Acute and Cumulative Effects of Different Times of Recovery From Whole Body Vibration Exposure on Muscle Performance

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Abstract

Da Silva-Grigoletto, ME, Vaamonde, DM, Castillo, E, Poblador, MS, García-Manso, JM, and Lancho, JL. Acute and cumulative effects of different times of recovery from whole body vibration exposure on muscle performance. *J Strength Cond Res* 23(7): 2073–2082, 2009—This experiment was designed to assess the acute (Study I) and cumulative response (Study II) of muscle performance to differing recovery times after exposure to whole body vibration (WBV). All subjects (mean age 19.7 ± 1.9) were healthy and physically active. In both studies, subjects were exposed to a WBV bout of 6 exposures of 60 seconds each, with frequency of 30 Hz and amplitude of 4 mm. In Study I, subjects ($n = 30$) underwent 3 trials (1 per day) on different days with a 2-day wash-out period between trials; each trial included either a 1, 2, or 3 minutes of recovery between exposures to WBV. All subjects underwent all trials, which were randomly assigned. Jump ability and muscle power were measured before and after each bout. In Study II, subjects ($n = 45$) underwent 12 sessions of WBV training in 4 weeks (3 bouts/wk). The subjects were randomly assigned to 1 of the following 3 groups: WBV with 1-minute recovery periods between exposures, WBV with 2-minute recovery periods between exposures, or control group. Jump ability, muscle power, and strength were measured before and after each bout. In the acute study (I), recovery times of 1 and 2 minutes enhanced all measured parameters ($p < 0.05$), with the 2-minute recovery being more effective. In the long-term study (II), however, although both periods also enhanced the measured parameters ($p < 0.05$), the 1-minute recovery proved more effective because the response was modified by systematic stimulation. In conclusion, 2-minute recovery periods provided the most effective acute enhancement of muscle activation, whereas the 1-minute recovery provided a more effective cumulative enhancement of muscle power and jump ability.

Key Words training, muscular strength, muscular power

Introduction

Optimization or modification of the body's functional capacity leads to improved performance (61). Workload-induced stimuli play a major role in the training process. The search for new, specific, and innovative technologies or methods represents a constant challenge to sports technicians and has already yielded interesting findings. In recent years, whole body vibration (WBV) platforms have been incorporated into physical training programs (19) as a means of enhancing muscle strength (3,4,56,58,20,60). Because much contradiction exists as to whether WBV is beneficial (43,48) and as to which parameters may be the most suitable for producing benefits, much current research centers on the development of specific training protocols based on vibration stimulus. Recent studies have addressed, among other things, the optimal frequency of vibration (12,18). However, work still needs to be done on making stimuli more efficient, with a view to enhancing the acute or cumulative response to WBV (28). Likewise, of the variables traditionally used to characterize training loads (volume, intensity, duration, and recovery), optimization of the latter 2 variables poses a considerable challenge to strength and conditioning coaches opting to use WBV.

To the best of our knowledge, no published studies deal specifically with recovery or with its effect on the acute and cumulative strength response to WBV. A review by Luo et al. (36) analyzing various parameters used in this type of training (frequency, amplitude, duration, and vibration method used) makes no mention of recovery as a part of research. It is well

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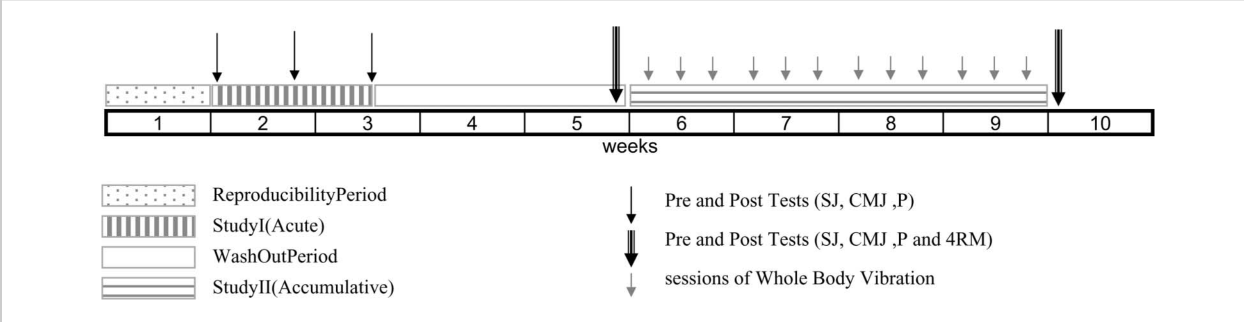

Figure 1. General layout and timing of studies, including training sessions and tests performed: squat jump (SJ), countermovement jump (CMJ), muscular power (P), and 4 repetition maximum (4RM).

known that physical exercise generates states of fatigue (central or peripheral) whose intensity is governed by the magnitude and duration of the stimulus (51); the application of vibration stimuli can produce a similar fatigue (52). Because fatigue is a common feature of any physical exercise, the sports technician aims to recover initial homeostasis, and even to improve upon initial values, when seeking to optimize training loads. The interval required to achieve a return to initial values is termed the recovery phase (62,46).

