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Four-week whole-body vibration training and its effects on strength, power and sprint performance in young basketball players - a randomized control trial

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Abstract

We aimed to investigate whether the addition of whole-body vibration (WBV) to resistance training (RT) will be more beneficial in improving lower limbs muscle strength, power and sprinting performance than RT alone in young basketball players. We recruited 30 young basketball players to participate in four weeks of training and assessments. They were randomized into the WBV resistance training group (VRTG, n=15) and a conventional resistance training group (RTG, n=15), performed 3 times per week. At the beginning and end of the four weeks a back squat one-repetition maximum (1RMBS), Countermovement jump (CMJ), Squat jump (SJ), 10 meters (10m) and 20 meters sprint (20m) were performed. We found that: a) VRTG when added to RT can induce greater improvements in 1RMBS (percentage difference [PD], 8.4%, $p < 0.001$), CMJ (PD = 4.7%, $p = 0.001$) and SJ (PD = 1.6, $p = 0.02$) than RT alone. In contrary, significant time*group interactions were found for sprint times at 10m ($p=0.08$, $F=3.2$) and 20m ($p=0.17$, $F=1.93$). An additional 4-week WBV resistance training program proved effective in improving lower limb power and strength in young basketball players. When performed on a vibration platform (with accurate and constant vibration stimulus parameters), the resistance exercises were superior to their conventional forms and resulted in additional gains on measures of muscle power and strength, while sprint performance remained unchanged.

Keywords: *vibration training, countermovement jump, squat jump, barbell squat, neuromuscular performance, conditioning, muscle strength, athletic performance*

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Introduction

Lately, a modern training technology development increased the total number of available training methods used to enhance athletic performance. One of these is whole-body vibration (WBV) training which includes an additional mechanical stimulus to musculotendinous structures characterized by oscillatory motion determined by its amplitude, frequency, and magnitude (Cardinale & Bosco, 2003; Osawa, Oguma, & Ishii, 2013).

It has been shown that this type of stimuli increases overall training intensity through enhanced neuromuscular excitability and tonic vibration reflex (Luo, McNamara, & Moran, 2005). Additionally, the oscillatory motion affects the whole body, including both agonist and antagonist muscle groups, adding to the overall muscle performance enhancement (Nordlund & Thorstensson, 2007).

Numerous studies showed that WBV can cause a significant positive short- (Dallas, Kirialanis, & Mellos, 2014) and long-term (Hartard et al., 2022) effects on strength, power and sprinting abilities. Previously published meta-analyses showed greater long-term WBV training effects on muscle strength and power than without WBV (Osawa et al., 2013) with vertical platforms eliciting larger effects as compared to oscillating platforms (Marín & Rhea, 2010). These long-term effects are accompanied by greater gains in muscle mass and an enhancement in muscle contraction properties (Nordlund & Thorstensson, 2007).

However, come conflicting data can be found in previous studies conducted over short period (up to four weeks in duration). For example, Dolny and Reyes (2008) stated WBV alone will provide limited or no benefit in improving muscle strength and/or jumping performance compared with similar exercise training without WBV in young athletes. In contrary, Colson, Pensini, Espinosa, Garrandes, and Legros (2010) found that 4-week of WBV training in young basketball players improves solely isometric strength with small improvements in squat jump (SJ) performance but no significant effects in lower limb dynamic explosive performance involving stretch-shortening cycle actions like countermovement or drop jumps as well as 30-second rebound jumps or sprint running performance. However, latter authors used unloaded static exercise as a training stimulus, which might have a training specific effect as showed elsewhere.

The WBV volume ranges from 15-75 sec per set, while the intensity depends on the type, frequency and amplitude of the vibration applied. WBV modalities with both low frequency and amplitude can improve flexibility and balance (Despina et al., 2014), while high frequency and amplitude showed potential to augment strength, power and sprinting performance (Alam, Khan, & Farooq, 2018; Osawa et al., 2013). To our knowledge, the present study differs from previously published (Colson et al., 2010; Mahieu et al., 2006; Pérez-Turpin et al., 2014) in terms of the resistance exercises intensity used in both WBV and resistance intervention and the comparison of its effects on strength, power and sprinting performance in young basketball players. Thus, we aimed to evaluate a 4-week WBV loaded resistance training program effects and compare them with same resistance training without WBV. The assumption that resistance training with added whole-body vibration will provide greater improvements in strength, power and sprinting performance seems justified.

