with the baseline pretreatment measure greater than the measures at baseline posttreatment 1 through 48 hours posttreatment 2 in the WBV group. For PPT, a main effect for time was revealed ($P < .05$), with the measure at baseline pretreatment greater than at 24 hours pretreatment and all other time points for the vastus medialis, greater than 24 hours pretreatment through 48 hours posttreatment 2 for the vastus lateralis, and greater than 24 hours pretreatment and 48 hours pretreatment for the rectus femoris. For dynamic muscle pain, we observed a main effect for time ($P < .001$), with the baseline pretreatment measure less than the measures at all other time points. No main effect for time was noted for thigh circumference ($P = .24$). No main effect for group was found for any variable ($P > .05$).

***Conclusions:*** The WBV treatment approach studied did not aid in alleviating DOMS after high-intensity exercise. Further research is needed in various populations.

***Key Words:*** range of motion, edema, pressure-pain threshold

**Key Points**

- Exposure to whole-body vibration did not effectively manage delayed-onset muscle soreness after high-intensity exercise in healthy, recreationally trained women.
- Researchers should study treatments to alleviate muscle pain in various populations.

Novel eccentric muscle contractions have been shown to cause exercise-induced muscle damage (EIMD). This damage typically results in decreased force production,[1,2] z-line streaming of sarcomeres,[3,4] delayed-onset muscle soreness (DOMS) and pain, edema,[5,6] and increased muscle tension, resulting in decreased range of motion (ROM).[5,6] Evidence has suggested that DOMS may result from sensitization of group III and IV afferent nociceptors by a host of inflammatory mediators[7] and from large-fiber mechanoreceptors (ie, muscle spindles and tendon organs).[8,9] Researchers have reported that EIMD and DOMS lead to disability,[10] impair daily activities,[11,12] and promote self-care behaviors similar to those of patients with pain observed and measured in the clinical setting (ie, clinical pain).[11,12] Pain and disability after exercise also have been reported as barriers to exercise[13]; consequently, limiting the deleterious effects of EIMD could improve exercise adherence.

Prophylactic and therapeutic modalities (eg, massage, cryotherapy, stretching, ultrasound, electrical stimulation, anti-inflammatory drugs) designed to reduce DOMS have been studied widely,[14] with most interventions demonstrating limited efficacy. Vibration is a modality that has shown efficacy in the treatment of chronic musculoskeletal pain,[15,16] suggesting promise for the treatment of DOMS as well. Whereas the effects of vibration on muscle pain from DOMS have not been widely studied, inconsistent and conflicting results have been reported. Local vibration applied directly to a damaged muscle has been reported to lead to heightened pain sensitivity, as evidenced by reduced pressure-pain thresholds (PPTs),[8,9,17] likely due to central sensitization of large-fiber mechanoreceptors. Conversely, prophylactic[18,19] application of whole-body vibration

(WBV) before eccentric exercise and therapeutic application of both direct[20,21] and WBV plus stretching[22] have been shown to reduce perceived levels of pain after EIMD.

When applying a single 1-minute bout of 35-Hz WBV before eccentric exercise, Aminian-Far et al[18] demonstrated pronounced attenuation of pain during movement and PPTs in the days after EIMD. However, it is unclear from their results if the vibration protocol attenuated pain per se or if vibration before eccentric exercise reduced the subsequent EIMD as evidenced by the markedly smaller decline in force-production ROM. Thus, we hypothesized that applying WBV after a high-intensity exercise may help decrease DOMS. Therefore, the purpose of this study was to investigate the effects of short-term WBV on DOMS over a 72-hour period after a high-intensity exercise protocol.

