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# An Acute Bout of Whole-Body Vibration Does Not Improve Jumping Performance in Those With Anterior Cruciate Ligament Reconstruction

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***Context:*** Individuals with anterior cruciate ligament reconstruction (ACLR) often fail to return to their previous level of sport performance. Although multifaceted, this inability to regain preinjury performance may be influenced by impaired plyometric ability attributable to chronic quadriceps dysfunction. Whole-body vibration (WBV) acutely improves quadriceps function and biomechanics after ACLR, but its effects on jumping performance outcomes such as jump height, the reactive strength index (RSI), and knee work and power are unknown.

***Objective:*** To evaluate the acute effects of WBV on measures of jumping performance in those with ACLR.

***Design:*** Crossover study design.

***Setting:*** Research laboratory.

***Patients or Other Participants:*** Thirty-six individuals with primary, unilateral ACLR.

***Intervention(s):*** Participants stood on a WBV platform in a mini-squat position while vibration or no vibration (control) was applied during six 60-second bouts with 2 minutes of rest between bouts.

***Main Outcome Measure(s):*** Double-leg jumping tasks were completed preintervention and postintervention (WBV or control) and consisted of jumping off a 30-cm box to 2 force plates half the participant's height away. The jumping task required participants to maximally jump vertically upon striking the force plates.

***Results:*** Whole-body vibration did not produce significant improvements in any of the study outcomes (ie, jump height, RSI, and knee work and power) in either limb ($P = .053–.839$).

***Conclusions:*** These results suggest that a single bout of WBV is insufficient for improving jumping performance in individuals with ACLR. As such, using WBV to acutely improve jumping performance post-ACLR is likely not warranted. Future research should evaluate the effects of repeated exposure to WBV in combination with other plyometric interventions on jumping performance.

***Key Words:*** jump height, work, power, reactive strength index (RSI)

**Key Points**

- Whole-body vibration did not improve jumping performance in those with anterior cruciate ligament reconstruction.
- An acute bout of whole-body vibration may not be an effective modality in attempts to improve jump height, reactive strength index, or lower extremity work and power.

The ability to return to full sport participation and preinjury levels of performance is limited after anterior cruciate ligament reconstruction (ACLR), with only 43% to 65% of patients returning to their preinjury level of sport performance.[1–4] Deficits in plyometric ability (eg, the ability to rapidly generate force over short periods of time) may contribute to poor sport performance post-ACLR and limit the capacity to achieve preinjury levels of performance. Impaired plyometric performance (eg, lesser jump height and distance, power, reactive strength index [RSI]) is common after ACLR, particularly in the reconstructed limb, and novel strategies to improve these deficiencies should be evaluated.[5–8]

Various functional tests are used to evaluate readiness to return to sport (RTS) and often include determinants of plyometric performance.[9,10] Common tests include single-leg (SL) hop tests (eg, single and triple hop for distance), drop vertical jumps, the Landing Error Scoring System, and countermovement jumps, among others.[10] These functional tests allow clinicians to elucidate limb symmetry, with symmetry greater than 90% often being a threshold for RTS readiness.[9,11] Laboratory techniques have also been used to evaluate metrics of performance such as work and power at the knee and center of mass (CoM) and the RSI (jump height divided by ground contact time).[5,8,12,13] Work and power at the knee may provide joint-specific information regarding deficits in stretch-shorten cycle energy storage and generation during plyometric tasks that could be obscured by gross estimates of lower extremity performance such as jump height and the RSI.[5] Conversely, measures such as the RSI provide holistic representations of overall lower extremity "explosiveness."[14]

