

Effects of whole-body vibration training frequency on neuromuscular performance: a randomized controlled study

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ABSTRACT: This study compared the efficacy of two whole-body vibration (WBV) protocols with equal training volume and different frequency of training sessions/week on body composition and physical fitness. Sixty male air force cadets (age: 20.5 ± 1.4 years) were randomly assigned to a lower frequency (Lf-WBV), a higher frequency (Hf-WBV) or a control group (CG). The training volume was equated (20 training sessions) between the two WBV groups, but the number of weekly training sessions was different. The Lf-WBV group trained three times per week, the Hf-WBV group trained five times per week, while the CG did not perform any training. Each training session, for both groups, included 10 sets x 1 min with 1 min rest of WBV on a synchronous vibration platform (25–35 Hz, 4–6 mm). Body composition, flexibility, maximal strength, 30 m sprint time, squat jump (SJ) and countermovement jump (CMJ) performance, Wingate test performance, and 20 m shuttle run performance were evaluated before and after training. Only the Hf-WBV group demonstrated an increase in flexibility (+7%; $p < 0.01$; $d = 0.33$) and maximal strength (+10%; $p = 0.016$; $d = 0.59$), and a significant reduction in fat mass (-6.2%; $p < 0.01$; $d = 0.21$). SJ performance improved to a similar extent in both Hf-WBV and Lf-WBV groups (+7%; $p < 0.01$; $d = 0.32$). There were no changes in any parameter in the CG. In conclusion, only the condensed weekly WBV protocol was effective in improving body composition, flexibility, lower limb strength and power in young active individuals. The WBV protocol with the higher dispersion of training sessions per week (lower training frequency/week) improved SJ performance but did not have any effect on body composition, flexibility, or maximal strength.

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INTRODUCTION

Whole-body vibration (WBV) has emerged, in sports and rehabilitation settings, as a less fatiguing and a less time-consuming mode of exercise for the prevention of injury and for improving neuromuscular performance, particularly in less fit individuals [1]. There is evidence that the effects of WBV exercise on fitness parameters are influenced by the mode of vibration that is transmitted to the body (synchronous vs. side alternating vibration), the WBV loading parameters (frequency, amplitude, peak-to-peak displacement, acceleration) and by the subject's characteristics [2–9]. The structure of training sessions during the microcycle, the weekly training frequency, as well as the recovery time between the weekly training sessions, are additional factors that could influence the effects of WBV exercise on the human body [10].

With this in mind, research has been focusing on examining the efficacy of short-term (consecutive training sessions per week with

short intervals between them) and long-term (usually 2–3 non-consecutive training sessions per week with long intervals between them) WBV training programmes [11–17]. Several studies that examined the effects of long-term WBV training (2–3 training sessions/week) in different aspects of physical fitness in young individuals have reported equivocal findings. The subjects' characteristics (e.g. training and health status, age) are important factors that could affect the efficacy of long-term WBV training programmes. That is, long-term WBV training programmes have been shown to improve neuromuscular performance especially in untrained and elderly individuals, whereas no significant improvements have been reported in young trained individuals [11–12, 16].

So far, no study has compared the efficacy of short- vs. long-term WBV training programmes in order to find the most effective exercise training regimen. The only study [10] on WBV which examined the

effect of weekly training frequency, compared two *long-term* WBV training programmes with different training frequency (2 vs. 3 training sessions per week). The aforementioned study showed that a 6-week WBV training programme with 2 or 3 training sessions per week elicits similar training adaptations in isokinetic strength and total fat-free mass in recreationally active individuals.

There is evidence, however, that the number of training sessions per week (low vs. high training frequency; 2–3 vs. > 3 training sessions per week), the structure of training sessions during the micro-cycle (consecutive vs. non-consecutive training sessions per week) and the interval between them (short vs. long interval) can cause different aerobic and neuromuscular adaptations [18–20]. Furthermore, there is a notion that, in trained individuals, an exercise programme with consecutive sessions per week and short intervals between them is more effective for performance enhancement than an exercise programme with non-consecutive training sessions per week and long intervals between them [19–20].