## METHODS

### Participants

Thirty recreationally trained women volunteered to participate in a 7-session protocol and were assigned randomly to a WBV group (n = 16; age = 21.0 ± 1.9 years, height = 164.86 ± 6.73 cm, mass = 58.58 ± 9.32 kg) or a control group (n = 14; age = 22.00 ± 1.97 years, height = 166.65 ± 8.04 cm, mass = 58.69 ± 12.92 kg). *Recreationally trained* was defined as participating consistently in physical activity 3 or more times per week for at least 6 months. We excluded any volunteer who had sustained a lower body musculoskeletal or orthopaedic injury in the 6 months before the study; was taking medication known to alter balance, musculoskeletal, or central nervous system functions relating to posture and motor control; or was taking prescription pain or psychiatric medication. In addition, we used a questionnaire to screen volunteers for potential risk factors to the exercise protocol (eg, rhabdomyolysis). Participants were instructed not to perform any lower body exercise or take any pain medication throughout the study, to keep food and water intake consistent, and to refrain from caffeine consumption for 8 hours before each testing session. We scheduled them to avoid testing in the 2 days before the onset of and during menses to aid in compliance with the instructions.

All participants provided written informed consent, and the study was approved by the Institutional Review Board of The University of Mississippi.

### Experimental Design

Before testing, participants performed 3 familiarization sessions over a week's time. These sessions included anthropometric measurements and familiarization with all experimental measures. We introduced participants to all testing protocols at least once during the 3 sessions and assessed PPT on all 3 days to show reliability of measurements. After the 3 familiarization sessions, participants reported to the laboratory for testing on 4 consecutive days and were assigned randomly to either the control or WBV treatment group. The investigator (N.C.D.) who collected all measures was not blinded to treatment group because she had to administer the treatment. We assessed all participants for baseline PPT, ROM, thigh circumference, and muscle pain in the quadriceps on movement. After baseline measures were taken, participants performed an exercise designed to induce DOMS. The protocol consisted of front-loaded split squats performed using a Jones Machine (BodyCraft Inc, Lewis Center, OH). They performed 4 sets to task failure using each lower extremity, and exercise was alternated between the right and left extremities with a 1-minute rest between exercises with each extremity. The Jones Machine was loaded with 40% of the body weight of each participant. During the split squat, the back extremity was placed on a padded bench for support, and the knee was placed into 90° of flexion, allowing focus on single-legged performance of the front extremity. We provided assistance in the concentric phase after the participant reached 90° of knee flexion with the front knee of the exercising extremity, allowing greater focus on the eccentric phase.[23]

Immediately after the high-intensity exercise protocol, participants in the control group performed 2 sets of body-weight quarter squats on a flat surface for a 30-second 1:1 work-to-rest ratio. Participants in the WBV group performed 2 sets of body-weight quarter squats on the vibration platform. An AIRdaptive Power Plate system (Performance Health Systems LLC, Northbrook, IL) was used for triaxial vibration exposure. Vibration frequency was set at 30 Hz with an amplitude of 2 to 4 mm.[23] After the WBV or control treatment protocol, we assessed participants for PPT, ROM, thigh circumference, and muscle pain in the quadriceps on movement. After a 10-minute rest period, all measures were reassessed for longer effects. We instructed participants to adhere to the restrictions of the study and to refrain from any other treatments (ie, icing, stretching, heating).

Participants returned to the laboratory 24, 48, and 72 hours (±1 hour of initial testing time) after the high-intensity exercise protocol to reevaluate PPT, ROM, thigh circumference, and muscle pain on movement. These sessions consisted of initial assessments of PPT, ROM, thigh circumference, and muscle pain on movement in the quadriceps, followed immediately by the WBV or control treatment protocol. The WBV and control treatment followed the same protocol as on the baseline day, consisting of quarter-squats with or without WBV. After the WBV or control treatment protocol, we immediately assessed all measures. We took a third set of measurements after a subsequent 10-minute rest period.[24]

### Measurements

**Pressure-Pain Threshold.** We assessed PPT during all 7 visits to the laboratory in the left quadriceps while participants were seated comfortably on a padded table. We placed a mark on the rectus femoris (RF) at the midpoint between the patella and the proximal head of the femur (midpoint between the knee and the hip) and over the bellies of the vastus medialis (VM) and vastus lateralis (VL) of the left thigh. Throughout the test, participants were instructed to keep their quadriceps relaxed. We placed a handheld pressure algometer (model FPX; Wagner Instruments, Greenwhich, CT) on each test site and applied mechanical pressure at a rate of approximately 60 kPa per second to the muscles in the following order: VM, VL, and RF. Three trials were performed at each muscle site with approximately 20 seconds between trials. This rate of pressure application was chosen because it has been

shown to produce reliable results in skeletal muscle.[25] We instructed participants to indicate when the pressure transitioned from being uncomfortable to faintly painful by saying, "Pain," and we immediately removed the pressure stimulus. The corresponding force value was recorded. The values from the 3 trials were averaged and used to represent the criterion value for each muscle during that testing session.