Persistent deficits in quadriceps function (eg, lower surgical limb quadriceps peak torque [PT]) are common after ACLR and are associated with poor performance outcomes; thus, enhancing quadriceps function may also improve functional performance.[7,12,13,15] Whole-body vibration (WBV) has been previously demonstrated to improve quadriceps function in individuals with ACLR (eg, increases in quadriceps PT and early rate of torque development [RTD]); however, it is unknown if WBV similarly improves performance metrics in individuals with ACLR.[16–18] Quadriceps strength and the RTD are associated with jumping performance in those with ACLR; thus, using WBV, which has previously been demonstrated to improve these measures of quadriceps function, may also improve jumping performance.[12,19] Previous research in uninjured individuals has demonstrated increases in countermovement and squat jump height after training paradigms that incorporate WBV, potentially due to concurrent enhancement of quadriceps strength.[20–24] We are unaware of previous literature evaluating the influence of WBV on knee and CoM work and power or the RSI, all functional measures that may be related to performance ability in sport. Practically, if WBV demonstrates an acute improvement in these performance measures, it may be a viable modality to incorporate into a functional warm-up routine before practice or competition in those with ACLR, particularly those who are cleared to return to full sport participation. Thus, the purpose of this study was to evaluate the acute effects of WBV on measures of functional performance in individuals with ACLR. We hypothesized that WBV would improve jump height, the RSI, and both knee and vertical CoM work and power compared with a control intervention.

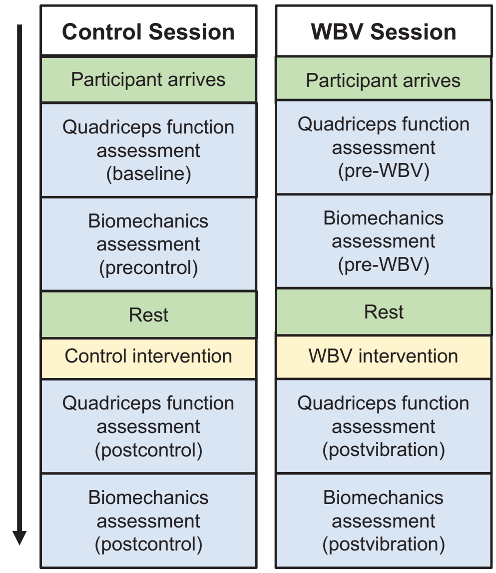


**Figure. Flow diagram of the experimental design. Abbreviation: WBV, whole-body vibration.**

## METHODS

A repeated-measures, crossover design was implemented to evaluate the influence of WBV on quadriceps function, landing biomechanics related to secondary ACL injury, and jumping performance in individuals with ACLR during 2 testing sessions separated by approximately 1 week. For each session, testing order was fixed for all participants such that they completed pretest assessments of quadriceps function (maximal voluntary isometric contraction and corticomotor excitability) followed by double-leg (DL) and SL jumping/landing biomechanics assessments. After pretest assessments, participants rested for 20 minutes to mitigate the influence of the biomechanical assessment on posttest corticomotor excitability and fatigue. Participants then received either a WBV or control intervention, after which posttest assessments were completed in the same order as the pretest. Both condition (WBV versus control) and jumping/landing task (SL versus DL) orders were counterbalanced. The Figure represents the experimental design for the testing procedures. Only DL performance, quadriceps PT, and RTD outcomes are reported here.

### Participants

We conducted an a priori power analysis based on work by Yang et al, who reported increases in vertical jump height after acute exposure to WBV in healthy individuals.[24] This analysis suggested that 29 participants ($d = 0.54$) would be necessary to achieve 80% power to identify a significant increase in jump height with $\alpha = .05$. However, this previous study was conducted in healthy individuals rather than those with ACLR; thus, we enrolled a convenience sample of 36 individuals (Table 1) between 18 and 35 years old with a history of primary, unilateral ACLR. All ACLR participants were medically cleared for unrestricted physical activity but were no more than 5 years removed from ACLR, were not knowingly pregnant, and had no history of other lower extremity surgery, other lower extremity injury in the 6 months before participation, or neurologic disorder (eg, cerebral palsy, spinal cord injury, multiple sclerosis). Additionally, all participants were required to possess quadriceps dysfunction, defined as isometric peak knee extension torque less than 3.0 $Ns^2m/kg$ in the ACLR limb, which was assessed during a screening session.[25] This study was approved by the university's institutional review board, and all participants were informed of the benefits and risks before providing written informed consent via an institutionally approved consent document.

