

# EFFECTS OF WHOLE BODY VIBRATION ON STRENGTH AND JUMPING PERFORMANCE IN VOLLEYBALL AND BEACH VOLLEYBALL PLAYERS

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**ABSTRACT:** The primary aim of this study was to examine the effects of 6-week strength training with whole body vibration (WBV) on leg strength and jumping performance in volleyball and beach volleyball players. Twenty-three sub-elite male volleyball (VB; n=12) and beach volleyball players (BVB; n=11) aged 21.2±3.0 years were divided into two groups and subjected to 6 weeks of strength training (three one-hour sessions per week): (I) 12 players (6 VB and 6 BVB players) underwent training with WBV (30-40 Hz, 1.7-2.5 mm, 3.0-5.7 g), and (II) 11 players (6 VB and 5 BVB players) underwent traditional strength training. Squat jump (SJ) and countermovement squat jump (CMJ) measurements by the Ergo Tester contact platform and maximum leg press test (1RM) were conducted. Three-factor (2 time x 2 WBV use x 2 discipline) analysis of variance for SJ, CMJ and 1RM revealed a significant time main effect ( $p<0.001$ ), a WBV use effect ( $p<0.001$ ) and a discipline effect ( $p<0.001$ ). Significantly greater improvements in the SJ ( $p<0.001$ ) and CMJ ( $p<0.001$ ) and in 1RM ( $p<0.001$ ) were found in the WBV training groups than in traditional training groups. Significant 3-way interaction effects (training, WBV use, discipline kind) were also found for SJ, CMJ and 1RM ( $p=0.001$ ,  $p<0.001$ ,  $p=0.001$ , respectively). It can be concluded that implementation of 6-week WBV training in routine practice in volleyball and beach volleyball players increases leg strength more and leads to greater improvement in jump performance than traditional strength training, but greater improvements can be expected in beach volleyball players than in volleyball players.

**KEY WORDS:** athletic performance, volleyball, adults, mechanical vibrations

## INTRODUCTION

The use of whole body vibration (WBV) as a method of training for enhancing performance in sport has recently been of growing interest, despite the mechanisms of adaptations to WBV not being sufficiently recognized. WBV training is based on an external drive that stimulates the muscle and nervous system, through direct or indirect devices [1]. Direct application of vibration was analysed mostly in the earliest sports studies, but since it has been shown that WBV training protocols could also be effective in enhancing performance, the use of WBV platforms has increased [2]. The WBV platform has different mechanisms of stimulation; it can vibrate vertically or horizontally or use pivot/wobble vibrations [3]. Vibration refers to an oscillatory displacement with an alternating change in velocity and direction. The platform motors generate oscillatory displacements which are transmitted to the human body, enhancing the tonic vibration reflex, mediated by monosynaptic and polysynaptic pathways [4] and stimulating reflex involuntary muscle contractions [5].

The chronic effect of training is probably gained by neuromuscular and neural adaptations [4]. A huge variety of stimuli adjustments are described – the vibration frequencies and accelerations, exposure times and training duration, types of exercise, work and total loading are most important [6,7]. Generally, the higher the frequencies and amplitudes that are induced, the greater is the muscle activity during a regular isometric squat during WBV [8].

Jumping ability is one of the most important determinants of performance in volleyball. In the volleyball match game, vertical jumps (VJ) are performed frequently, setting and attacking players performing at least one jumping movement during a 12 s rally. Moreover, frontcourt players perform approximately four block jumps and three spike jumps, each of the players averaging nearly 22 jump-landings per game [9]. It was determined that players of better performing teams have higher VJ values [9]. The VJ height (spike and vertical) also influences the performance of beach volleyball