**Range of Motion.** We measured active and passive knee ROM to assess stiffness and mobility in the knee flexors. For reference, we placed the mobile arm of a goniometer (model 62; Prestige Medical, Northridge, CA) along the lateral fibula, the fixed arm along the lateral femur, and the axis of rotation on the lateral epicondyle. *Full knee extension* was defined as 0°. Participants lay prone on a padded table. During active ROM measurements, we asked participants to flex their right knees as much as possible. During passive ROM measurements, we instructed them to relax the knee flexors, and the researcher passively flexed the right extremity. Participants were told to say, "Pain," if they developed pain in the musculature at any point, and we stopped taking measurements. If they expressed no pain, we stopped at the point of no further flexion.

**Thigh Circumference.** We measured thigh circumference to assess localized edema of the right quadriceps at the distal end and midpoint of the quadriceps. Distal measurements were taken over the belly of the VM and midpoint measurements between the anterior-superior iliac spine and the patella. Three measures (cm) were obtained at each site using a measuring tape (Gulick, Ann Arbor, MI) and averaged.

**Muscle Pain During Movement.** To assess muscle pain, we instructed participants to rate the intensity of pain in their quadriceps during a body-weight half squat using a 10-cm visual analog scale (VAS). They placed a mark along the 10-cm line that corresponded to the intensity of pain experienced during the half-squat after they reached 90° of knee flexion. The researcher (N.C.D.) visually assessed when participants reached 90° of knee flexion and then instructed them to pause and move into the upward phase of the squat. Anchors of *no pain* and *worst pain imaginable* were placed on the left and right ends, respectively, of the 10-cm line.

**Reliability and Variability of PPT Measurement.** We obtained 3 days' worth of measurements during the familiarization sessions and a set of baseline measures on the first testing day of RF PPT. Measurements of reliability were quantified through the calculation of intraclass correlation coefficients (ICCs) with 95% confidence intervals. The ICC (3,1) value for RF PPT was 0.92. We analyzed the coefficient of variation within each familiarization day and baseline measures for RF PPT. The average PPT from all 4 days was used for analysis; the coefficient of variation was less than 6%.

### Statistical Analyses

To test changes in PPTs, ROM, thigh circumference, and muscle pain over time and between groups, a 12 × 2 (time by group) mixed-factor repeated-measures analysis of variance (ANOVA) was conducted. We used 3 time points from each testing day (baseline: 0 hours pretreatment [0Pre], 0 hours posttreatment 1 [0Post1], 0 hours posttreatment 2 [0Post2]; 24 hours after EIMD: 24 hours pretreatment [24Pre], 24 hours posttreatment 1 [24Post1], 24 hours posttreatment 2 [24Post2]; 48 hours after EIMD: 48 hours pretreatment [48Pre], 48 hours posttreatment 1 [48Post1], 48 hours posttreatment 2 [48Post2]; and 72 hours after EIMD: 72 hours pretreatment [72Pre], 72 hours posttreatment 1 [72Post1], and 72 hours posttreatment 2 [72Post2]), and the group factors were control and WBV. If interactions occurred, they were followed up with a 1-way ANOVA. If we observed main effects in the absence of an interaction, we conducted least significant difference post hoc analyses for pairwise differences. We used SPSS statistical software (version 21; IBM Corporation, Armonk, NY) for all analyses. When sphericity was violated, the Greenhouse-Geisser correction of degrees of freedom was used. We set the $\alpha$ level at .05 and calculated $\eta^2$ to determine effect sizes. We performed an a priori power analysis using an effect size of 0.2, $\alpha$ level of .05, and power of .80 and determined that a sample size of 28 was needed to observe results that were different.