Taking all the above into consideration, it is of interest to know whether the different frequency of training sessions per week (higher or lower training frequency per week), maintaining, however, equal total training volume (total number of training sessions), is more effective in improving indices of body composition and physical fitness. Thus, the main objective of this study was to examine and directly compare the efficacy of two whole-body vibration (WBV) protocols with equal training volume (20 training sessions) and different frequency of training sessions per week (3 vs. 5 weekly training sessions) on body composition, neuromuscular performance, lower body strength and power, and aerobic/anaerobic fitness in young, physically active individuals. Based on the above studies, it has been hypothesized that the long-term WBV training programme would not induce significant changes in indices of physical fitness and body composition. It was also hypothesized that the short-term WBV training programme would provoke significant improvements in body composition and neuromuscular performance in male air force cadets.

MATERIALS AND METHODS

Subjects

Sixty young male air force academy cadets (18–22 years old) volunteered to participate in the present study. Prior to the start of the study, participants' health and activity status were assessed by a standardized health history questionnaire as previously described by the American College of Sports Medicine (ACSM) [21]. All the participants were healthy non-smokers, free of any musculoskeletal injuries, did not report the use of any medication and did not have previous experience in WBV training. All participants followed the programme of the Air Force Academy during the study. Before the initiation of the study, the participants were informed about the experimental procedures and possible risks during the study and signed an informed consent form. The study was approved by the Institutional Ethics Committee and the scientific council of the National Air

Force Academy and all procedures were in accordance with the Declaration of Helsinki.

Data Collection Procedure

The effects of WBV exercise on neuromuscular performance, body composition, anaerobic power, and aerobic fitness were examined using a randomized controlled design. One week prior to the start of the study, subjects were familiarized with the testing and training procedures. Then, the baseline measurements were performed on three separate days. Following pre-training testing, the subjects were randomly assigned to either a lower frequency training group (Lf-WBV, $n=20$, age: 20.3 ± 1.6 years), a higher frequency training group (Hf-WBV, $n=20$, age: 20.7 ± 1.2 years) or a control group (CG, $n=20$, age: 20.4 ± 1.4 years). A computer-generated list of random numbers was used for allocation of the participants to one of the three groups of the present study. The two WBV training groups performed the same number of training sessions (20 training sessions) but differed only in the weekly frequency of training. The Lf-WBV group trained three times per week, the Hf-WBV group trained five times per week, while the CG did not perform any training. Two days after completion of the last training session, the pre-training measurements were repeated in the same order and at the same time of day. The two-day post-training measurement was selected to avoid potential fatigue and acute effects of the last WBV training session. All the participants followed the same diet, as Air Force cadets, and were instructed to maintain their normal daily living activities and to retain their regular dietary habits throughout the duration of the study.

Intervention

A total of twenty sessions of WBV training were performed by each training group. WBV training was performed on a commercial vibrating platform (Power Plate Pro5, Power Plate North America Inc, USA) that produces simultaneous vibration in 3 planes, left to right, front to back, and up and down. Each training session lasted 40 min and consisted of 10 min warm-up (5 min cycling and 5 min stretching exercises), 20 min of intermittent WBV exercise, and 10 min cool-down (5 min cycling and 5 min stretching exercises). Since prolonged exposure to a continuous vibration is known to suppress the tonic vibration reflex and decrease muscle activation and force, an intermittent vibration protocol was used in this study. Specifically, the intermittent WBV training protocol consisted of 10 sets \times 1 min WBV exercise, with 60 s rest between sets and an additional 2 min rest after the first 5 sets. The frequency of WBV exercise was progressively increased during the training programme from 25 Hz (1st to 6th training session), to 30 Hz (7th to 12th training session) and 35 Hz (13th to 20th training session), while the peak-to-peak displacement of vibration was kept unchanged throughout the study (4–6 mm). The selection of the frequencies and amplitudes was based on the fact that most studies that have used synchronous vibration applied frequencies of 25–35 Hz and peak-to-peak displacement 4–6 mm [16, 22, 23].