Materials and methods

Study design

The study was a randomized controlled trial including young basketball players. Screening of players was done using questionnaires filled individually indicating eligibility data based on following criteria: 1) minimum 2-year of resistance training experience, 2) at least 5 training sessions per week, and 3) free of any neurological problems and lower extremity injuries in the past two years before study begun. In total, 36 players were assessed for eligibility criteria of whom six players did not meet the criteria. Testing was performed at the baseline and after four weeks of intervention. Players were randomly assigned to two training groups using a computer-based system (Research Randomizer, https://randomizer.org/). The staff involved did not influence the randomization procedure. The subjects were randomized 1:1 to the WBV resistance training group (VRTG, n=15) or conventional resistance training group (RTG, n=15). Players not receiving their assigned intervention or being absent ~10% from the intervention were excluded from the study. Overall, two subjects from both VRTG and RTG were excluded (Figure 1). Both groups performed intensity and volume matched resistance training with additional WBV in the VRTG group. The players were minors so legal representative/parental consent was obtained prior to inclusion. The

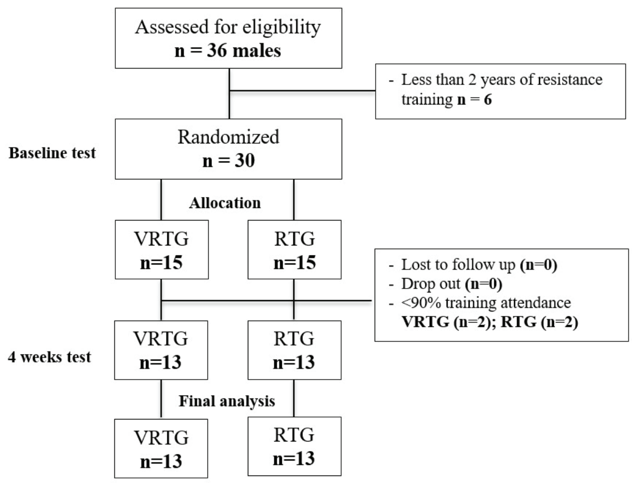

Figure 1. Intervention flow throughout the study of the intervention groups; VRTG and RTG

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study was carried out in accordance with the ethical standards of the 1964 Helsinki Declaration and approved by the University Ethics Committee.

Participants

In the conceptualization phase of the study, we conducted a power analysis using the G*Power . Based on previous studies with similar design we expected to find small to medium effects between baseline and final evaluation between VRTG and RTG groups (0.30) (Rhea & Kenn, 2009) with power of 0.90 and α = 0.05, two-tiled, which calculated a sample size of 26 participants in total. Therefore, thirty young male basketball players were included in the study. After completing the study, the final number for the analysis was n=13 in both groups. Except for a body height (p<0.001), there were no differences between groups for the participants' demographic characteristic at the baseline. (Table 1). All players were members of the local club and were participating in basketball training and competitions for 2-4 years.

Table 1. Baseline characteristics of subjects randomized to resistance training with vibration group (VRTG) or resistance training group (RTG).

	VRTG (n=13)	RTG (n=13)
Age (years)	15.1±0.8	15.1±0.7
Heigh (cm)	188.1±5.5	194.8±6.1**
Weight (kg)	79.5±10.0	85.5±9.5
BMI (kg/m²)	22.5±2.6	22.5±1.6

**Significantly different from VRTG p<0.001

Training intervention

Both groups performed intervention in a local fitness facility using the same equipment. Training sessions were supervised by the investigators and two experienced strength and conditioning coaches. All players attended 12 resistance training sessions lasting 55 minutes on average. Training protocol included 3-5 sets and 5-8 reps at 80-90 RM % of the following exercises: 1) dynamic back squat, 2) alternative lounge, 3) deadlift and 4) donkey calf raise (with partner similar in weight). Training session consisted of a 7-8 min warm-up, resistance exercise routine as presented in Table 2 and 7-8-min cooldown (stretching exercises). Inter-set and inter-exercise rest intervals were set to one and three minutes, respectively.

VRTG group performed all sessions standing on a vertical oscillatory vibration platform (Pro Evolution 2.7, Powrx Gmbh, D) with 35 Hz frequency and 4mm peak-to-peak displacement. According to the formula, the acceleration amounted to 7.6 G.