## RESULTS

### Pressure-Pain Threshold

**Vastus Medialis.** We did not observe an interaction of time by group for PPT in the VM ($F_{4.04,109.22} = 1.16$, $P = .33$, $\eta^2 = 0.04$). We found a main effect for time ($F_{4.04,109.22} = 5.62$, $P < .001$, $\eta^2 = 0.17$; Figure), with differences from baseline to pretreatment measures at 24, 48, and 72 hours after muscle damage but no main effect for group ($F_{1,27} = 3.3$, $P = .07$, $\eta^2 = 0.11$). Post hoc analysis showed that 0Pre and 0Post1 were greater than 24Pre and all other times thereafter and that 0Post2 was greater than values from 24Pre through 48Pre (Table).

**Vastus Lateralis.** No time-by-group interactions existed for PPT in the VL ($F_{4.56,123.35} = 2.1$, $P = .07$, $\eta^2 = 0.07$). We observed a main effect for time ($F_{4.56,123.35} = 7.05$, $P < .001$, $\eta^2 = 0.20$) but not for group ($F_{1,27} = 2.30$, $P = .14$, $\eta^2 = 0.07$). Post hoc analysis showed that 0Pre and 0Post1 were greater than 24Pre through 48Post2; 0Post2 was greater than 24Pre, 24Post1, and 48Pre; 24Pre was less than 24Post2; and 24Pre through 48Post2 were less than 72Pre through 72Post2 (Table).

**Rectus Femoris.** No interaction of time by group was noted for PPT in the RF ($F_{4.57,123.63} = 1.78$, $P = .12$, $\eta^2 = 0.06$). We observed a main effect for time ($F_{4.57,123.63} = 4.09$, $P = .002$, $\eta^2 = 0.13$) but not for group ($F_{1,27} = 2.21$, $P = .14$, $\eta^2 = 0.07$). Post hoc analysis showed that 0Pre and 0Post2 were greater than 24Pre and 48Pre; 0Post1 was greater than 24Pre and 24Post2 through 48Post1; 24Pre was less than 24Post1, 24Post2, and 48Post2 through 72Post2; and 24Post2 through 48Post1 were less than 72Pre through 72Post2 (Table).

### Range of Motion

We found an interaction of time by group for active ROM ($F_{6.85,191.86} = 2.66$, $P = .01$, $\eta^2 = 0.08$). The 12 × 1 repeated-measures ANOVA for each group revealed a main effect for time in the WBV group ($F_{11,165} = 3.37$, $P < .001$, $\eta^2 = 0.18$). Post hoc analysis showed that 0Pre was greater than 0Post1 through 48Post2; 24Pre was less than 24Post1; 24Pre, 24Post2, 48Pre, and 48Post2 were less than 72Pre

**Table. Pressure-Pain Threshold, Active and Passive Range of Motion, and Thigh Circumference Between Groups and Across 72 h After Exercise-Induced Muscle Damage, Mean ± SD Extended on Next Page**