As with any other strength training technique, the rest period applied after any WBV exercise is intended to regain the muscle's mechanical potential and its functional ability to develop the tension required. More specifically, the aim is that when repeating a stimulus or applying force during a sporting activity the muscle should be in a state of maximal postactivation potentiation (PAP), thus favoring optimally efficient contraction (59,26). The duration and kinetics of the recovery period in any training program are determined by a number of factors, some endogenous (e.g., age, muscle volume, fiber type) and others exogenous to the athlete (e.g., prior fatigue level, years of training, prior vibration-training experience). Recovery is thus dependent on the principles of individuality and specificity that should guide the design of any training program (57); both principles are involved in determining the acute and cumulative response to training of varying duration and intensity.

This study is based on the hypothesis that the duration of the recovery interval is affected by the number of times that the vibration stimulus is applied during training. With that in mind, the following were examined in young physically active males: (a) the acute response of muscle performance to differing recovery times after WBV; (b) the effect of short-term training on optimal recovery times after WBV.

Methods

Experimental Approach to the Problem

The whole experimental procedure lasted 10 weeks. After a first week devoted to reproducibility testing, the first study was performed to evaluate the effect of different rest intervals on acute power response (measured by jumping and squat tests); for this purpose, a repeated measures design was used. After completion of the acute study (Study I), a 3-week wash-out period was applied to avoid any carryover effect. With use of the results derived from the acute study, a randomized longitudinal study (Study II) was performed to assess the cumulative effect on power and strength (4 repetition maximum [4RM]) production (Figure 1).

Subjects

Forty-five young male subjects volunteered to participate in the study (30 in Study I and 45 in Study II). The mean (*SD*) characteristics of the subjects are shown in Table 1.

Medical histories were reviewed by a doctor to assess suitability for the study, and each subject completed a questionnaire on physical activity. Subjects with osteoarticular conditions (including fracture or injury) were excluded. Participants were informed about the study procedure and its possible risks and benefits and signed a consent form approved by the University of Córdoba Ethics Committee. All subjects were physically active and engaged in various sporting activities in university teams (nonprofessional) but had not

Table 1. Number of subjects in 2 studies and main morphologic characteristics

	n	Age	Height	Weight	Body fat (%)
Study I	30*	19.6 (2.0)	176.7 (5.5)	71.1 (10.3)	14.8 (3.1)
Study II	45†	19.7 (1.9)	176.5 (5.3)	71.5 (10.7)	15.1 (3.3)

*One subject failed to complete study.
†Five subjects failed to complete study.

Figure 2. Subject in half squat position on vibration platform.

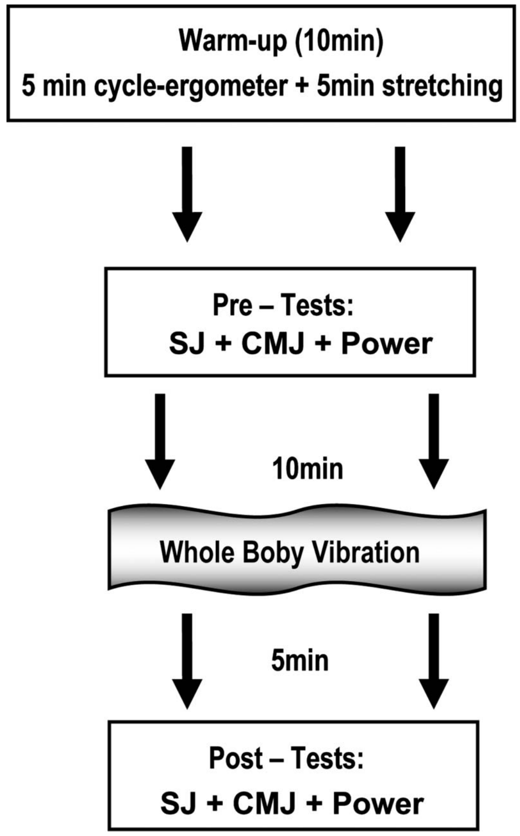

Figure 3. Data-recording protocol for Study I.

been engaged in regular resistance or jump-training programs for the last 12 months. All subjects had a very similar training volume (min 3/wk and max 4/wk), spread into 1-hour sessions. The sports they practiced were the following: indoor soccer ($n = 26$), basketball ($n = 12$), volleyball ($n = 3$), and paddle ball ($n = 4$). None of the selected subjects performed specific physical preparation exercises because, given the category they play in and the small amount of time they train, training was focused on game exercises. All research was undertaken during the in-season period.