players, and consequently the performance of their teams [10]. Beach volleyball (BVB), similarly to volleyball, is performed intermittently at moderate-to-high intensity with brief bouts of high intensity exercise interspersed by long low-intensity periods. Nevertheless, there are some biomechanical differences in movements performed on sand and a solid surface. It was shown that jumping on sand surfaces was characterized by significantly smaller jumping heights during squat jumps, countermovement jumps, volleyball spikes, and block jumps, compared with jumps on rigid surfaces [11]. Jumping height is significantly smaller on a sand surface than a rigid one due to compliance and instability of the sand, and this results in a reduction in maximum vertical forces, smaller maximum powers, vertical impulses and take-off velocity [12]. As a result of the compliance of the sand surface, during the spike jump the BVB players slow down their movements, especially during the phase of transition from knee flexion to extension and during the extension phase [13]. During the sprinting performance on a sand surface, successful sprinters are characterized by a greater angle of trajectory at start take-off than in non-elite sprinters. As Lockie and Vickery suggested, this could be facilitated by a longer start time that allows for more force generation, and a greater degree of hip flexion of the swing leg and trunk lean at start take-off [14].

To date, improvements in performance related to the use of WBV training have been reported from studies conducted across a wide spectrum of sporting activities and level of sport ability. The improvements in explosive activities such as weightlifting or vertical jumping were probably the most frequently reported in sports science study [7]. However, the training effect may be diminished in well-trained athletes as they could reach the limit of their adaptive potential and due to the lower rate of possible improvement compared with untrained subjects [15]. Contrary to that, Luo et al. suggested that benefits from vibration training may be greater in elite athletes than non-elite athletes [1]. Training effects of different training modes dedicated to improving jumping performance have been published widely, but reports about training effects in well-trained BVB are almost unavailable. Thus the primary aim of this study was to examine the effects of a short-term strength training programme with whole body vibration (WBV) on leg strength and jumping performance in volleyball and beach volleyball players.

## MATERIALS AND METHODS

**Subjects.** Twenty-three sub-elite male volleyball (VB; n=12) and beach volleyball (BVB; n=11) players ( $21.2 \pm 3.0$  years;  $1.85 \pm 0.06$  metres;  $78.3 \pm 5.9$  kg;  $22.7 \pm 0.8$  BMI) volunteered for this study. All of the participants were well-trained athletes, members of a university team, participants of a university technical training programme, and were all fully informed of the research procedures, which were approved by the University of Alicante Ethics Committee. On the first day of intervention, the subjects completed a questionnaire about their state of health. None of the athletes had to be excluded from participation in the study due to health conditions.

**TABLE 1.** BASELINE SUBJECTS' CHARACTERISTICS

Variable	Beach volleyball		Volleyball	
	WBV (N = 6)	CON (N = 6)	WBV (N = 6)	CON (N = 5)
Age (years)	19.7±2.2	21.2±3.3	22.7±3.3	21.2±3.1
Height (m)	1.85±0.05	1.87±0.06	1.86±0.06	1.82±0.05
Body mass (kg)	78.7±5.6	79.9±6.8	79.4±5.6	74.4±5.6
BMI (kg·m <sup>-2</sup> )	22.8±0.6	22.7±0.9	22.9±0.7	22.5±1.2

Note: WBV – whole body vibration group, CON – control group

A pre-test/post-test equivalent-group design was used to investigate whether traditional strength training combined WBV can enhance the strength and jumping performance of trained athletes compared with the results of traditional strength training alone for 6 weeks. Players were randomly assigned to the training combined with WBV (WBV; n=12 players, 6 VB and 6 BVB) and the control with isolated strength training (CON; n=11 players, 6 VB and 5 BVB) groups. The physical characteristics of the participants of each group are shown in Table 1. The independent variables were training, WBV use and discipline kind.

### Training protocol

The four groups completed the 6-week training programme in the same weight-training room, performing the following 4 lower limb exercises: leg press, alternative lunge, squat and front squat for 4 sets x 12 repetitions at 70% of repetition maximum (RM).

All sessions were documented, surveyed, and supervised by the investigators. The training of the control group was matched with the training of the WBV group; i.e. training duration, number of sets, rest periods and task-specific instructions were identical for both groups.