The two WBV training programmes had the same training volume (total training sessions: 20), but differed only in the frequency of training per week. The Lf-WBV group trained three times per week, with at least 48 hours between sessions, so that the total of 20 training sessions were completed in 7 weeks. The Hf-WBV group trained five times per week on consecutive days, and a total of 20 training sessions were completed in 4 weeks. The CG did not perform any training, but followed the general programme of the academy, as did the subjects allocated to the two training groups.

During the WBV sessions, the participants wore non-slippery socks in order to avoid any dampening effect attributable to footwear [9]. The participants were instructed to place their feet equidistant from the rotation axis and maintained an upright position with their feet in full contact with the platform and their knees flexed at 70°. The knee angle was controlled during the WBV training sessions with a goniometer (Lafayette Gollehon; Lafayette Instrument Co., Lafayette, IN, USA). Participants were instructed to direct their head and eyes forward, breathe normally, and place their hands on the machine's handles without any grasping.

At the completion of WBV, most participants mentioned a hot sensation at the bottom of their feet (the part closest to the vibration plate), and a few participants ($n = 5$) in the first 3–4 training sessions reported minor pruritus, which subsided within a few minutes of vibration. None of the participants complained of any other side-effects in response to WBV training.

Measurements

Before and after training, anthropometric and physical performance parameters were assessed on three separate days. On the first testing day, anthropometric characteristics, flexibility, vertical jumping ability and 30 m sprint were evaluated. On the second testing day, maximal strength of lower limbs was assessed. On the third testing day, anaerobic power and aerobic fitness were assessed. All pre- and post-training measurements were conducted at the same time of the day (10:00–12:00), in the same order, and were separated by a 10-min resting period. Prior to each physical fitness testing day, subjects performed a standardized 10 min warm-up that included 5 min of stationary cycling and 5 min of static and dynamic stretching exercises. All measurements were performed by the same investigator who was blinded regarding the type of training protocol and the allocation of the participants to the three groups.

Anthropometric characteristics and body composition: Body mass and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using a calibrated physician's scale (Seca, Hamburg, Germany) [21]. Furthermore, the percentage of body fat, and subsequently fat and lean body mass, were calculated from the sum of 7 skinfolds (chest, midaxillary, triceps, subscapular, abdominal, suprailium, thigh), using the equation of Jackson and Pollock [24]. All skinfold measurements were performed to the nearest 0.2 mm, using a calibrated Harpenden Skinfold Caliper [21].

Flexibility: Flexibility was assessed using the sit-and-reach test using a Flex-Tester box (Novel Products Inc, Rockton, IL) [21]. Subjects were instructed to lean forward slowly as far as possible, while exhaling, without bending their knees, and hold the final position for at least 2 s [21]. Subjects performed three maximal trials with a rest period of 10 s and the best score (in cm) was considered for analysis.

Muscle strength and power of lower limbs: The maximal strength of lower limbs was assessed using the one repetition maximum (1RM) testing protocol on Parallel Back Squat exercise, as previously described by Baechle & Earle [25]. The measurement was terminated when the participants performed 3–6 maximal repetitions and the 3–6 RM load was used to calculate 1RM using the Lombardi prediction equation expressed in absolute and relative terms (in relation to body mass in kg).

The vertical jumping performance was assessed using the squat jump test (SJ) and the countermovement jump test (CMJ) with a force platform (Bertec Corp., Worthington, OH) [26]. Before the initiation of the testing, the participants underwent 2–3 familiarization trials to ensure the proper execution technique for the SJ and CMJ. During the SJ and CMJ, the participants kept their trunk in an upright position and their hands on their hips. The SJ test started from a semi-squatting position with the knees flexed at 90°, which was maintained for 3 s before jumping vertically. No countermovement was allowed during the SJ. For the CMJ, the participants were allowed a downward movement by rapidly bending (at 90°) and extending their knees to jump as high as possible. The selection of a 90° knee angle (semi-squat position) was based on the fact that at this angle the knee is better stabilized during the phase of contact with the ground [26]. To ensure consistency in jumping technique, the 90° knee angle was measured using a goniometer (Gollehon, Lafayette). The main testing protocol consisted of three maximal trials for each type of jump with a rest period of 60 s. The best performance (jump height in cm) was considered for analysis [26].