Tests Performed

The first 3 tests described below (jump tests and muscular power test) were performed in Study I and Study II. The last test (4RM) was performed only in Study II.

All tests were preceded by a 5-minute warm-up (3 min 25 W + 2 min 50 W) on a cycloergometer (Ergoline 900, Ergometrics, Bitz, Germany) followed by a 5-minute program of stretching for femoral quadriceps, hamstrings, and triceps surae.

Jump Tests. Lower-body explosive strength characteristics, expressed as elevation of the body's center of gravity (vertical jump), were assessed using an infrared-ray platform (A.F.R technology) built into the MuscleLab system (Model PFMA 3010e, Ergotest, Langesund, Norway).

Two different vertical jumps were used for data recording: squat jump (SJ) and countermovement jump (CMJ) (7,31). The SJ is a test used to assess lower-body power as well as the ability to recruit motor units. It is performed from the half squat position with a knee angle of 90°; after a brief pause, the subject performing the test jumps upward as high as possible. The CMJ is a test used to assess explosive strength with reutilization of elastic energy and takes advantage of the myotatic reflex (7). The test starts with a preparatory movement of knee extension going down to a 90° knee flexion and, without pausing, jumping upward as high as possible. Both jumps were performed without use of the arms; subjects were asked to keep their hands on their hips. Elevation of the center of gravity (height in meters) above ground level was calculated for both tests as flight time (t_v) in seconds, applying the laws of ballistics:

$$H = t_v^2 \cdot g \cdot 8^{-1} \text{ (m)};$$

where "h" is height, and "g" is gravitational acceleration ($9.81 \text{ m} \cdot \text{s}^{-2}$).

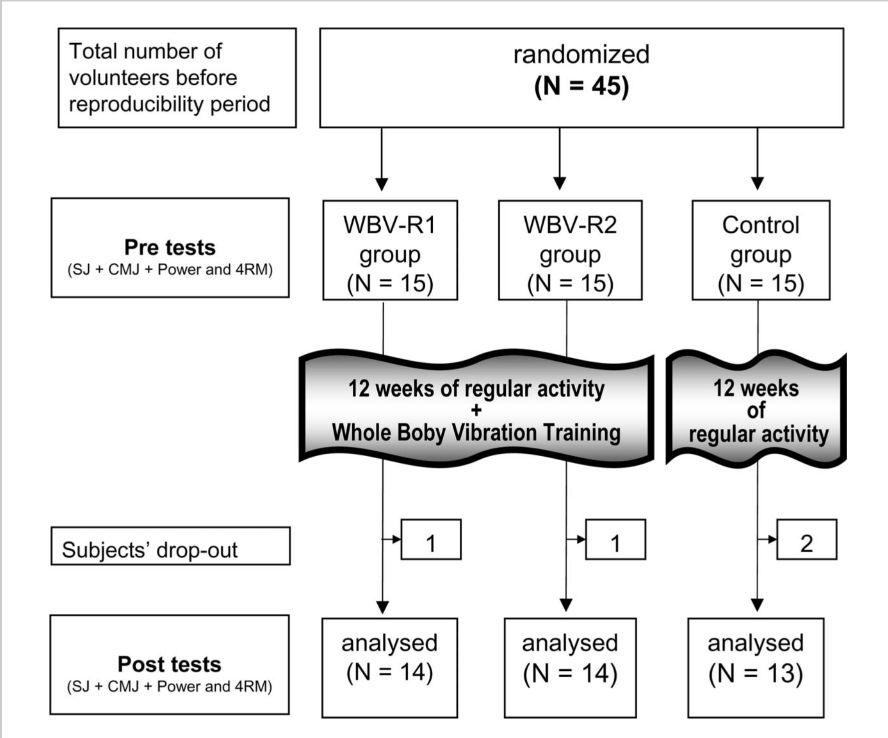

Figure 4. Data-recording protocol for Study II.

The jump flight time was measured on a digital chronometer connected to the platform of the the MuscleLab system.

Three jumps were performed for each type, the best result being used for statistical analysis.

Muscle Power. Although subjects had previously performed the jump tests, they performed a set of 8 repetitions at loads of 30–40% of the perceived maximum as a specific warm-up.

Lower-body maximal power was assessed using the MuscleLab system. Subjects were placed in a half squat position, with shoulders touching the bar; the starting knee angle for movement execution was set at 90°. When told to do so, subjects performed a concentric extension of the leg muscles (extensors of hip, knee, and ankle) starting from the flexed knee position and reaching full extension at 180°; this movement was performed

Table 2. Means and SD for performance test parameters: 10 minutes before (Pre) and 5 minutes after (Post) whole body vibration with 3 different recovery times: 1, 2, and 3 minutes, with respective *p*values; confidence interval = 95%.