Table 2. Prescribed training interventions

Week	Training sessions	Sets	Reps.	Exercises	Intensity	Vibration duration per exercise for VRTG	Training vibration duration
1	3	3	8	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	80% 1RM Partner*	32″ (35Hz, 4 mm)	8′
2	3	4	6	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	85% 1RM Partner*	24″ (35Hz, 4 mm)	8′
3	3	5	5	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	90% 1RM Partner*	20″ (35Hz, 4 mm)	8′20″
4	3	3	8	1. back squat, 2. alternate lounge 3. deadlift 4. donkey calf raises	80-90% 1RM Partner*	32″ (35Hz, 4 mm)	8′

* A partner of approximately the same body weight; Recovery time between sets was 60″and exercises was 180″

Measuring procedures

To evaluate the strength, power and speed, a back squat one-repetition maximum (1RMBS), Countermovement jump (CMJ), Squat jump (SJ), 10 meters (10m) and 20 meters sprint (20m) were evaluated at baseline and after 4 weeks. All measurements were performed early in the morning by experienced Sports Institute personnel. Players performed a standardized general 8–10-minute warm-up routine consisting of a 5-minute treadmill run at 6-10 km/h followed by three to five minutes of rest prior to assessment.

1RM back squat (1RMBS)

The maximal strength was measured using 1RM back squat test protocol. The expected/estimated 1RM value was used as a reference. The lower squat position was set at 90 degrees of knee flexion, measuring from the upright standing position (180°). After the first 5-10 reps with an unloaded barbell, participants completed 5-10 reps at 50%, 3-5 reps at 75% and 1-3 reps at 90% of the estimated 1RM with 3-5 minutes rest between sets. Further 5kg weight increment with 3-5 minutes rest and 1RM determination was conducted when the player failed to complete the lift.

Countermovement jump (CMJ) and Squat jump (SJ)

Subjects were asked to perform CMJ and SJ measured using Optojump™ photoelectric cells (Microgate, Bolzano, Italy). Each player performed three consecutive trials parted with one minute for recovery and the best result was used for further analysis. A standardized warm-up including 3-5 jumps at approximately 50% effort, followed by 3-5 minutes of rest, was conducted before the assessment.

Sprint on 10 meters (10m) and 20 meters (20m)

Two 20m sprints were performed and recorded to the nearest 0.01 second by using portable electronic timing gates (Speedtrap II, Brower Timing Systems, Draper, UT, USA) set 1 m high and 1 m apart at 0, 10 and 20 meters. All sprints were executed indoors on a basketball court from a standing start with the dominant foot to the front at a line 30 cm from the first gate to prevent false timer triggering. Once the participants were set, they started at their own volition.

Statistical analysis

Statistical analysis was performed using SPSS statistical software (version 27.0, IBM Inc, Chicago, USA). All data are presented in tables and charts as mean±SD. Descriptive statistics were used to summarize individual characteristics and all outcome measures. Normality was confirmed using the Shapiro-Wilk's test, while homogeneity of variances was tested using Levene's test for all variables. Coefficients of variation (CV%) were calculated as the percentage of standard deviation between test-retest results and mean values for 1RMBS, CMJ, SJ, 10m and 20m. Threshold of CV%<5 indicated low result variability. Intraclass coefficient (ICC) determined the test-retest reliability for CMJ, SJ 10m and 20m with ICC<0.5, between 0.5 and 0.75, between 0.75 and 0.9, and >0.90 were indicative of poor, moderate, good, and excellent reliability (Koo & Li, 2016). Baseline differences were examined using an independent sample t-test. Further on, inter and intra-group differences were analyzed by 2-way repeated-measures ANOVA (group*time). In the case of significant effects were found for group, or time, or 2-way interactions, post hoc comparisons with Bonferroni corrections were applied to address significant PRE-to-POST differences for each variable independently. The magnitude of change (ES) between baseline and 4 weeks of intervention was expressed using Cohens' d effect size and rated as Trivial (ES<0.2), Small (ES<0.50), Moderate (ES<0.80) and large (ES<0.79) . The level of statistical significance was set at p<0.05.

Results

There were no significant differences between VRTG and RTG at baseline measures except for body height where RTG subjects were taller compared to VRTG (Table 1 and 4, Fig. 2). Within-subjects variability was low (CV%<5) for all the tests conducted, while test-retest reliability was rated as excellent for $1RM_{BS}$, CMJ, SJ, 10- and 20-meter sprint times with ICC ranging from 0.902 – 0.981 (Table 3).