Peak, mean and minimum power as well as the % fatigue index were also assessed during the 30-second Wingate test [27]. The Wingate test included 30 seconds of maximal exercise on a leg cycle ergometer with a resistance of 7.5% of the participants' total body weight. Following a five-minute warm-up, which included three sprints at varying resistances, the participant stayed on the bike and cycled lightly. Then, the participant began to pedal as fast as possible without any resistance. Within three seconds, the fixed resistance (7.5% of the participants' total body weight) is applied to the flywheel and the participant continues to pedal "all out" for the duration of the test [27].

30 m sprint performance: A 30 m sprint test was performed from the split stance position, according to the Eurofit testing procedures [28]. Sprint time was recorded to the nearest 0.01 s using electronic timing lights (Newtest PowerTimer, Newtest Oy, Oulu, Finland). The participants performed all sprints starting from a split stance position. More specifically, they placed their front foot ~50 cm behind the first photocell and started their effort upon hearing an

audio signal from the system. Each participant performed 3 attempts with a 3-min rest between trials and the best sprint time (in s) was used in the subsequent analysis [29].

Aerobic fitness: Aerobic fitness was assessed using the multistage 20 m shuttle run test, according to the Eurofit protocol [28]. The multistage 20 m shuttle run test included continuous running between two lines 20 m apart. The participants stood behind one of the lines facing the second line and began running when instructed by the recording. The speed at the start is quite slow. The participants continued running between the two lines, turning when signalled by

the recorded beeps. The time between beeps decreased at one-minute intervals, indicating an increase in running speed [28]. The total distance covered during the shuttle run test was calculated for each participant and used for analysis.

Statistics

A software package (GPower 3.0) was used to calculate sample size based on power calculations. The statistical power, for all performance parameters, ranged from 0.85 to 0.94. All statistical analyses were performed using SPSS Statistics for Windows, version 21.0 (SPSS Inc., Chicago, Ill., USA). The normality of data was examined using the Shapiro-Wilk test. Two-way analysis of variance (ANOVA) [3 groups (Lf-WBV, Hf-WBV, and CG) x 2-time points (pre and post training)] with repeated measures on the «time» factor was used to analyse the data. A one-way ANOVA was used to compare the changes of each variable from pre- to post-training between the three groups (Lf-WBV, Hf-WBV, and CG). When a significant group x time interaction or group main effect was found, Tukey pairwise comparisons were applied to locate the significantly different means within and between groups. Cohen's effect sizes (ES) were calculated using the equation: $d = \text{difference between means/pooled SD}$. The level of significance for all statistical analyses was set at $p < 0.05$.

TABLE 1. Body composition (body mass, body fat and lean body mass) in the low frequency whole body vibration training group (Lf-WBV), high frequency whole body vibration training group (Hf-WBV) and control group (CG) pre- and post-training (Values are Means \pm SD).

Variables	Group	Pre-training	Post-training
BM (kg)	Hf-WBV	77.43 \pm 7.58	76.69 \pm 7.32
	Lf-WBV	75.71 \pm 6.89	74.75 \pm 6.61
	CG	78.98 \pm 9.81	78.33 \pm 9.02
BF (%)	Hf-WBV	16.04 \pm 4.06	15.13 \pm 3.78*
	Lf-WBV	14.90 \pm 3.06	15.40 \pm 2.89
	CG	15.58 \pm 3.77	15.23 \pm 3.31
FM (kg)	Hf-WBV	12.59 \pm 4.14	11.76 \pm 3.83*
	Lf-WBV	11.36 \pm 2.99	11.61 \pm 2.97
	CG	12.52 \pm 4.29	12.07 \pm 3.55
LBM (kg)	Hf-WBV	64.85 \pm 5.23	64.93 \pm 4.96
	Lf-WBV	64.35 \pm 5.28	63.14 \pm 4.58
	CG	66.47 \pm 6.98	66.26 \pm 6.87

BM: body mass, BF: percentage of body fat, FM: fat mass, LBM: lean body mass, * $p < 0.01$ vs. pre-training in Hf-WBV.