| | Measurement | | | | |
|---|---|---|---|---|---|
| Variable | 0 h Pre | 0 h Post1 | 0 h Post2 | 24 h Pre | 24 h Post1 |
| Pressure-pain threshold, kPa | | | | | |
| Vastus medialis | | | | | |
| Whole-body vibration | 440.04 ± 198.75 | 422.36 ± 161.71 | 398.60 ± 150.58 | 347.76 ± 135.86[b] | 352.14 ± 132.23[b] |
| Control | 356.64 ± 86.90 | 349.35 ± 100.80 | 352.89 ± 116.16 | 325.73 ± 110.50[b] | 327.74 ± 108.54[b] |
| Vastus lateralis | | | | | |
| Whole-body vibration | 317.88 ± 93.92 | 323.00 ± 99.87 | 311.56 ± 100.59 | 278.23 ± 92.65[b] | 286.03 ± 104.88[b] |
| Control | 298.14 ± 71.06 | 300.40 ± 86.79 | 288.71 ± 96.14 | 271.09 ± 88.23[b] | 278.41 ± 104.08[b] |
| Rectus femoris | | | | | |
| Whole-body vibration | 417.66 ± 150.05 | 434.33 ± 167.48 | 407.63 ± 159.27 | 373.48 ± 153.06[b] | 393.31 ± 184.47 |
| Control | 368.12 ± 102.15 | 377.45 ± 142.12 | 392.59 ± 151.74 | 337.53 ± 138.34[b] | 371.41 ± 156.75 |
| Range of motion, °[a] | | | | | |
| Active | | | | | |
| Whole-body vibration | 130.62 ± 4.30 | 128.93 ± 3.49[c] | 128.06 ± 4.34[c] | 127.25 ± 4.37[c] | 128.75 ± 4.17[c] |
| Control | 130.71 ± 6.98 | 129.71 ± 7.12 | 129.85 ± 6.52 | 130.07 ± 7.26 | 129.85 ± 7.09 |
| Passive | | | | | |
| Whole-body vibration | 145.00 ± 5.44 | 142.62 ± 5.08 | 142.18 ± 5.31 | 143.62 ± 5.71 | 143.75 ± 4.78 |
| Control | 142.85 ± 9.04 | 142.64 ± 7.42 | 143.14 ± 7.89 | 144.14 ± 7.54 | 145.28 ± 5.86 |
| Thigh circumference, cm | | | | | |
| Distal | | | | | |
| Whole-body vibration | 39.31 ± 3.48 | 39.64 ± 3.43 | 39.51 ± 3.51 | 39.42 ± 3.41 | 39.61 ± 3.34 |
| Control | 41.46 ± 3.37 | 41.82 ± 3.12 | 41.65 ± 3.24 | 41.72 ± 3.32 | 41.76 ± 3.43 |
| Midthigh | | | | | |
| Whole-body vibration | 52.20 ± 5.13 | 52.42 ± 5.29 | 52.31 ± 5.40 | 52.27 ± 5.27 | 52.03 ± 4.99 |
| Control | 53.19 ± 3.45 | 53.55 ± 3.24 | 53.41 ± 3.09 | 53.34 ± 3.55 | 53.35 ± 3.36 |

Abbreviations: Pre, pretreatment; Post1, posttreatment 1; Post2, posttreatment 2.

[a] Indicates group-by-time interaction ($P < .05$).

[b] Indicates main effect for time from 0 h Pre ($P < .05$).

[c] Indicates simple comparison with 0 h Pre.

and 72Post2 in the WBV group (Table). A main effect for time was also noted in the control group ($F_{4.85,63.13} = 2.54$, $P = .03$, $\eta^2 = 0.16$). Post hoc analysis demonstrated that 0Pre through 24Post1 were less than 48Pre and 72Pre, and 24Post2 was less than 48Pre in the control group (Table). We did not find an interaction of time by group for passive ROM ($F_{6.53,163.01} = 1.13$, $P = .34$, $\eta^2 = 0.03$). We also did not observe main effects for time ($F_{6.53,163.01} = 1.89$, $P = .77$, $\eta^2 = 0.06$) or group ($F_{1,28} = 0.17$, $P = .67$, $\eta^2 = 0.006$) for passive ROM (Table).

### Thigh Circumference

No interaction of time by group was present for distal thigh circumference ($F_{1.71,47.92} = 1.95$, $P = .15$, $\eta^2 = 0.06$). We did not observe main effects for time ($F_{1.71,47.92} = 1.44$, $P = .24$, $\eta^2 = 0.04$) or group ($F_{1,28} = 2.49$, $P = .12$, $\eta^2 = 0.08$) for distal thigh circumference (Table). No interaction of time by group was noted for midthigh circumference ($F_{1.55,43.62} = 1.61$, $P = .21$, $\eta^2 = 0.05$). We did not demonstrate main effects for time ($F_{1.55,43.62} = 1.40$, $P = .25$, $\eta^2 = 0.04$) or group ($F_{1,28} = 0.46$, $P = .50$, $\eta^2 = 0.01$) for midthigh circumference (Table).

### Muscle Pain

We did not observe an interaction of time by group for muscle pain in the quadriceps ($F_{3.86,108.20} = 0.38$, $P = .81$, $\eta^2 = 0.014$). We found a main effect for time ($F_{3.86,108.20} = 44.93$, $P < .001$, $\eta^2 = 0.616$) but not for group ($F_{1,28} = 0.05$, $P = .82$, $\eta^2 = 0.002$). Post hoc analysis revealed that 0Pre was less than all other time points; 0Post1 and 0Post2 were less than 24Pre through 72Post2; 24Pre through 24Post2 were less than 48Pre through 72Post2; and 48Pre through 48Post2 were greater than 72Pre through 72Post2 (Figure).