	Mean (*SD*)			95% confidence interval	
Minutes	Pre*	Post	Significance *p*†	Lower	Upper
Squat jump (cm)					
1	36.37 (3.25)	37.11 (3.85)	0.018	0.13	1.33
2	36.57 (3.74)	38.39 (3.59)	0.001	1.34	2.28
3	36.80 (4.09)	36.99 (4.21)	0.275	−0.15	0.52
Countermovement jump (cm)					
1	40.02 (4.11)	40.91 (4.09)	0.033	0.07	1.66
2	39.81 (4.67)	42.10 (4.97)	0.001	1.61	2.95
3	40.12 (4.48)	40.24 (4.63)	0.491	−0.23	0.47
Power (W)					
1	1,300.95 (191.23)	1,329.69 (190.67)	0.028	3.28	54.18
2	1,288.60 (189.26)	1,347.01 (184.26)	0.001	31.37	85.44
3	1,295.97 (182.02)	1,298.22 (191.81)	0.863	−24.18	28.68

*No differences between pretest values.
†Analysis of variance with repeated measures.

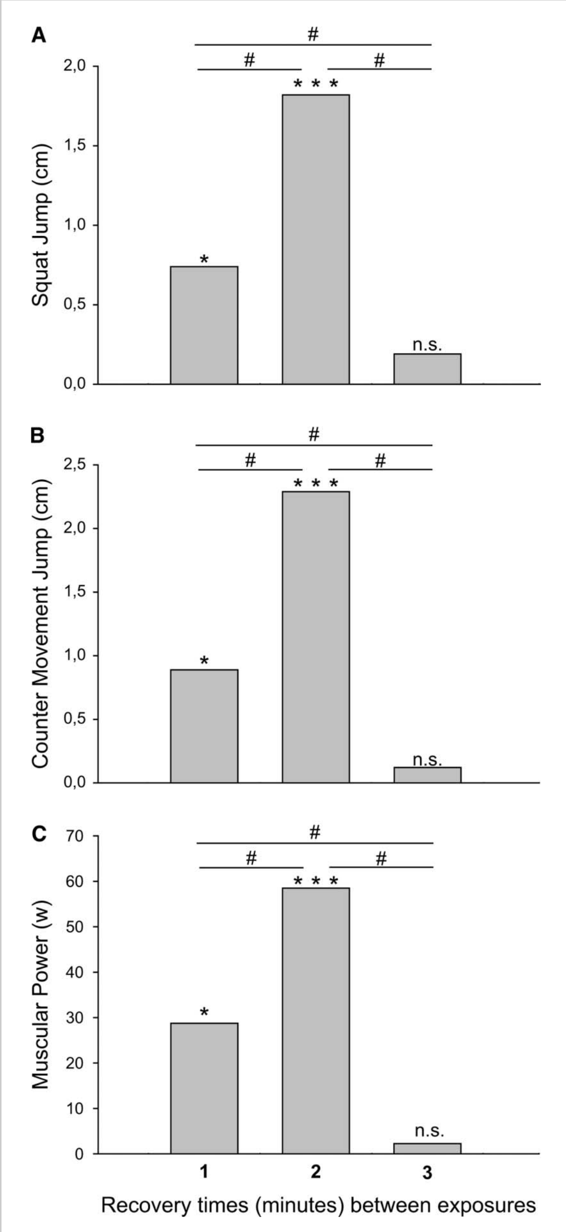

Figure 5. Mean difference between post-test and pretest results in Study I (acute): A) squat jump, B) countermovement jump, and C) muscular power, using 3 different recovery times between exposures to whole body vibration. *Mean differences significant for $p \leq 0.05$. ** Mean differences significant for $p \leq 0.01$. #Mean intergroup difference significant for $p \leq 0.05$.

against a resistance determined by weight plates added to both ends of the bar. Subjects were instructed to perform a purely concentric action from the starting point, keeping shoulders at an abducted position of 90° to assure consistency of shoulder and elbow joints during execution of the movement (42).

Subjects were also asked to keep the trunk as erect as possible throughout the movement. Because this test was used for estimating maximal power, subjects were asked to perform the movement as quickly as possible (53).

All tests were performed using a Multipower (GervaSport, Madrid, Spain) apparatus, designed for performance of squat exercises in which the bar is displaced only in the vertical position as allowed by linear bearings. Four different loads added to body weight were used for estimating both maximal and mean power: 25, 45, 65, and 85 kg. Three trials were performed for each load, and the best result (maximum average speed) was used for subsequent analysis. During the test, data were collected regarding bar displacement, maximum average speed (m/s), and average power (watts), using the lineal encoder built into the MuscleLab system, whose internal microprocessor works at a resolution of 10 μs. As the load is moved, the optical transducer signal interrupts the microprocessor at every 0.07 mm displacement. Power calculations were performed as previously described (2). Average power was calculated by means of the range of motion used to perform a whole repetition.