RESULTS

Body composition

The ANOVA revealed non-significant main effects of "group" and "group x time" interactions for body mass and lean body mass ($p = 0.35$ to 0.84 ; Table 1). However, there was a significant "group x time" interaction effect for percentage body fat ($F_{2,57} = 3.98$, $p < 0.05$) and fat mass ($F_{2,57} = 5.06$, $p < 0.01$). Post hoc comparisons revealed that the pre-training body fat and fat mass values were not different between groups (Hf-WBV, Lf-WBV, CG). However, post-training percentage of body fat and fat mass values were

TABLE 2. Flexibility, speed and aerobic capacity values in the low frequency whole body vibration training group (Lf-WBV), high frequency whole body vibration training group (Hf-WBV) and control group (CG) pre- and post-training (Values are Means \pm SD).

Variables	Group	Pre-training	Post-training
Flexibility			
Sit and reach test (cm)	Hf-WBV	21.43 \pm 5.76	23.40 \pm 6.33*#
	Lf-WBV	21.10 \pm 9.00	22.29 \pm 10.32
	CG	18.38 \pm 12.40	16.93 \pm 11.76
30 m sprint (s)	Hf-WBV	4.63 \pm 0.19	4.63 \pm 0.20
	Lf-WBV	4.72 \pm 0.20	4.75 \pm 0.22
	CG	4.64 \pm 0.21	4.67 \pm 0.24
Aerobic fitness			
Total distance during shuttle run test (m)	Hf-WBV	1567.00 \pm 196.42	1699.00 \pm 240.57
	Lf-WBV	1489.00 \pm 292.32	1529.00 \pm 327.57
	CG	1515.00 \pm 310.53	1547.00 \pm 319.89

* $p < 0.01$ vs. pre-training in Hf-WBV, # $p < 0.001$ vs. Lf-WBV and CG.

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significantly lower compared with pre-training values only in the Hf-WBV group ($p < 0.05$). In the Lf-WBV group and CG, the percentage of body fat and fat mass did not change (Table 1). Changes in per-

centage body fat (-5.3%) and fat mass (-6.2%) in the Hf-WBV group were greater compared with the Lf-WBV group ($ES=1.03$ and 0.99 , respectively) and the CG ($ES=0.37$ and 0.28 , respectively) (Table 1).

TABLE 3. Absolute and relative values of maximal strength and jumping performance in the low frequency whole body vibration training group (Lf-WBV), high frequency whole body vibration training group (Hf-WBV) and control group (CG) pre- and post-training (Values are Means \pm SD).

Variables	Group	Pre-training	Post-training
SJ (cm)	Hf-WBV	33.82 \pm 8.12	35.82 \pm 7.36#
	Lf-WBV	28.79 \pm 2.83	30.75 \pm 3.62#
	CG	34.09 \pm 5.03	35.24 \pm 4.93
CMJ (cm)	Hf-WBV	38.15 \pm 10.14	38.71 \pm 8.55
	Lf-WBV	37.31 \pm 4.71	39.03 \pm 8.42
	CG	36.88 \pm 5.77	37.96 \pm 5.63
Maximal strength (kg)	Hf-WBV	137.75 \pm 21.97	147.40 \pm 15.76*
	Lf-WBV	129.75 \pm 19.16	129.80 \pm 13.97
	CG	134.25 \pm 30.10	137.65 \pm 24.23
Maximal strength (kg/kg of BM)	Hf-WBV	1.79 \pm 0.29	1.93 \pm 0.21*
	Lf-WBV	1.73 \pm 0.29	1.75 \pm 0.23
	CG	1.71 \pm 0.36	1.77 \pm 0.31

BM: body mass (in kg), CMJ: counter movement jump, SJ: squat jump. * $p < 0.05$ vs. pre-training in Hf-WBV, # $p < 0.05$ vs. pre-training in Hf-WBV and Lf-WBV.

TABLE 4. Anaerobic power values in the low frequency whole body vibration training group (Lf-WBV), high frequency whole body vibration training group (Hf-WBV) and control group (CG) pre- and post-training (Values are Means \pm SD).