While standing on a vibration platform (Power Plate®, Power Plate International Ltd., London, UK) the isometric and dynamic (squat, one-leg squat) exercises were applied. The WBV training protocol involved performing 4 sets x 30 second bursts of each exercise with WBV with a 2 minutes recovery after each repeat, 3 days a week, for 3 weeks. For the following 3 weeks, the duration of repetition was increased to 60 seconds. The vibration frequency

**TABLE 2.** TRAINING VOLUME AND TRAINING INTENSITY OF THE WHOLE BODY VIBRATION (WBV) PROGRAMME

Week	Training frequency (days/week)	Vibration frequency (Hz)	Peak-to-peak vibration amplitude (mm)	Total session duration (min)	Vibration exposure per exercise (s)
1-3	3	30	1.7	60	30
4-6	3	40	2.5	60	60

range was 30–40 Hz, the amplitude was 1.7–2.5 mm, and acceleration was 3.0–5.7 g. The training protocol is shown in Table 2. In isometric exercise the athletes were required to maintain a static squat position bending their knees at an angle of 2.27 rad, which was standardized using a goniometer. Conventional and vibration exercises were combined in circuit-type resistance training. The same exercises without vibration in the control group training was performed on the floor.

Two practice sessions were conducted before starting the first session so as to familiarise the sportsmen with the exercises to be carried out during the treatment.

#### Measurements

The pre- and post-tests were performed 24 hours before and after training, respectively. All of the participants performed standardized warm-up activities (jogging and stretching) before the measurements. Testing was kept at the same time of day for all participants, to reduce the effect of the known diurnal fluctuations in strength. The jumping tests were performed on an infrared light mat (ERGO JUMP Plus-BOSCO SYSTEM; Byomedic, SCP, Barcelona, Spain), recording the light time in milliseconds. The best of three trials was recorded to determine the test score. The obtained light time ( $t$ ) was further used to determine the increase in the centre of gravity ( $h$ ), i.e.,  $h = gt^2/8$ , where  $g = 9.81 \text{ m} \cdot \text{s}^{-2}$ . CMJ test-retest reliability has been noted by Markovic et al. [16] as a Cronbach's alpha coefficient of 0.98 and a coefficient of variation of 2.4%.

#### Countermovement jump (CMJ)

A vertical CMJ was used to assess lower-body explosive strength after stretch shortening of the muscles. To avoid immeasurable work, horizontal and lateral displacements were minimized, and the hands were kept on the hips throughout the jump. During CMJ, the angular displacement of the knees was standardized so that the subjects were required to bend their knees to approximately 90°. The participants were instructed to freely flex the knees and to jump once as high as possible.

#### Squat jump (SJ)

For the squat jump test, the participants were asked to reach and hold a semi-squat position (at 110 degrees) until an acoustic signal was given, and to jump once as high as possible without performing any countermovement before jumping. The subjects jumped only when they had established the initial position measured by the goniometer.

#### 1 repetition maximum (1RM)

1RM was tested in the leg press exercise. For the starting position subjects were seated and bent their legs to 90 degrees. The 1RM was determined by a protocol of single repetition to failure, in which the load was gradually increased in the subsequent attempts by 10-20%, separated by a 3-minute rest.

#### Statistical analysis

Baseline group (WBV vs. CON) and discipline (BVB vs. VB) differences were assessed with 2-factor analysis of variance (ANOVA) and the main effects of time (within-subject), group (between-subject), discipline (between-subject), and their interactions on dependent variables were assessed via 3-factor ANOVA with time as a repeated measure. The main effect of time was considered to be the effect of resistance training and the main effect of group as the effect of kind of intervention. The change from baseline was defined as the post-intervention value minus the baseline value. Effects sizes (ES) were reported as eta-squared ( $\eta^2$ ). According to the classification, a large (strong) effect is given when  $\eta^2$  is greater than 0.14, a moderate-sized effect is given when  $\eta^2$  is 0.06–0.14, and a small effect is given when  $\eta^2$  is smaller than 0.06 [17]. Statistical significance was assigned if  $P < 0.05$ . The data are presented as mean ( $\pm$  SD) unless otherwise stated. Data processing and statistical evaluations were completed using SPSS version 19.0 for WINDOWS (SPSS Inc, Chicago, IL).