### Quadriceps Function Assessment

Isometric quadriceps strength was assessed via an isokinetic dynamometer (HUMAC NORM) with the participant's hip and knee flexed at 85° and 90°, respectively. The ACLR limb was secured to the lever arm of the dynamometer via an ankle pad located approximately 1 inch (2.54 cm) above the malleoli and knee positioned in line (in both the frontal and sagittal plane) with the axis of rotation of the dynamometer lever arm. For the pretest assessment for each condition, 3 warm-ups were completed at 25%, 50%, and 75% of perceived maximum effort. For recorded trials, participants were then instructed to "kick out as hard and fast as possible" for approximately 3 seconds. Three recorded trials were completed at each time point (precontrol, postcontrol, pre-WBV, post-WBV), and all torque data were sampled at 2000 Hz. Postprocessing of torque data was completed using custom LabVIEW scripts (National Instruments Corp) and low-pass filtered using a fourth-order

**Table 1. Participant Demographics**

| | All Participants (N = 36) | Included in Jumping Analyses (N = 34)[a] |
|---|---|---|
| Age, y | 21 ± 3 | 21 ± 4 |
| Height, m | 1.72 ± 0.08 | 1.72 ± 0.08 |
| Mass, kg | 74.6 ± 14.4 | 75.6 ± 14.1 |
| Time postoperation, y | 2.65 ± 1.22 | 2.67 ± 1.20 |
| Sex | 27 F, 9 M | 25 F, 9 M |
| Tegner activity level | 6.14 ± 2.02 | 6.21 ± 2.06 |
| Graft type | 18 patellar tendon, 15 hamstrings tendon, 2 quadriceps tendon,1 allograft | 17 patellar tendon, 14 hamstrings tendon, 2 quadriceps tendon,1 allograft |
| Meniscus pathology at time of ACLR | 23 yes, 13 no | 22 yes, 12 no |

Abbreviations: ACLR, anterior cruciate ligament reconstruction; F, females; M, males.
[a] One participant was removed due to corrupted ground reaction force data, and 1 participant was removed due to lost double-leg jumping data files; thus, all jumping analyses represent 34 participants.

Butterworth digital filter at 50 Hz. Onset was identified when quadriceps torque exceeded and stayed above 1 Nm for 1.25 seconds. Quadriceps PT was defined as the maximum torque value during a trial, and the RTD was defined as the change in torque divided by the change in time from 20% to 80% PT. Both PT and the RTD were averaged over each of the 3 recorded trials for each time point.

## Jumping Biomechanics Assessment

Jumping biomechanics were assessed via 3-dimensional motion capture (Vicon Motion System) interfaced with 2 in-ground force plates (Bertec Corp). Kinematic data were sampled at 200 Hz, and kinetic data were sampled at 2000 Hz. Participants were outfitted with 29 retroreflective markers that were placed bilaterally over the first and fifth metatarsal heads, calcanei, medial and lateral malleoli, medial and lateral epicondyles, tibial crests, midthighs, greater trochanters, anterior superior iliac spines, posterior superior iliac spines, and acromia. Individual markers were placed over the sternum, L4-L5 interspace, and coccyx. A static trial was completed to estimate joint centers and align the participant with the capture volume while they stood with the feet shoulder-width apart and pointed forward, knees extended, and arms abducted 90°. The ankle-joint center was the midpoint between the medial and lateral malleolus, the knee-joint center was the midpoint between the medial and lateral epicondyle, and the hip-joint center was calculated using the Bell method.[26] The thigh and shank segments were created similarly to the method used by Kadaba et al by using the hip- and knee-joint centers and thigh marker to create the thigh and using the knee- and ankle-joint centers and tibia marker to create the shank.[27] The foot segment was created as described by Robertson et al, with the lateral and medial malleoli, first and fifth metatarsal, and calcaneus markers.[28] For all jumping tasks, the medial epicondyle and medial malleolus markers were removed to permit unrestricted motion.

Both SL and DL tasks were performed with participants jumping from a 30-cm box to 2 force plates located 50% of their height away from the front of the box. Participants were instructed to jump off the box with both feet at the same time while minimizing upward displacement (ie, to jump down and out rather than up and off). For the DL task, participants were further instructed to perform a maximal vertical leap immediately upon landing (ie, countermovement).[29] For the SL landing task, the uninvolved limb was always assessed before the ACLR limb, and participants were instructed to land with 1 foot, "stick the landing," and maintain balance for 10 seconds. A minimum of 3 practice trials were completed for each DL and SL (both ACLR limb and uninvolved limb) task before 3 recorded trials.