Variables	Group	Pre-training	Post-training
Absolute values			
Peak power (W)	Hf-WBV	931.49 \pm 114.75	956.07 \pm 125.50
	Lf-WBV	888.80 \pm 155.91	896.10 \pm 118.92
	CG	962.75 \pm 179.74	976.13 \pm 165.29
Mean power (W)	Hf-WBV	626.00 \pm 58.08	634.56 \pm 68.06
	Lf-WBV	587.15 \pm 48.41	596.90 \pm 47.04
	CG	651.75 \pm 101.13	638.90 \pm 93.31
Minimum power (W)	Hf-WBV	392.80 \pm 41.19	408.25 \pm 47.19
	Lf-WBV	390.15 \pm 46.98	377.35 \pm 46.05
	CG	397.82 \pm 59.10	401.70 \pm 62.94
Relative values			
Peak power (W/kg)	Hf-WBV	12.11 \pm 1.56	12.54 \pm 1.50
	Lf-WBV	11.76 \pm 2.01	11.86 \pm 1.60
	CG	12.15 \pm 1.54	12.42 \pm 1.20
Mean power (W/kg)	Hf-WBV	8.13 \pm 0.71	8.32 \pm 0.66
	Lf-WBV	7.77 \pm 0.65	7.90 \pm 0.61
	CG	8.24 \pm 0.78	8.14 \pm 0.59
Minimum power (W/kg)	Hf-WBV	5.09 \pm 0.49	5.36 \pm 0.67
	Lf-WBV	5.17 \pm 0.66	4.99 \pm 0.60
	CG	5.07 \pm 0.69	5.13 \pm 0.56
Fatigue index %	Hf-WBV	57.50 \pm 5.28	56.88 \pm 6.33
	Lf-WBV	54.91 \pm 9.16	57.28 \pm 6.94
	CG	58.00 \pm 5.55	58.47 \pm 4.82

Flexibility, speed, and aerobic capacity

A significant “group \times time” interaction effect was observed for flexibility ($F_{2,57} = 9.19$; $p < 0.001$; Table 2). Post hoc comparisons showed that pre-training flexibility values were not different between the three groups (Hf-WBV, Lf-WBV, CG). Post-training flexibility values were significantly higher compared with pre-training values in the Hf-WBV group ($p < 0.01$). In the Lf-WBV group and CG, flexibility did not change. Post hoc comparisons between groups revealed that flexibility was significantly greater in the Hf-WBV group vs. the CG at the post-training time point ($p < 0.001$). The percent improvement in flexibility (+7%) in the Hf-WBV group was greater compared with that in the Lf-WBV group (+3%) and the CG (ES=0.28 and 1.26, respectively) (Table 2). In contrast, ANOVAs revealed non-significant main effects of “group” and “group \times time” interactions for 30 m sprint time ($p = 0.24 - 0.59$) and shuttle run performance ($p = 0.10 - 0.32$), which remained unchanged throughout the study for all groups (Table 2).

Muscle strength and power of lower limbs

There was a non-significant “group \times time” interaction effect for both estimated absolute and relative to body mass maximal strength ($p = 0.09$). However, there was a significant “time” effect ($F_{1,57} = 5.94$; $p < 0.001$), indicating an increase in post-training values. Analysis of the effect sizes and post hoc t-tests revealed that estimated maximal strength was increased in absolute (+9%, $p=0.01$, ES=0.51) and relative terms (+10%, $p=0.016$, ES= 0.59) at the completion of the training programme only in the Hf-WBV group. In contrast, estimated maximal strength did not change throughout the study in the Lf-WBV group or CG. Thus, the improvement in relative strength in the Hf-WBV group was greater compared with that in the Lf-WBV group (ES=0.73) and the CG (ES=0.43).

There was a non-significant “group \times time” interaction effect for SJ performance ($p = 0.54$). However, there was a significant “time” effect ($F_{1,57} = 23.2$; $p < 0.001$), indicating an increase in post-training values. Analysis of the effect sizes and post hoc t-tests revealed an equal improvement in SJ in the Hf-WBV and Lf-WBV training groups (+7%, $p<0.01$, ES=0.32) after training. SJ remained unchanged in the CG ($p=0.07$). The improvements in SJ in the Hf-WBV and Lf-WBV training groups were greater than the change in the CG (ES=0.32 for both groups).