Significant time*group interaction was found for 1RMBS (p<0.001, F=21.07). Pairwise comparisons revealed an increase (p<0.001) of 37% (31.7±8.84 kg, Large) and 28.6% (24.0±6.94 kg, Large) over 4 weeks for VRTG and RTG, resulting in an 8.4±32.1% greater weight lifted in VRTG. (Table 4; Fig. 2 a) and b)).

Significant time*group interactions were observed for CMJ (p=0.025, F=11.37) and SJ (p=0.039, F=10.29). Over 4 weeks CMJ and SJ was increased by 8.4% (3.01±2.4 cm; p=0.001, t=4.512; Small) and 3.0% (1.14±3.75 cm; p=0.02, F=2.14; Small) in VRTG, while non-significant increase of 2.7% (1.04±2.92 cm; p=0.22, t=1.22; Trivial) and 1.4% (0.5±2.96 cm; p=0.57, t=0.59; Trivial) were noted in RTG, respectively (Table 4; Fig. 2 a) and b)).

No significant time*group interactions were found for sprint times at 10m (p=0.08, F=3.2) and 20m (p=0.17, F=1.93). Pairwise comparisons showed that after 4 weeks times on 10 and 20 meters were lowered by 2.8 % (0.06±0.08 sec, p=0.03, t=2.57; Moderate) and 1.8% (0.06±0.1 sec, p=0.04, t=2.32; Small) in VRTG, with corresponding changes of 3.4% (0.08±0.07; p=0.004, t=3.58; Moderate) and 2.7 (0.1±0.1; p=0.006, t=3.29; Moderate) for RTG (Table 4; Fig. 2 a) and b)).

Table 3. Coefficients of variation (CV%) and intraclass correlation coefficients (ICC) for squat ($1RM_{BS}$), countermovement jump (CMJ), squat jump (SJ), 10 meters sprint time (10m) and 20 meters sprint time (20m).

	$1RM_{BS}$	CMJ	SJ	10m	20m
CV%	3.8%	4.4%	4.4%	2.6%	2.0%
ICC	0.902	0.981	0.964	0.965	0.912
ICC rating	Excellent	Excellent	Excellent	Excellent	Excellent

Table 4. Squat one repetition maximum ($1RM_{BS}$), countermovement jump (CMJ), squat jump (SJ), 10 meters (10m) and 20 meters (20m) sprint time in young basketball players at baseline and after 4 weeks of additional resistance training with vibration (VRTG) and resistance training (RTG).

	VRTG (n=13)				RTG (n=13)			
	Baseline	4 weeks	ES	Δ%	Baseline	4 weeks	ES	Δ%
$1RM_{BS}$ (kg)[a]	85.8±17.9	117.50±23.6**	Large	37.0%	84.03±18.04	108.07±16.44**	Large	28.6%
CMJ (cm)[a]	40.40±5.92	43.41±6.59**	Small	7.4%	38.58±6.03	39.62±6.90	Trivial	2.7%
SJ (cm)[a]	37.44±5.22	38.58±5.75**	Small	3.0%	36.55±4.83	37.05±5.55	Trivial	1.4%
10m (s)	2.13±0.1	2.07±0.07**	Moderate	-2.8%	2.16±0.12	2.08±0.08**	Moderate	-3.4%
20m (s)	3.46±0.14	3.40±0.12**	Small	-1.8%	3.51±0.17	3.41±0.14**	Moderate	-2.7%

Values are presented as Mean±SD; ** Significantly different from baseline p<0.001; [a] Significant group*time interaction p<0.001; ES – Magnitude of effect based on Cohen d effect size

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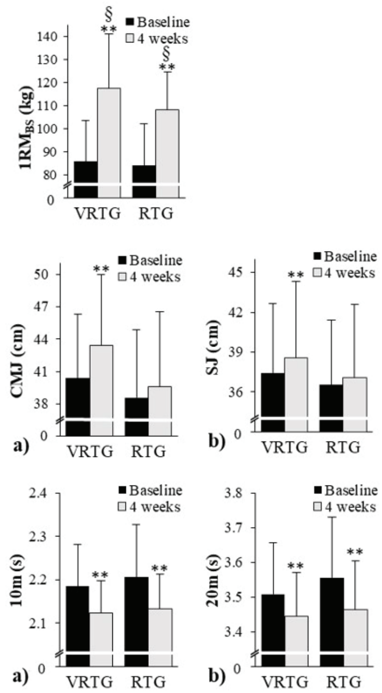