## Jumping Biomechanics Data Processing

For the purposes of this study, only the DL tasks results are reported, as this task is primarily relevant to the assessment of jumping performance, while the SL task includes only a landing component (ie, no jump after landing). All data processing was completed via commercial software (Visual3d, C-Motion Inc, and LabVIEW, National Instruments, Inc). Kinematic data were low-pass filtered at 10 Hz, and kinetic data were low-pass filtered at 75 Hz, both using a fourth-order Butterworth filter.[30–32] Euler angles were used to calculate knee-joint angles as the position of the shank relative to the thigh in a sagittal-frontal-transverse sequence and were combined with kinetic and anthropometric data to calculate sagittal power and work of the knee and vertical power and work of the CoM (the vertical midpoint between the coccyx and L4-L5 marker) via an inverse dynamics approach.

Performance outcomes were assessed during the initial landing phase. The initial landing phase was identified during the first landing (the landing that occurred upon striking the force plates after jumping from the box; no variables were analyzed during the second landing—ie, the return to the ground following the vertical jump) as the interval between initial ground contact (IGC) when the vertical ground reaction force was greater than 20 N and subsequently decreased to less than 20 N (toe off) due to the vertical jump and was then further divided into absorption and propulsion phases. The absorption phase was defined as the interval from IGC to the lowest vertical position of the CoM, and the propulsion phase was defined as the interval from the lowest vertical position of the CoM to toe off. Outcomes included work, peak and average power acting on the knee, and peak and average vertical power acting on the CoM during both the absorption (ie, negative work and power) and propulsion (ie, positive work and power) phases. Knee power was calculated via standard inverse dynamics as the instantaneous product of the internal sagittal-plane joint moment and sagittal-plane angular velocity, and joint work was calculated as the area under the power-time curve using the trapezoid method.[33] Vertical power for the CoM was calculated as the instantaneous product of total vertical force and vertical velocity of the CoM, and vertical work was calculated as the area under the power-time curve using the trapezoid method.[33] Only vertical work and power were calculated, as performance was holistically related to the ability of the participants to

Table 2. Marginal Means (95% CIs) for Performance in the ACLR Limb

| ACLR Limb Performance Measures | Pre-WBV | Post-WBV | Precontrol | Postcontrol | *P* Value |
|---|---|---|---|---|---|
| Absorption | | | | | |
| Knee work, × BW × height | −0.068 (−0.070, −0.066) | −0.070 (−0.072, −0.068) | −0.068 (−0.070, −0.066) | −0.067 (−0.069, −0.064) | .107 |
| Knee average power, × (BW × height)/s | −0.382 (−0.396, −0.369) | −0.391 (−0.405, −0.378) | −0.382 (−0.396, −0.369) | −0.380 (−0.394, −0.367) | .420 |
| Knee peak power, × (BW × height)/s | −1.32 (−1.37, −1.27) | −1.37 (−1.42, −1.33) | −1.32 (−1.37, −1.27) | −1.34 (−1.9, −1.29) | .488 |
| Propulsion | | | | | |
| Knee work, × BW × height | 0.039 (0.037, 0.040) | 0.037 (0.036, 0.039) | 0.039 (0.037, 0.040) | 0.038 (0.036, 0.039) | .662 |
| Knee average power, × (BW × height)/s | 0.169 (0.161, 0.178) | 0.162 (0.154, 0.171) | 0.169 (0.161, 0.178) | 0.168 (0.160, 0.176) | .527 |
| Knee peak power, × (BW × height)/s | 0.436 (0.421, 0.450) | 0.427 (0.412, 0.442) | 0.435 (0.420, 0.450) | 0.431 (0.416, 0.446) | .752 |

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BW, body weight; WBV, whole-body vibration.

perform work and power in the vertical direction (eg, during the countermovement). Joint work (joules) and power (watts) were normalized to the product of body weight (BW) and height (work, × BW × height; power, × [BW × height]/s), and CoM work and power were normalized to BW (work, × BW; power, × BW/s). All variables were averaged over 3 trials for each time point in each condition. Additionally, jump height and the RSI were evaluated. Jump height was calculated as the difference between the maximal vertical position of the CoM during the countermovement jump and the vertical position of the CoM during the static calibration trial. The RSI was calculated as jump height divided by ground contact time (from IGC to toe off) during the initial landing phase.