## DISCUSSION

We investigated the effects of WBV as a treatment modality for pain management and function after EIMD and noted that 4 sets of split squats performed to failure successfully induced muscle soreness and increased pain sensitivity to pressure stimuli. Our WBV treatment protocol applied immediately after and at 24, 48, and 72 hours after high-intensity DOMS-inducing exercise had no effects either acutely (immediately or for 10 minutes after) or on the day-to-day progression of muscle pain, knee ROM, and

**Table. Extended From Previous Page**

| Measurement | | | | | | |
|---|---|---|---|---|---|---|
| 24 h Post2 | 48 h Pre | 48 h Post1 | 48 h Post2 | 72 h Pre | 72 h Post1 | 72 h Post2 |
| 360.40 ± 136.24[b] | 352.22 ± 136.86[b] | 380.33 ± 183.07[b] | 381.58 ± 183.75[b] | 373.66 ± 116.42[b] | 395.21 ± 145.85[b] | 386.11 ± 126.25[b] |
| 335.97 ± 115.92[b] | 260.69 ± 97.78[b] | 265.11 ± 102.78[b] | 264.44 ± 109.54[b] | 273.05 ± 104.82[b] | 269.22 ± 114.40[b] | 273.72 ± 103.52[b] |
| 293.46 ± 108.32[b] | 285.11 ± 85.24[b] | 304.03 ± 110.06[b] | 312.82 ± 111.81[b] | 339.58 ± 96.16 | 347.35 ± 120.50 | 340.43 ± 113.06 |
| 278.06 ± 91.74[b] | 232.97 ± 84.39[b] | 234.83 ± 88.01[b] | 235.95 ± 86.52[b] | 249.67 ± 91.27 | 253.00 ± 98.67 | 250.48 ± 90.13 |
| 389.17 ± 175.45 | 401.05 ± 154.61[b] | 410.66 ± 187.69 | 411.89 ± 189.62 | 455.79 ± 166.56 | 457.08 ± 168.57 | 455.47 ± 170.43 |
| 366.27 ± 140.37 | 291.12 ± 126.61[b] | 297.04 ± 129.52 | 316.94 ± 139.05 | 307.66 ± 139.63 | 323.99 ± 167.69 | 327.71 ± 139.04 |
| 127.75 ± 4.94[c] | 127.31 ± 4.92[c] | 128.43 ± 4.76[c] | 127.93 ± 5.20[c] | 129.93 ± 4.10 | 128.93 ± 4.97 | 129.50 ± 4.64 |
| 130.64 ± 5.13 | 132.78 ± 6.11[c] | 131.42 ± 6.23 | 130.85 ± 5.92 | 132.21 ± 7.17[c] | 132.21 ± 7.12 | 131.35 ± 5.94 |
| 143.06 ± 6.04 | 142.81 ± 7.05 | 143.62 ± 5.18 | 142.50 ± 5.57 | 144.62 ± 4.60 | 143.25 ± 5.20 | 144.87 ± 5.18 |
| 144.35 ± 6.91 | 144.35 ± 6.27 | 143.78 ± 5.88 | 144.14 ± 5.84 | 145.28 ± 6.08 | 146.35 ± 5.58 | 145.21 ± 5.51 |
| 39.58 ± 3.28 | 40.75 ± 5.56 | 39.84 ± 3.30 | 39.98 ± 3.43 | 39.55 ± 3.29 | 39.52 ± 3.33 | 39.51 ± 3.46 |
| 41.77 ± 3.45 | 41.54 ± 3.42 | 41.60 ± 3.31 | 41.61 ± 3.46 | 41.73 ± 3.38 | 41.69 ± 3.49 | 41.66 ± 3.71 |
| 52.07 ± 4.75 | 52.31 ± 5.19 | 52.33 ± 5.07 | 52.20 ± 5.05 | 51.97 ± 4.89 | 52.02 ± 4.96 | 51.83 ± 4.84 |
| 53.36 ± 3.42 | 52.14 ± 5.75 | 53.38 ± 3.38 | 53.44 ± 3.43 | 53.41 ± 3.47 | 53.30 ± 3.53 | 53.16 ± 3.52 |