4RM. Load capabilities were calculated for 4RM in the half-squat exercise using a Multipower (GervaSport, Madrid, Spain) machine equipped with calibrated disks and the standard protocol for submaximal strength testing developed by Kraemer and Fry (33). The cadence used was 3 seconds per exercise (1.5 s for the eccentric phase and 1.5 s for the concentric phase) controlled by a digital metronome (MA-30, Korg, Tokyo, Japan).

Study Design and Procedure

Vibration parameters for Study I and Study II were as follows: 6 exposures of 60 seconds each, frequency 30 Hz, shown to be most effective (12,18), amplitude (peak-to-peak displacement) 4 mm. Recovery time was the only variable in both studies. Vibration was applied using a vibrating platform producing sinusoidal oscillations (Nemes, Ergotest, Rome, Italy) (Figure 2). Subjects adopted a squatting position, knees flexed at 100°, as measured by a manual goniometer. To avoid bruising, all subjects wore trainers for vibration exercises. To avoid variations in vibration transmission, subjects were asked to wear the same footwear at all training sessions.

Study I. Recovery times between exposures varied during each session and were randomly assigned. All subjects were exposed to the 3 different recovery times: 1, 2, and 3 minutes. The rest period between sessions was a minimum of 72 hours to avoid carryover effects from previous sessions. Vibration was applied after the warm-up and tests described earlier; postvibration tests were also performed (Figure 3).

Study II. In this longitudinal study, all subjects were subjected to the same prestudy and poststudy tests. Pretest data were recorded 3 days before the start of training and poststudy data 3 days after the last training session to avoid the acute effects of WBV. All subjects completing the study attended all 12 scheduled training sessions (100%). During the study, groups

Table 3. Means and SD for performance test parameters before (Pre) and after (Post), 4 weeks' whole body vibration training using different recovery times: 1 minute (WBV-R1) and 2 minutes (WBV-R2), with respective *p* values, confidence interval (CI 95%), and effect size.

Group	Mean (*SD*) Pre*	Mean (*SD*) Post	Significance *p*†	95% confidence interval Lower	95% confidence interval Upper	Effect size
Squat jump (cm)						
WBV-R1	35.37 (±3.09)	38.61 (±2.94)	0.001	2.16	4.30	1.04
WBV-R2	36.49 (±3.98)	38.08 (±4.46)	0.008	0.44	2.73	0.40
C	35.28 (±3.86)	35.57 (±4.91)	0.866	−1.09	1.29	0.07
Countermovement jump (cm)						
WBV-R1	39.70 (±3.45)	42.64 (±4.17)	0.001	2.02	3.85	0.85
WBV-R2	39.68 (±5.15)	41.33 (±5.17)	0.002	0.66	2.63	0.32
C	39.31(±4.77)	39.68 (±4.98)	0.170	−0.31	1.73	0.07
4 repetition maximum (kg)						
WBV-R1	155.32 (±22.70)	175.92 (±25.92)	0.001	11.02	26.19	0.90
WBV-R2	157.25 (±23.31)	174.27 (±24.48)	0.021	2.229	30.11	0.53
C	156.29 (±24.18)	158.01 (±25.31)	0.779	−6.92	10.01	0.04
Muscular power (W)						
WBV-R1	1,293.80 (±140.32)	1,390.74 (±168.51)	0.003	35.99	157.88	0.69
WBV-R2	1,292.20 (±228.85)	1,358.24 (±234.35)	0.048	0.56	131.49	0.28
C	1,268.24 (±241.38)	1,282.28 (±288.12)	0.338	48.77	130.31	0.04

*No difference between pretest values.
†Analysis of variance (3 × 2).

WBV with 1-minute recovery periods between exposures (WBV-R1) and WBV with 2-minute recovery periods between exposures (WBV-R2), underwent vibration training, whereas subjects in the control group continued with their usual sporting activities, controlled by a self-recording questionnaire (Figure 4).

Vibration training sessions took place 3 days a week (Monday, Wednesday, and Friday) for 4 weeks. After a standing stretching program for femoral quadriceps, hamstrings, and triceps surae, subjects started the vibration training session. The 2 groups undergoing vibration training, WBV-R1 and WBV-R2, rested for 1 and 2 minutes, respectively, between WBV exposures.

Reproducibility of Variables

Tests were repeated over 3 different days (Monday, Wednesday, and Friday) in the week before training. The intraclass correlation values (interday) were SJ = 0.93, CMJ = 0.96, 4RM = 0.94, and power = 0.95.