### Intervention

All participants completed a WBV protocol that has been shown to acutely improve quadriceps function for up to an hour and gait biomechanics in individuals with ACLR.[16–18,34] Participants stood on a WBV platform (Power Plate pro5) in a mini squat position while vibration was applied during six 60-second bouts with 2 minutes of rest between bouts. Whole-body vibration was delivered in the vertical direction at an acceleration of 2*g* and a frequency of 30 Hz (displacement = 1.6 mm). The control intervention was identical to the WBV protocol with the exception that no vibration was applied.

### Statistical Analyses

One participant was removed due to corrupted ground reaction force data, and 1 participant was removed due to lost DL jumping data files; thus, all jumping analyses represent 34 participants. Statistical significance was set a priori at $P \leq .05$. We conducted separate linear mixed-effects models for each dependent variable, with condition and time point as a fixed interaction effect, pretest values and time post-ACLR (as performance continues to improve even after successful RTS) as fixed-effect covariates, and participant as the random effect.[35] Although we statistically controlled for pretest values within the models, we additionally conducted paired-samples *t* tests for the pretest values between the WBV and control conditions for all dependent variables to ensure pretest values did not differ between conditions. Additionally, for any significant interaction effects, post hoc pairwise comparisons were evaluated using the Tukey honestly significant difference test.

## RESULTS

Participant demographics are listed in Table 1. There was no difference in pretest values between conditions for any dependent variables ($P = .182$–$.972$). There were no significant condition by time point interaction effects ($P = .053$–$.839$) for jumping performance. There was a condition by time point interaction effect for quadriceps PT ($P = .002$), but not for the RTD ($P = .891$). Post hoc pairwise comparisons demonstrated smaller PT at postcontrol compared with post-WBV ($P < .001$), precontrol ($P = .001$), and pre-WBV ($P = .001$). All marginal means and 95% CIs are listed for each variable at each time point in Tables 2 through 5.

## DISCUSSION

The primary findings of this study were that jump height, the RSI, and knee and vertical CoM work and power were unaffected by WBV in those with ACLR. There were no other significant differences for any jumping performance variable changes after WBV in either limb compared with changes in the control condition. This is contrary to our hypothesis, in which we expected WBV to improve jumping performance. Thus, a single session of WBV may not be sufficient to stimulate an increase in plyometric ability.

Evaluating and attempting to improve plyometric performance after ACLR is imperative, as detriments in performance are commonly not fully resolved at RTS and continue to improve up to 3 months post-RTS.[35] Moreover, between-limbs deficits in performance outcomes have also been reported, with peak power, jump height, and the RSI during SL jumping and landing being smaller in the ACLR limb.[5,6,8] Jump height is associated with sport-specific measures such as block and attack performance in professional volleyball players and weight-lifting performance and is used as a metric in aiding selection to various sports teams.[36–38] However, jump height alone may not provide sufficient insight into the lower extremity neuromuscular system; thus, joint and CoM power are relevant to evaluate as well.[39] As plyometric performance is related to sport performance, and the majority of individuals who undergo ACLR anticipate successful RTS, improving jump height and other jumping performance metrics may be necessary for successful reintegration to sport after ACLR.[40]

Previous researchers have attempted to use WBV to improve performance outcomes in healthy individuals. A systematic review by Manimmanakorn et al reported a moderate-to-large

Table 3. Marginal Means (95% CIs) for Performance in the Uninvolved Limb

| Uninvolved Limb Performance Measures | Pre-WBV | Post-WBV | Precontrol | Postcontrol | *P* Value |
|---|---|---|---|---|---|
| Absorption | | | | | |
| Knee work, × BW × height | −0.097 (−0.100, −0.095) | −0.095 (−0.098, −0.092) | −0.098 (−0.100, −0.095) | −0.092 (−0.095, −0.090) | .279 |
| Knee average power, × (BW × height)/s | −0.521 (−0.547, 0.496) | −0.529 (−0.555, 0.504) | −0.534 (−0.559, 0.508) | −0.501 (−0.526, 0.475) | .112 |
| Knee peak power, × (BW × height)/s | −1.90 (−1.96, −1.84) | −1.81 (−1.87, −1.75) | −1.90 (−1.96, −1.85) | −1.80 (−1.86, −1.74) | .839 |
| Propulsion | | | | | |
| Knee work, × BW × height | 0.050 (0.048, 0.051) | 0.048 (0.046, 0.049) | 0.050 (0.048, 0.051) | 0.048 (0.047, 0.050) | .657 |
| Knee average power, × (BW × height)/s | 0.203 (0.184, 0.221) | 0.211 (0.193, 0.230) | 0.208 (0.190, 0.227) | 0.203 (0.184, 0.222) | .466 |
| Knee peak power, × (BW × height)/s | 0.547 (0.528, 0.566) | 0.530 (0.511, 0.549) | 0.547 (0.528, 0.566) | 0.543 (0.524, 0.562) | .482 |