Finally, ANOVAs revealed non-significant main effects of “group”, “time” and “group \times time” interactions for CMJ performance and anaerobic power ($p= 0.15-0.72$; Tables 3 & 4), which remained unchanged throughout the study for all groups.

DISCUSSION

To the best of our knowledge, no previous study has compared the efficacy of short- versus long-term WBV training programmes (of equal volume) for improving indices of physical fitness. This study showed that only the higher frequency (5 consecutive training sessions

per week) WBV training programme (short-term programme), using simultaneous movement, was effective for decreasing body fat and improving flexibility, SJ performance and maximal strength of lower limbs. In contrast, the lower frequency WBV training programme (3 non-consecutive training sessions per week) improved only SJ performance, despite the same total number of sessions (20 training sessions).

It seems that the frequency of training sessions during the micro-cycle and the frequency of training per week can cause different training adaptations to the human body. Several studies have examined and compared the effects of different training frequencies per week in various exercise modalities without, however, equating the total training volume between training programmes [10, 19–20]. In the present study, the total number of training sessions was the same in the two training groups, allowing a more valid comparison of the effects of the different frequency of training sessions during the microcycle (training frequency per week). Our findings differed from a previous study [10] which examined the effect of WBV training frequency in recreationally active individuals. This study compared two *long-term* WBV training programmes (non-consecutive training sessions per week) with different training frequency per week (2 vs. 3 training sessions per week, for 6 weeks) [10]. According to the result of the former study, a 6-week WBV training programme with 2 (12 training sessions in total) or 3 (18 training sessions in total) training sessions per week may increase isokinetic strength and total fat-free mass in recreationally active individuals. However, the two different WBV training frequencies that were used in the Martínez-Pardo *et al.* study [10] elicit similar training adaptations. On the other hand, the results of this study are in line with previous research using different exercise modalities, where it was found that programmes with higher training frequency per week (i.e. 5 consecutive training sessions) are more effective for improving cardiovascular indices in trained individuals (i.e. cyclists, cross-country skiers) than training programmes with a lower training frequency per week (non-consecutive training sessions and long intervals between them) [19–20].

The effects of a short-term WBV training programme on flexibility, using simultaneous movement, have not been previously examined. This study showed that a short-term WBV training programme, using vertical simultaneous movement and five consecutive training sessions per week, resulted in a 7% gain in the flexibility of the hamstrings and the lower back muscles in young, physically active individuals. The findings of the present study are in line with a previous investigation reporting similar gain in flexibility after a short-term side-to-side alternating WBV training programme in young, physically active females [13], while another previous study, which combined side-to-side WBV training with stretching exercises, reported even greater flexibility gain (22%) [11]. The increase in flexibility following the WBV training programme has been previously attributed mainly to neural, circulatory and thermoregulatory factors [22–23]. Specifically, vibration exercise has been reported to increase the

pain threshold during and after muscle application [30], allowing greater stretch limits. Furthermore, vibration exercise inhibits activation of the antagonist muscles by the Golgi organ and Ib afferent neuronal mediated effect; this may reduce the braking force around the hip and lower back joints, potentiating performance [31]. Finally, vibration has been reported to increase blood flow [32], generating thermal effects and, as a result, flexibility gains.

An important finding of the present study was the 9–10% improvement in maximal squat strength only in the Hf-WBV group following a relatively short-term training programme. The few studies that have examined the effects of short-term WBV training on vertical jump and strength of knee extensors muscles have used *side-to-side alternating* vibration, reporting either a marginal increase [33] or no change [13–15, 34]. It may be argued that the lack of effect in the previous studies may be due to the very short duration of WBV training (20 sessions in the present study vs. 6–10 in previous studies) and/or to the vibration mode (simultaneous in the present study vs. side-to-side alternating movement in the previous studies) [13–15, 34]. However, the findings of the present study suggest that the commonly used 10 x 1 min WBV protocols should be repeated frequently in the week (5 out of the 7 days) in order to bring about an increase in maximal strength. In contrast, training with longer recovery periods (i.e. 3 times per week), as is commonly employed in practice, does not result in any strength improvement, despite the fact that the total number of sessions was the same.