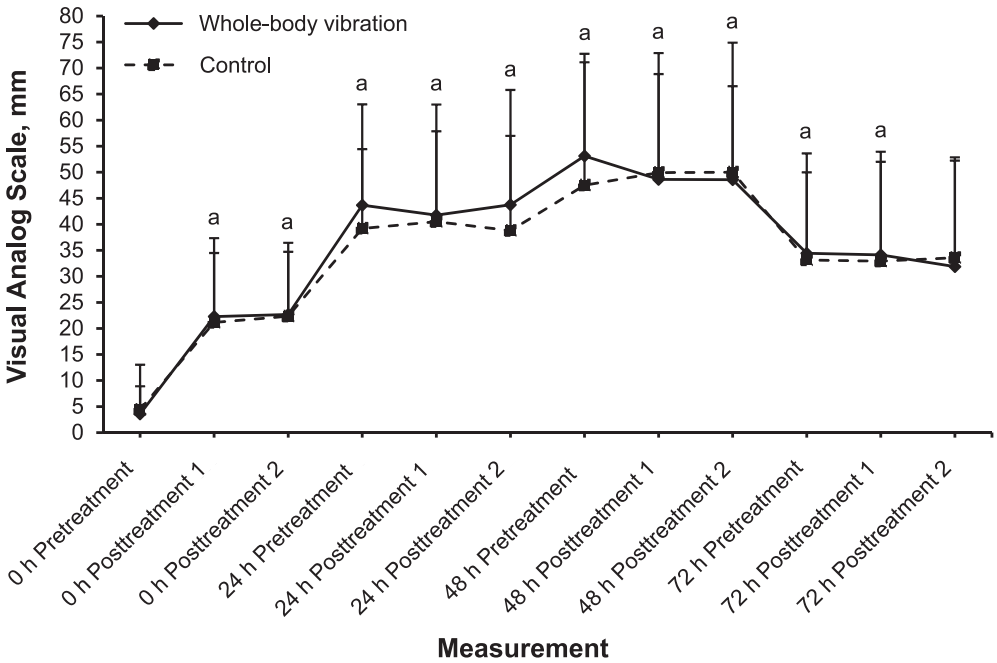


**Figure. Pain during movement between groups and across all time points after exercise-induced muscle damage using a visual analog scale (mean ± SD). [a] Indicates different from 0 h pretreatment ($P < .05$).**

thigh circumference, indicating that WBV was not an effective recovery modality in this study.

In populations with clinical pain, researchers[22] have suggested that WBV may inhibit pain receptors, allowing individuals to be more tolerant to pain. Melzack and Wall[26] proposed that activating vibration receptors in the skin may stimulate inhibitory interneurons in the spinal cord, which in turn reduce nociceptive inputs transmitted to the brain. Vibration also has been suggested to act via gate-control theory; the vibration may function to "gate" the afferent signal from nociceptors to the spinal column and brain, thereby reducing pain sensitivity.[26] This suggestion has been supported by findings that vibration applied to an unexercised muscle reduces sensitivity to pressure pain in normal, healthy individuals[8,9] and in individuals with chronic muscle pain.[9,27] However, Kakigi and Shibasaki[28] showed that, when DOMS was present 24 hours after the induction of EIMD, perceived pain from local pressure increased with analgesia from vibration. We suggest that this increase results from sensitization of nociceptors to the point where they become vibration responsive.[9,26] In contrast to these findings, we observed that our WBV protocol had no effect on muscle pain associated with DOMS.