Statistical Analyses

Traditional statistical methods were used to calculate means and *SD*. Sample normality was calculated using the Shapiro-Wilks test. An analysis of variance and the Bonferroni adjustment for multiple comparisons were used to compare mean values. The following symbols were used to denote statistical significance: $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.001$ (***). The significance level was set at $p \leq 0.05$ (*); the SPSS 10.0 package for Windows (Chicago, IL, USA) was used for all statistical tests.

Results

Results of the acute and chronic studies are presented separately for a clearer understanding.

Study I

The values obtained for the 3 parameters tested (SJ, CMJ, and power) are shown in Table 2. No differences were recorded in pretest values for any of the randomly applied recovery times.

SJ, CMJ, and Power. The 3 tests yielded similar results: significant increases were observed for the application of both 1- ($p < 0.05$) and 2-minute ($p < 0.01$) recovery periods, whereas no difference was noted for application of the 3-minute recovery period. Post hoc analysis displayed significant differences between all groups for poststudy versus prestudy increases (Table 2) (Figure 5).

Study II

Values obtained for the 4 parameters tested (SJ, CMJ, 4RM, and power) after 4 weeks' training are shown in Table 3. As in Study I, there were no differences in prestudy values among the 3 groups (WBV-R1, WBV-R2, and control), to which subjects had been randomly assigned.

SJ, CMJ, and Power. A similar pattern was observed in the results obtained for the 3 tests in the WBV-R1 and WBV-R2

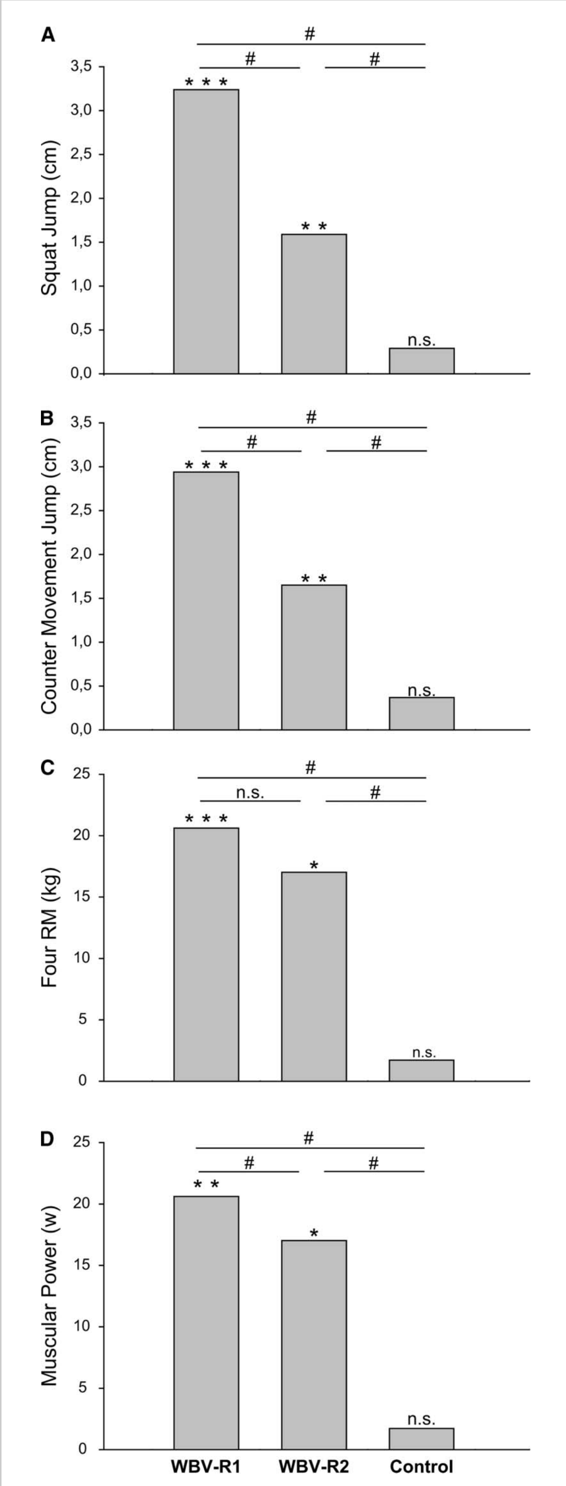

Figure 6. Mean between post-test and pretest results in Study II (cumulative): A) squat jump, B) countermovement jump, C) 4 repetition maximum, and D) muscular power for different recovery times during exposure to whole body vibration; 1 minute (WBV-R1), 2 minutes (WBV-R2) y control. *Mean differences significant for $p \leq 0.05$. **Mean differences significant for $p \leq 0.01$. #Mean intergroup difference significant for $p \leq 0.05$.

groups; the control group displayed no significant differences. Both WBV-R1 and WBV-R2 showed statistically significant increases for SJ, CMJ, and P; when comparing both groups, WBV-R1 showed significant differences with regard to WBV-R2 ($p < 0.05$) in all analyzed parameters. Post hoc analysis revealed significant differences between all groups for poststudy versus prestudy increases (Table 3) (Figure 6).