## RESULTS

At baseline, statistically significantly higher values of SJ, CMJ and 1RM ( $p=0.002$ ,  $p<0.001$  and  $p=0.004$  respectively) were found in VB than BVB players. However, no significant differences were found between the WBV training and standard strength training groups for any of the measured variables (SJ  $p=0.62$ ; CMJ  $p=0.33$ ; 1RM  $p=0.78$ ) before intervention.

The results of three-factor ANOVA for SJ revealed a significant strong ( $\eta^2=0.42$ ) time (training) effect ( $p<0.001$ ); higher SJ performance was noted after training period than before. A significant and strong ( $\eta^2=0.24$ ) time x WBV use interaction effect ( $p<0.001$ ) and strong ( $\eta^2=0.17$ ) time x discipline interaction effect ( $p<0.001$ ) was found for SJ (Table 3). Greater changes were noted in groups using WBV in training than trained without WBV and among BVB than VB players. Furthermore, a moderate ( $\eta^2=0.07$ ) significant time x WBV use x discipline interaction effect ( $p=0.001$ ) was noted for SJ. Post hoc comparisons indicated greater changes among BVB players using WBV in training ( $+6.0 \pm 1.4 \text{ cm}$ ) than in VB players using WBV ( $+1.5 \pm 0.6 \text{ cm}$ ) or VB players not using WBV ( $0.1 \pm 1.6 \text{ cm}$ ). No statistically significant differences were found between training improvements in BVB ( $+1.0 \pm 0.6 \text{ cm}$ ) and VB players ( $+0.1 \pm 1.6 \text{ cm}$ ) not using WBV in training ( $p=0.13$ ) (Table 4).

Three-factor ANOVA for CMJ revealed a significant strong ( $\eta^2=0.45$ ) time (training) effect ( $p<0.001$ ); higher CMJ value was noted after the training period than before (Table 3). A significant and strong ( $\eta^2=0.19$ ) time x WBV use interaction effect ( $p<0.001$ ) and moderate ( $\eta^2=0.11$ ) time x discipline interaction effect ( $p<0.001$ ) were found for SJ. Greater changes were found in groups using WBV in training than those without WBV and among BVB than VB players. Furthermore, a moderate ( $\eta^2=0.14$ ) significant time x WBV use x discipline interaction effect ( $p<0.001$ ) was noted for CMJ. Post hoc comparisons indicated greater changes among BVB players using WBV in training ( $+5.5 \pm 1.6 \text{ cm}$ ) than in VB players using

**TABLE 3.** EFFECTS OF WHOLE BODY VIBRATION TRAINING ON SQUAT, COUNTERMOVEMENT JUMPS AND LEG MUSCLE STRENGTH IN VOLLEYBALL AND BEACH VOLLEYBALL PLAYERS

		WBV Group		Control Group		Within-subjects effects				
		Pre	Post	Pre	Post	Time	Time x Group	Time x Disc	Time x Group x Disc	Error
SJ (cm)	Beach Volleyball	41.3±2.2	47.3±2.8	40.7±2.3	41.7±2.3	P	<0.001	<0.001	<0.001	=0.001
	Volleyball	46.0±3.7	47.5±3.7	45.4±4.0	45.4±4.0	$\eta^2$	0.42	0.24	0.17	0.07
						OP	1.00	1.00	1.00	.95
CMJ (cm)	Beach Volleyball	44.6±2.9	50.2±2.6	43.7±2.6	44.3±2.9	P	<0.001	<0.001	<0.001	<0.001
	Volleyball	51.0±3.1	52.1±3.4	48.8±4.1	49.6±3.8	$\eta^2$	0.45	0.19	0.11	0.14
						OP	1.000	1.000	.99	.99
1RM (kg)	Beach Volleyball	285.0±12.6	312.5±18.9	292.5±12.1	295.8±13.2	P	<0.001	<0.001	<0.001	=0.001
	Volleyball	312.5±18.4	320.0±20.7	302.0±5.7	304.0±4.2	$\eta^2$	0.43	0.23	0.12	0.09
						OP	1.000	1.000	.99	.95