The physiological mechanisms explaining these discrepancies remain to be explored, but may involve different effects of weekly training frequency on the activation of the “tonic vibration reflex”, hormonal factors, and alterations in proprioceptors’ discharge [35–37]. It has been reported that WBV evokes a “tonic vibration reflex” through the stimulation of sensory receptors and the afferent pathways. It is assumed that this tonic vibration reflex increases the sensitization of the muscle spindle reflexes and facilitates the reflex action of the motoneuron pool. Thus, given the involvement of the stretch reflex, and of the Ia afferent input, WBV training may result in more efficient use of the stretch reflex. In addition, at the motor unit level, the tonic vibration reflex may increase the individual’s ability to generate high firing rates within the high-threshold motor units, potentially improving neuromuscular performance [35–37]. There is also evidence that WBV training can cause significant hormonal alterations, increasing the levels of growth hormone [38–39], testosterone [38], epinephrine and norepinephrine [40]. In addition to the possible hormonal effects of testosterone and growth hormone on strength gains, these hormonal alterations are also involved in the process of lipolysis and thus may decrease body fat [40–41]. Thus, the effects of training frequency on fat reduction in the Hf-WBV group may be explained by different alterations of the hormonal profile in the two training groups.

The finding that neither WBV training programme improved speed or aerobic and anaerobic capacity in young, physically active individuals is in accordance with previous studies that examined the

effects of short- and long-term WBV training, *using side-to-side alternating vibration or vertical simultaneous vibration* on speed, aerobic and anaerobic capacity, and reported no change. Several studies that examined the effects of long-term WBV training (6–10 weeks, 2–3 non-consecutive training sessions/week), using vertical simultaneous vibration, have reported an increase in different aspects of physical fitness in young individuals. This effect appears to be load-dependent, with significant improvements following training of moderate-high WBV load (30–50 Hz, 4 mm), whereas no changes have been reported when training has been performed at a low-moderate WBV load (30–40 Hz, 1.7–2.5 mm) [16, 22, 42–47]. The findings of the present study suggest that when the frequency of training is 3 times/week (vibration frequency: 25–35 Hz, amplitude: 4–6 mm), the load may not be sufficient to improve most physical fitness indices in young trained individuals. In this case, increasing the training frequency to 5 times per week results in significant improvements in strength, power and body composition, keeping a short training session duration (10 x 1 min).

Our findings are clearly limited to young healthy trained individuals; therefore, future studies should compare the efficacy and safety of the short- and long-term WBV training programmes in untrained individuals, as well as in individuals with chronic diseases. Furthermore, the findings of this study are limited to the use of vertical synchronous vibration platforms. Side alternating vibration platforms may induce different training adaptations. Another limitation of this study is that the control group did not perform the same static exercise (knees flexed at 70°) as that used in the training groups but without the concurrent application of vibration. Future studies should examine the effect of static exercise training (knees flexed at 70°) on neuromuscular performance. Finally, further studies are needed to elucidate the physiological mechanism underlying the improvements in body composition and neuromuscular performance following the two training regimens of WBV training.

CONCLUSIONS

Short-term *vertical simultaneous* WBV training performed at high frequency is an effective and time-efficient mode of exercise for reducing body fat and for improving flexibility, jumping performance and maximal strength of lower limbs in young, physically active individuals. On the other hand, no effects were documented on the speed, anaerobic and aerobic capacity, suggesting that greater WBV loading parameters or a longer training period may be required to improve these parameters in this population.

The results of the present study have important practical implications, demonstrating that a high frequency (5 consecutive days/week) WBV training programme, even with a limited training duration per session of 10 min, provokes significant improvements in neuromuscular performance and body composition. Thus, a high-frequency WBV training programme may be used by fitness professionals as an alternative, time-efficient (session duration: 20 min) and well-tolerated exercise modality for improving neuromuscular performance

in young individuals. Lower frequency WBV training programmes (3 non-consecutive days per week) may not be as effective for improving indices of physical fitness and health in young, physically active individuals.

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Conflict of interest

The authors declare no conflict of interest.

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