The changes in muscle-pain ratings during movement and PPTs that we observed are consistent with previous observations reported after EIMD.[17,18,20,22,29] Group differences between WBV and control have been demonstrated for muscle pain,[18,20,22] indicating WBV could aid in reducing muscle pain after high-intensity exercise bouts. Muscle-soreness protocols varied in these studies. Some researchers used 6 sets of 10 repetitions of eccentric-only exercises on an isokinetic dynometer[18,20] in the elbow flexors[20] and knee flexors,[18] whereas Rhea et al[22] used a combination of resistance training, running, and sprints to induce muscle damage. However, the soreness protocol that we used has been reported to result in reduced force production in vertical jump up to 72 hours after EIMD but a WBV group showed no differences.[23] These investigators also used different forms of vibration. Lau and Nosaka[20] applied direct vibration from a handheld device, whereas other authors have used WBV platforms.[18,22] We tested the knee extensors during a lower body resistance-training exercise on the WBV platform, which may explain the difference between our findings and other studies. However, similar WBV protocols with the same vibration platform have been used in multiple performance studies[24,30] and in 1 muscle-soreness study, in which the authors[23] reported that WBV was not effective. These differences are important because the upper and lower body musculature may respond differently and different levels of vibration may elicit different responses. Whereas some researchers[20,21] have reported a decrease in muscle-pain rating (eg, DOMS intensity), they also have shown that PPTs were not different with vibration treatment, which is consistent with our observations. Another consideration is sex differences. We investigated only recreationally trained women; however, other researchers have studied men only,[17,20–22] women only,[29] or men and women together[18] but have not compared sex differences in pain measures after DOMS. In their study of women only, Dannecker and Sluka[29] reported similar results in PPT measures, showing an increase in sensitivity up to 2 days after exercise, but did not have a WBV intervention. Researchers[17,20–22] investigating men only have reported mixed results for different measures along with a different training status of male participants. More research using pain measures after DOMS is needed to determine if responses differ between sexes.

Our findings that WBV had no effect on thigh circumference were consistent with previous research after an eccentric-only damage protocol.[18,20] In this study, thigh circumference was unaffected by DOMS (ie, no swelling was detectable). Thus, it is difficult to draw definitive conclusions about the effects of WBV on muscle swelling from this study. Our findings of differences in ROM over time were similar to previous research[20] showing a return to baseline ROM after vibration. Our conflicting results may be due to the position in which ROM was measured and the stiffness and extent of inflammation in the muscle.

It is difficult to understand exactly why the WBV did not have any positive effects in this study. One limitation may have been that we assessed recreationally trained individuals because previous training has been shown to alter results in muscle-damage protocols.[5] However, we were interested in the responses to DOMS of recreationally trained individuals, which is why we sampled them. Our investigation was limited because we used only subjective pain measures to determine if the quadriceps experienced soreness, which is not a direct measure of muscle damage. Having force measurements would provide us with more confidence that muscle damage occurred. Another possible limitation was that, during the WBV and control treatment protocols and VAS pain measurements, we instructed participants to perform body-weight squats. These protocols may have affected the results of measures, possibly causing more soreness or damage to the muscle. However, the intent of the squats during these protocols was to provide dynamic functional movements that recreationally trained individuals typically perform and to ensure that all quadriceps muscles were exposed to vibration and incorporated in the muscle-pain measurements.

Researchers[14] have studied several ways to control or prevent EIMD symptoms. Decreasing these symptoms is critical in many populations. In physically active people, decreasing swelling, stiffness, and pain will allow for a quicker return to activity. In individuals with clinical pain, decreasing muscle pain for any period of time helps to manage pain and enable activities of daily living. Whole-body vibration may be more effective for generally healthy, recreationally active individuals, and direct vibration may be more effective for individuals with clinical pain or injury; however, this has not been identified in the literature. The scientific support for most of the currently employed treatment modalities for muscle pain, such as massage, cryotherapy, stretching, homeopathy, ultrasound, and electrical stimulation, is inconsistent and underwhelming. Our results also cast doubt on the efficacy of short-term WBV as a potential treatment.

## CONCLUSIONS

We provided a novel exercise to produce EIMD in the quadriceps that, to our knowledge, has not been established previously. In addition, no one has investigated the effects of using WBV to improve lower body muscle pain during

movement, PPTs, ROM, and thigh circumference in recreationally trained individuals. Our results are consistent with those of other investigators, showing that our participants experienced exercise-induced muscle soreness in the quadriceps. Therefore, we are confident that the WBV exposure we studied does not effectively help manage muscle pain in healthy recreationally trained women. Researchers should investigate treatments that alleviate muscle pain in a variety of populations (ie, patients with chronic and acute pain, recreationally trained males, and athletically trained populations).

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