Note: SJ – squat jump, CMJ – countermovement jump, 1RM – maximum repetition in leg press, WBV – whole body vibration, Pre/Post – pre/post training results, Time – training effect (within-subjects comparison), Group – kind of training (WBV use or standard training), Disc – discipline effect, P – p value,  $\eta^2$  – effect size, OP – observed statistical power

WBV (+1.2 ± 0.7 cm) or not using WBV (0.8 ± 1.2 cm). No statistically significant differences were found between BVB (+0.6 ± 0.3 cm) and VB players (+0.8 ± 1.2 cm) not using WBV in training ( $p=0.33$ ) (Table 4).

The results of three-factor ANOVA for 1RM revealed a significant strong ( $\eta^2=0.43$ ) time (training) effect ( $p<0.001$ ); higher 1RM performance was noted after the training period than before (Table 3). A significant and strong ( $\eta^2=0.23$ ) time x WBV use interaction effect ( $p<0.001$ ) and strong ( $\eta^2=0.12$ ) time x discipline interaction effect ( $p<0.001$ ) were noted for 1RM. Greater increase in 1RM was noted in groups using WBV in training than those trained without WBV and among BVB than VB players. Furthermore, a moderate ( $\eta^2=0.09$ ) significant time x WBV use x discipline interaction effect ( $p=0.001$ ) was noted for 1RM. Post hoc comparisons indicated greater changes among BVB players using WBV in training (+27.5 ± 8.2 kg) than in VB players using WBV (+7.5 ± 2.7 kg) or not using WBV (2.0 ± 7.6 kg). No statistically significant differences were found between BVB (+3.3 ± 2.6 kg) and VB players (+2.0 ± 7.6 kg) not using WBV in training ( $p=0.99$ ) (Table 4).

## DISCUSSION

The primary findings of this study was that 6-week strength training with whole body vibration produced a significantly greater improvement in jumping performance and maximal leg strength than conventional training alone in well-trained volleyball and beach volleyball players. Interestingly, greater effects could be expected among beach volleyball players. To the author's knowledge, this is one of the first studies aimed at examining the effect of WBV added to routine training on jumping performance in well-trained volleyball and beach volleyball players. The results of the present study support previous findings indicating that WBV training produces a moderate-to-large effect on jump performance [18].

Firstly, significant improvements in CMJ, SJ and 1RM ( $p<0.001$  and  $\eta^2= 0.42-0.45$ ) were noted in response to strength training, regardless of the additional stimulus. The observed increase in strength and jumping performance could be simply explained by the fact that all initial tests were performed before conditioning preparation for the season. Players' functional capacities could have been low due to the off-season period. A strong training effect seems to

**TABLE 4.** MEAN DIFFERENCES OF PRE-/POST TRAINING RESULTS OF JUMPING AND STRENGTH PERFORMANCE

		SJ (cm)				CMJ (cm)				1RM (kg)			
		Mean	SE	CI	P-value	Mean	SE	CI	P-value	Mean	SE	CI	P-value
WBV	BVB	6.0	0.5	5.1 - 6.9	<0.001	5.5	0.4	4.6 - 6.4	<0.001	27.5	2.4	22.5 - 32.5	<0.001
	VB	1.5	0.5	0.6 - 2.5	0.003	1.2	0.4	0.3 - 2.1	0.015	7.5	2.4	2.5 - 12.5	0.005
Controls	BVB	1.0	0.5	0 - 1.9	0.041	0.6	0.4	-0.3 - 1.5	0.203	3.3	2.4	-1.6 - 8.3	0.175
	VB	0.1	0.5	-1 - 1.1	0.917	0.8	0.5	-0.2 - 1.8	0.100	2.0	2.6	-3.4 - 7.4	0.450

Note: SJ – squat jump, CMJ – countermovement jump, 1RM – maximum repetition in leg press, WBV – whole body vibration, BVB – beach volleyball players, VB – volleyball players, SE – standard error of measurements, CI – coefficient interval.

be important for further analysis as an inadequate exercise protocol could greatly limit the interpretations.