Abbreviations: BW, body weight; WBV, whole-body vibration.

effect of repeated administration of WBV alone on jump height compared with a control group (no WBV or exercise).[20] Additionally, WBV embedded in a strength training program has been demonstrated to improve jump height to a greater extent than strength training alone in uninjured individuals.[21,22] The results of our study demonstrate that an acute bout of WBV has no effect on jumping performance in individuals with ACLR. This is the first study, to our knowledge, that has evaluated the influence of WBV on jumping performance measures in those with ACLR. Mechanistically, WBV has been demonstrated to acutely improve quadriceps function, a common consequence of ACLR.[16–18] Previous studies have identified relationships between quadriceps function (eg, quadriceps strength and RTD) and jumping performance in individuals with ACLR; thus, the theoretical construct was to use WBV, a modality previously demonstrated to improve quadriceps strength and the RTD, to determine if jumping performance could also be acutely improved.[12,13,19] Jumping performance is influenced by the quadriceps' ability to efficiently produce torque about the knee to propel a person upwards; thus, quadriceps strength and the RTD are influential to jumping performance.[19] However, these studies did not evaluate changes in quadriceps strength or the RTD with jumping performance via an intervention; thus, it is possible that improvements in quadriceps function may not cause improvements in jumping performance. Additionally, there was not a significant change in quadriceps strength or the RTD after WBV in this study. There was a significant condition by time interaction effect for quadriceps strength ($P = .002$), but this was primarily predicated on a decrease in quadriceps strength after the control condition with no change in the WBV condition ($P = .990$). Interestingly, PT postcontrol was significantly smaller when compared with the post-WBV time point; thus, WBV may have been able to mitigate decreases in quadriceps PT that were demonstrated during the control condition. It is possible that the preintervention jumping assessment could have caused fatigue of the quadriceps before any postintervention testing, which WBV may have mitigated. Although this explanation is speculative, there was a 20-minute rest period after the preintervention assessments in attempts to mitigate fatigue from the assessments, and the Borg rating of perceived exertion was administered at the end of each testing session, with participants reporting a mean of 9.4 and 9.2 after the control and WBV sessions, respectively, demonstrating "very light" effort during each session. Regardless, as a whole, neither quadriceps strength nor the RTD improved with WBV in this study. This may also be an explanatory factor as to why jumping performance was not acutely improved after WBV.

Similarly, previous authors have reported no additive effect of WBV on jumping performance.[41,42] However, these studies were conducted in highly trained individuals and professional athletes; thus, a ceiling effect could have impaired the ability of WBV to influence performance. Our study evaluated only an acute bout of WBV, and it is possible that a single exposure to