4RM. Muscle strength measured by means of the 4RM test showed significant difference for WBV-R1 ($p < 0.01$) and for WBV-R2 ($p < 0.05$) between prestudy and poststudy tests; no differences were found for the control group. Post hoc analysis showed significant differences between the control group and both experimental groups but not between the latter (Table 3) (Figure 6).

Discussion

The main finding was that short recovery times between exposures to WBV enhanced the acute response of muscle performance to WBV. Moreover, the cumulative effect of WBV training reduced the effective recovery time.

All repeated or intermittent exercise programs intended to develop either strength or endurance should take into account 4 factors: volume, duration, intensity, and recovery (57). A number of articles have analyzed and suggested optimum recovery times after strength training exercises (62,57,23,46,45,63), as well as investigating their effect on perceived exertion (64). However, this appears to be the first study designed to assess the effects of different recovery times after WBV training. Recovery, which varies depending on the duration and intensity of the stimulus, is aimed at restoring the muscle to its initial prestimulus state (22). Therefore, an adequate recovery is essential to ensure that the muscle eliminates activation-induced fatigue and returns to a state favoring the successful undertaking of a new activity (27). On the other hand, an incomplete recovery hinders the muscle's ability to meet the demands of further contraction (55). It has to be noted, however, that the recovery process is not linear over time; at certain moments in the process there is a transient increase in muscle contractile performance with respect to the levels that would be achieved from a state of total rest. This phenomenon is termed PAP or moment of muscle supercompensation (59,1,55,57). Based on this, Study I mainly aimed to achieve this state in the absence of muscle fatigue by identifying the optimum recovery time after stimulation of leg extensor muscles by WBV training.

The results suggest that a 2-minute recovery period between exposures is the most effective in prompting acute enhancement of jump ability and muscle power. A 1-minute recovery period prompted significant changes for both parameters ($p < 0.05$), a finding also noted by other authors both for SJ (13) and for CMJ (5, 47). Increases in muscle power, similar to the ones observed in the present study, have also been reported by Bosco et al. (4,5) previously. The jump and power results obtained here suggest that a 2-minute recovery period leads to greater optimization of the training session; in fact, improvements were significantly greater ($p < 0.05$) than after 1 minute. By contrast, Ruiter et al. (52), using a WBV protocol including a 2-minute recovery period, recorded a decline in jump ability (CMJ). This may be because they used a vibration amplitude twice that used here (8 mm vs. 4 mm). Cardinale et al. (11) have shown that amplitude has a decisive influence on the response to WBV training. Therefore, the amplitude used by Ruiter et al. may have prompted a greater muscle fatigue, thus requiring a longer recovery period to achieve peak PAP.

Strikingly, although 1-minute and 2-minute recovery periods appeared to be effective, the 3-minute recovery interval led to no significant improvements. For the subjects tested here, the longer recovery interval would appear to be excessive for the stimulus used, prompting the loss of the improvement achieved after a shorter interval. Cormie et al. (15) have suggested that WBV could be used for warm-up purposes; because short recovery times (1, 2 min) ensured in our study an enhanced PAP, we could postulate that they could be used when WBV is used as part of a warm-up routine.

WBV stimulus entails subjecting the body to small oscillations that prompt small changes in the length of skeletal muscle fibers; these, in turn, activate reflex mechanisms. This gives rise to activation of Ia afferent fibers through spindle excitation, an effect similar to that prompted in the tonic vibration reflex (TVR) described by Hagbarth and Eklund (24), and to improved Ia loop activity (8). Other authors have pointed to the possible existence of an excitatory inflow over short connections between muscle spindles and motorneurons (34) and to increased activation of motor areas of the central nervous system (39). Because of these complex associations, WBV training provides intense stimulus of the skeletal muscle, even though the exact mechanism is still not entirely understood.

Training, however, rarely pursues such short-term goals, seeking rather to achieve a cumulative adaptive response (Study II) as a means of stabilizing useful muscle behavior during sporting activity. This is known as sequential adaptation or chronic adaptation (57).

Most studies addressing the adaptive response to strength training can be classed under 2 main headings: those focusing on structural changes and those dealing with alterations taking place in the central or peripheral nervous system (32). Chronologically speaking, it is widely accepted that this adaptive response starts with changes in the nervous system and ends with morphologic changes involving a number of structures (mainly muscles, bones, and tendons). This is clear from reports that short-term strength training increases muscle strength without apparently modifying muscle structures (40,54). Any potentially strength-enhancing changes taking place during short-term training are mainly nerve related. For that reason, no morphologic or anthropometric variables were monitored in the present study with a view to charting muscle hypertrophy in activated areas.