Figure 2. Difference in squat one repetition maximum weight (1RMBS), a) countermovement jump (CMJ) and b) squat jump (SJ) and sprint times at a) 10 meters (10m) and b) 20 meters (20m) for young basketball players in the Vibration resistance training group (VRTG) and Resistance training group (RTG) at baseline and after 4 weeks. ** p<0.001; § time*group interaction p<0.001

Discussion

The present study demonstrated that a short-term resistance training applied over a 4-week period with added WBV develops muscle strength and power more effectively, and sprinting abilities equally well compared to resistance training alone. The main findings were that additional WBV resulted in a significant pre-post improvement in jumping performance measured by CMJ and SJ, which was not observed after resistance training alone. Furthermore, back squat 1RM increased after both training interventions with higher relative improvement after WBV indicating that additional performance impact is primarily caused due to added WBV. Changes and comparisons in sprinting performance were inconclusive with slight improvements after both interventions.

Since resistance exercise stimulus is induced by workload intensity, its variations as well as its duration and frequency (Kraemer & Ratamess, 2004), it seemed reasonable to hypothesize that additional WBV, which involves forces that might exaggerate resistance training stimulus, would have a larger potential for performance improvement in trained athletes. Although both interventions significantly improved strength performance, our primary hypothesis was confirmed by showing the relative enhancement in 1RMBS were for 8.4% higher in the VRTG than RTG after 4-week intervention period. Previous investigations (Colson et al., 2010; Dallas et al., 2014; Mahieu et al., 2006; Pérez-Turpin et al., 2014) have also shown marked lower limb 1RM strength increase after short and long-term WBV. Further on, Rønnestad (2004) found 24.2% and 32.4% in both non- and WBV group, respectively, which complies with our study results. Additionally, in their systematic review, Nordlund and Thorstensson (2007) reported changes in muscle strength performance in the WBV groups ranging from -0.9% to 24.4%. The observed increase in strength performance regardless of additional WBV stimulus might be caused by subjects' relatively low baseline physical fitness since the testing was performed before the preparation period. Also, some of the players had poor technique in performing basic strength exercises which explains the fact that several players improved 1RMBS by nearly 50% just by learning proper techniques. Such individual improvement was notably higher in 3 participants in VRTG, hypothetically indicating that WBV might enhance motor learning development (Fereydounnia & Shadmehr, 2020).

It is evident that differences in training interventions notably emphasized the diversity of the magnitudes on the strength performance impact. Some studies compared acute effects of WBV and resistance training using bodyweight exercises (Dallas et al., 2014) while others used traditional strength training (Pérez-Turpin et al., 2014) or performed strength exercises using the fixed machine to avoid balance and problems related to exercise technique (Rønnestad, 2004). On the other side, the magnitude of the WBV training effects primarily depended on the vibration training methodology and, the magnitude of the external load applied(Marín & Rhea, 2010). Differences in WBV frequency mainly ranged from 25 Hz (Özsu, Ertan, Simsek, Özçaldiran, & Kurt, 2018), 30-40Hz (Delecluse, Roelants, Diels, Koninckx, & Verschueren, 2005; Pérez-Turpin et al., 2014) and up to 50Hz (Adams et al., 2009) with unloaded static and dynamic exercises while amplitudes ranged from 1.7 to 2.5mm for up to 4mm with relatively similar training gains after the interventions. Özsu et al. (2018) concluded that WBV, when combined with dynamic squatting in well-trained athletes by using similar amplitude and frequency as in current study (i.e., 4mm and 40Hz), enhances neuromuscular activation to greater extent than resistance training alone resulting in higher muscle strength output. Other studies suggested that greatest effect is obtained by using combination of a high amplitude and the frequency (<4mm and 50Hz) (Adams et al., 2009). It still remains inconclusive how to optimise and apply WBV parameters concerning athletes age, experience, gender, type of exercise, body position and health status to maximise the muscle activation and strength gains (Hartard et al., 2022).