Table 4. Marginal Means (95% CIs) for Non–Limb-Specific Performance

| Performance Measures | Pre-WBV | Post-WBV | Precontrol | Postcontrol | *P* Value |
|---|---|---|---|---|---|
| Jump height, m | 0.393 (0.385, 0.400) | 0.395 (0.387, 0.402) | 0.393 (0.385, 0.400) | 0.383 (0.376, 0.391) | .135 |
| Reactive strength index, m/s | 0.944 (0.912, 0.977) | 0.942 (0.909, 0.975) | 0.948 (0.915, 0.980) | 0.916 (0.883, 0.949) | .371 |
| Absorption | | | | | |
| CoM work, × BW × height | −0.556 (−0.564, −0.547) | −0.558 (−0.566, −0.549) | −0.557 (−0.565, −0.548) | −0.544 (−0.553, −0.536) | .091 |
| CoM average power, × (BW × height)/s | −2.92 (−2.99, −2.85) | −2.92 (−2.99, −2.85) | −2.93 (−3.00, −2.86) | −2.88 (−2.95, −2.82) | .511 |
| CoM peak power, × (BW × height)/s | −11.7 (−12.0, −11.3) | −11.6 (−11.9, −11.2) | −11.7 (−12.1, −11.4) | −11.2 (−11.6, −10.9) | .228 |
| Propulsion | | | | | |
| CoM work, × BW × height | 0.569 (0.559, 0.579) | 0.578 (0.568, 0.588) | 0.569 (0.559, 0.579) | 0.558 (0.548, 0.568) | .053 |
| CoM average power, × (BW × height)/s | 2.40 (2.34, 2.47) | 2.42 (2.36, 2.48) | 2.41 (2.35, 2.47) | 2.34 (2.27, 2.40) | .163 |
| CoM peak power, × (BW × height)/s | 4.53 (4.45, 4.61) | 4.60 (4.52, 4.68) | 4.53 (4.45, 4.61) | 4.46 (4.38, 4.54) | .089 |

Abbreviations: BW, body weight; CoM, center of mass; WBV, whole-body vibration.

**Table 5. Marginal Means (95% CIs) for Quadriceps Function Measures**

| Quadriceps Function Measures | Pre-WBV | Post-WBV | Precontrol | Postcontrol | *P* Value |
|---|---|---|---|---|---|
| Quadriceps PT, Nm | 2.13 (2.08, 2.18)[a] | 2.14 (2.09, 2.19)[b] | 2.13 (2.08, 2.18)[c] | 1.98 (1.92, 2.03)[a,b,c] | .002[d] |
| Quadriceps RTD, Nm/s | 5.01 (4.68, 5.35) | 4.68 (4.35, 5.02) | 5.01 (4.67, 5.34) | 4.73 (4.39, 5.06) | .891 |

Abbreviations: PT, peak torque; RTD, rate of torque development; WBV, whole-body vibration.
[a] Indicates a significant pairwise comparison between pre-WBV and postcontrol ($P = .001$).
[b] Indicates a significant pairwise comparison between post-WBV and postcontrol ($P < .001$).
[c] Indicates a significant pairwise comparison between precontrol and postcontrol ($P = .001$).
[d] Indicates a significant condition by time point interaction effect.

vibration may be insufficient to adequately improve jumping ability. Plyometric training has often been used to improve jumping performance; thus, future research should evaluate the additive effects of WBV with plyometric training to determine if the addition of WBV is of supplementary value.[43]

Individuals with ACLR often fail to return to their preinjury levels of sport performance and present with perpetual deficits in jumping performance.[1,5,8] As an acute bout of WBV did not influence jumping performance outcomes, future researchers should evaluate the influence of WBV embedded in a rehabilitation program after ACLR, similar to previous studies embedding WBV into strength training paradigms in uninjured individuals.[21,22] The continual evaluation of novel modalities aimed to improve functional outcomes after ACLR is imperative to facilitate adequate RTS and return to activity.

### Limitations

We did not control for sex, graft type, physical activity level, or meniscus status to preserve external validity. Additionally, the experimental design dictated that the posttest assessments of performance outcomes took place after an assessment of quadriceps function rather than immediately after WBV application. However, this was kept consistent between both control and WBV conditions, and the effects of WBV on quadriceps function have been demonstrated to last up to an hour.[16] Similarly, this study evaluated only the acute effects of WBV on landing performance in individuals with ACLR, and it is unknown if embedding WBV into rehabilitation may improve landing and jumping performance over time. Previous research has demonstrated that incorporating WBV into strength-training paradigms improves measures of jumping performance in uninjured individuals; thus, it is possible that those with ACLR may see similar benefits if exposed to repeated WBV.

## CONCLUSIONS

A single, acute bout of WBV did not improve jumping performance in individuals with ACLR; thus, it may not be advisable to use this intervention in isolation if the goal is to acutely improve jump height, the RSI, or knee work and power in this population. Evaluating novel modalities that improve measures of physical performance is imperative as plyometric performance is often reduced after ACLR and may be related to sport-specific performance. Future research should be conducted to evaluate the influence of repeated exposure to WBV on measures of physical function in addition to embedding WBV into rehabilitation interventions.

## ACKNOWLEDGMENTS

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