A key feature of the present study is that the subjects, although routinely engaged in a range of sporting activities, had no prior experience of weight training. For that reason, body weight was used for loading over the 4-week training period. Even so, WBV prompted a significant improvement in jump ability, strength, and power. Some studies of conventional short-term strength training report that, over such short periods, no significant improvement was observed in jump ability either in subjects similar to those used here (25) or in top-level volleyball players (6).

However, in the present study, WBV appears to improve such characteristics after a short-term treatment, which appears to agree with the theory that WBV technology has beneficial effects in a wide range of sporting activities (10), as well as in motor rehabilitation (9) and general health (14). Moreover, the 2 protocols tested in Study II (WBV-R1 and WBV-R2) prompted significant improvements in jump ability, the best results being achieved with the shortest recovery period (1 min). This would appear to contradict the finding reported for the acute study (Study I) in which the best results for jump ability were recorded using a 2-minute recovery period. However, if acute muscle response had been charted over the whole 4-week period, the recovery period providing the best acute response, initially 2 minutes, might gradually have diminished as the number of training sessions increased because of cumulative adaptation. This hypothesis would be supported by the results obtained by Bosco et al. (3), which reflect an improvement of jump ability in athletes, similar to the ones obtained in the present study, after 10 sessions in 2 weeks of 90-second-exposure and 40-second-recovery periods.

Although most studies (29,4,12,13,52,47), including the present one, have evaluated the effect of WBV on standing subjects, there have also been reports of improvements of jump ability in subjects undergoing dynamic exercises. Indeed, Ronnestad (50) reported a significant increase in CMJ ability after 5 weeks of training using loads of up to 90% of 1RM in the group subjected to WBV.

As with jump ability, the present study recorded significant increases in muscle power, particularly after a 1-minute recovery period. Although a number of articles have addressed the acute effect of WBV training on muscle power (4,30), there has been very little specific research into the cumulative effect. Likewise, muscle strength (4RM) was also enhanced by WBV training. Other authors report positive effects of WBV on muscle strength over a relatively short period (29,58). In line with our results, Mester et al. (38), comparing conventional strength training using 2 dynamic-exercise protocols (half squat with 50% of 1RM) with WBV (2 and 4 mm), reported significantly better results both in maximum isometric force and in muscle strength for the groups using WBV (particularly at an amplitude of 4 mm). Both training protocols (WBV-R1 and WBV-R2) showed significant increases in muscle strength (13.26%, $p < 0.001$; 10.82%, $p < 0.05$, respectively). Although not statistically significant, there were differences observed in the strength increase magnitude the 2 groups experienced (effect size = 0.90 vs. 0.53, respectively).

It has been suggested that increased muscle strength may be caused largely by a neuromuscular activation linked to the TVR (10), although a number of articles point to other possible explanations. Issurin (28) reports that the cumulative effect of WBV stimulus improves monosynaptic stretch reflexes induced by afferent signals from muscle spindles, as well as reducing the inhibiting impact of Golgi tendon organs located at myotendinous junctions. Other possible causes may include a change in perceived exertion (35), improved motorneuron excitability (10,20,49), increased muscle temperature and increased blood flow (44,30), possible improvements in the anabolic hormone balance (37,10), and muscle hypertrophy (41,21).

Necking et al. (41) found that the cumulative effect of WBV increased the size of both slow-twitch and fast-twitch fibers in rats. It is not clear why the training protocol including a 1-minute recovery period proved more effective in Study II. Further research is undoubtedly required into training-load design techniques when using vibratory platforms. The literature on the effects of WBV training still contains disparate results, largely because of the use of different amplitudes, frequencies, exposure times, total number of exposures, and recovery intervals. The parameters selected for use here, with the exception of amplitude, had been proved suitable in previous studies by our research group (16,17).

To summarize, WBV training appears to be a safe and effective method of achieving a favorable acute response in muscle performance. In moderately active subjects, a 2-minute recovery period appears most effective in maximizing PAP and thus improving acute response. Optimum recovery times, however, may be modified as a result of systematic WBV training. Twelve WBV training sessions reduced optimum recovery times to 1 minute for jump and power tests. Both recovery times (1 min and 2 min) appeared equally effective in the case of 4RM.

Practical Applications

It is considered that WBV training sessions for moderately active subjects should include 2 different recovery times after exposure: a recovery time of roughly 1 minute to improve short-term performance in actions requiring high explosive force or high levels of maximum dynamic strength, thus optimizing the limited time generally available for training and a longer recovery period (approximately 2 min) when WBV is used to enhance muscle activation during warm-up.

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