The present study found that both CMJ (4.7%) and SJ (1.6%) were significantly higher in WBV than RTG following the intervention. Similar findings were reported in the previous studies (Colson et al., 2010; Dallas et al., 2014; Fernandez-Rio, Terrados, Fernandez-Garcia, & Suman, 2010; Pérez-Turpin et al., 2014). After 4 weeks of training, the CMJ and SJ height increased by 7.4% and 3.0% in VRTG, whereas the level of improvement was roughly the same as that found in the studies with a similar intervention regimes that lasted for up to 6 weeks (Pérez-Turpin et al., 2014), 12 weeks (Delecluse et al., 2005) and in longer (Torvinen et al., 2002) from 1% (Owen, 2004) to 12% (Bosco et al., 1998) for CMJ and 3.4% (Fernandez-Rio et al., 2010) to 17.9% (Mester, Kleinöder, & Yue, 2006) for SJ. By the best of the authors knowledge, only two studies (Mahieu et al., 2006; Pérez-Turpin et al., 2014) compared resistance training with and without added WBV similar to our study. Latter authors found that additional WBV had cumulative effect of 3-12% on jumping performance in volleyball, beach volleyball players and young skiers (Mahieu et al., 2006; Pérez-Turpin et al., 2014). These results indicate that 4-week WBV resistance training improves jump height regardless of the jumping regime considering the type of muscle actions such as purely concentric (Pérez-Turpin et al., 2014) or combination of both the eccentric and concentric (Mahieu et al., 2006). In contrast, in study of Delecluse et al. (2005) five weeks of additional vibration training protocol did not provide any auxiliary improvements compared to the resistance training in sprint athletes. However, subjects were experienced and well-trained athletes, suggesting that implementation of the short-term WBV training to ongoing training regime of well-trained athletes cannot provide added benefits to their power capacities.

To our knowledge, this is the first study that evaluated WBV resistance training effects on sprint performance in junior basketball players. Players improved significantly sprint time from baseline by 1.8% to 3.4%. Although 10m and 20 m sprint performance significantly improved in both groups, between-group interaction effects difference was not found, suggesting that the WBV has no surplus effect over resistance training on sprint performance. The results of this study showed that WBV training caused a decrease in sprint time by 2.8% at 10m and 1.8% at 20m which suggests that the WBV effect on sprint time between 10 and 20m, considering the results, is due to a significantly better result in the initial 10m sprint. Similar results were found by Giorgos and Elias (2007) with 3% at 20m and 4.3% at 10m in the physically active population. Only three studies (Cochrane, Legg, & Hooker, 2004; Giorgos & Elias, 2007; Owen, 2004) found long-term WBV training effects on sprint time at 5 to 60m to be up to 4.3%.

A large number of previously conducted studies (Bosco et al., 1998; Delecluse, Roelants, & Verschueren, 2003; Giorgos & Elias, 2007; Mester et al., 2006; Osawa et al., 2013; Torvinen et al., 2002; Torvinen et al., 2003) found significantly greater WBV effects compared to standard and/or placebo group subjects. Additionally, differences in WBV application methodologies among recent studies, population characteristics, and the duration of the experimental process may be a key factor in explaining the differences in the magnitude of the effects observed. Undoubtedly, based on the differences between the WBV and non-WBV training effects, this study proved the net effects of short-term vibration stimulus as more beneficial gains in strength and power of lower extremities than conventional training were found. The observed strength and power gains are more likely to be related to neural adaptation in contrast to the physiological or hormonal long-term responses (Pérez-Turpin et al., 2014). Additionally, the neural adaptations and gains of WBV were uniform likewise in the resistance training, including the augmented rate of motor unit firing and synchronization, inhibition of antagonist as well as contraction of synergist muscles (Bosco et al., 1998; Torvinen et al., 2003).

Finally, we should mention the limitations of the current study. Firstly, the players, as well as the investigators were not blinded to their assigned intervention which might compromise the results. Secondly, the passive control group was not included in the present investigation to indicate the level of performance changes due to basketball training alone.

Further research should investigate the prolonged effects of WBV application. In addition, to determine the optimal training stimulus of WBV, prior and post-application effects on power, strength, speed, flexibility and injuries during follow-up should be examined. Also, further studies aimed to investigate the muscle structure and endocrine system response to WBV in relation to the specific age of young athletes are warranted.

Conclusion

An additional 4-week WBV resistance training program proved effective in improving lower limb power and strength in young basketball players. When performed on a vibration platform (with accurate and constant vibration stimulus parameters), the resistance exercises were superior to their conventional forms and resulted in additional gains on measures of muscle power and strength, while sprint performance remained unchanged. The additional training effects of WBV were probably caused by the neural adaptation to vibration stimuli, although it should emphasize effects from potential load increase of mechanical oscillation source, muscle hypertrophy and hormonal response to WBV. Thus, to investigate this question a well-designed original study is warranted.

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Availability of data and material

The data that support the findings of this study are available on reasonable request from the corresponding author.

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