It was found that WBV training produced greater improvements than traditional training alone. In this study strong effects of WBV were found for both SJ and CMJ ( $\eta^2 = 0.42$  and  $\eta^2 = 0.45$ , respectively). Similarly, Osawa et al. [19] found that the additive effect of WBV on countermovement jump performance could be classified as 'large'. Previously, also Issurin [20] and Rehn et al. [15] reported a surplus effect of WBV on jump height. The improvements by 7.0% in the CMJ test were similar when compared with the results reported by Delecluse [21] from 12-week training (3 sessions per week) and Torvinen [22] from 4-month training (3-5 sessions per week), who found an improvement of 7.6% and 9% respectively. Findings from this study are also in agreement with the results obtained by Russo [23], who observed a jump power increase by 4.7% in the SJ test after 6 months of WBV training applied for 6 min per session in 2 sessions per week. Mahieu et al. [24] applied WBV 3 times a week during 6 weeks to competitive athletes and found that a strength training programme that includes WBV appears to have additive effects in young skiers compared with an equivalent programme that does not include WBV.

In contrast, others have found little or no effect. Cochrane et al. [25] applied short-term WBV training to sports science students (non-elite athletes), and the results did not show a significant change in jump heights, either in within-subject comparison or between exercising controls. Also Delecluse [26] found that a specific whole body vibration protocol (35-40 Hz, 1.7-2.5 mm with unloaded static and dynamic exercise on a vibration platform) of 5 weeks training had no surplus value over the conventional training programme to improve speed-strength performance in sprint-trained athletes.

In this study, improvements in jumping performance were followed by an increase in leg strength; significantly greater changes in 1RM ( $p < 0.001$  and  $\eta^2 = 0.23$ ) were observed in the WBV group. To date, numerous studies have demonstrated that WBV training enhances muscle strength [27]. Changes in muscle strength performance in the WBV study groups ranged from -0.9% to 24.4% [28]. Ronnestad found even a 31.6% increase in 1RM in squat [29]. But the advantage of WBV training, when compared to similar training load regimens, is far less documented. Delcluse et al. [30], who applied a 12-week programme of knee-extensor exercises on a vibration platform with a progressive load (35-40 Hz, 2.5-5.0 mm, 1-3 series of 30-60 s bouts), found that strength increases after WBV training are not attributable to a placebo effect and the strength gain of previously untrained females could be reached to the same extent as resistance training at moderate intensity. In the meta-analysis conducted by Osawa et al. [31] it was concluded that the use of WBV would lead to greater improvements in knee extension muscle strength and countermovement jump than under identical conditions without WBV. Also, the findings from Marin [32] confirm that vibration exercise can be effective at eliciting chronic muscle strength adaptations. On the other hand, Kvorning et al. [33], who conducted a study in three

groups of trained young men performing a 9-week programme of resistance training alone or with WBV alone or combined, found that maximal isometric voluntary contraction (MVC) equally increased when using resistance training or the combination protocol. Simultaneously, there were no differences in improvement in CMJ performance in relation to kind of training. Kvorning et al. also concluded that WBV alone did not increase MVC and mechanical performance in spite of increased growth hormone concentration [33].

The WBV training response observed in the current study also contrasts with the other previous studies which documented that adding WBV exercise to 6-week resistance training did not result in larger improvements in isokinetic strength or CMJ and 3RM, when compared to an identical exercise programme performed in the absence of vibration in recreationally active young adults [34].

Such inconsistencies occur probably due to insensitive subjects (higher levels of fitness) or inadequate study design (poor compliance of WBV training or high variation of routine exercise during the intervention period) [7]. The inconsistency could also be a result of differences in training methods, loading parameters, body positions, and types of platforms [35]. Higher frequencies, higher amplitudes, longer exposures per session in training protocols and longer training periods are more likely to enhance muscle power [7].

In the current study greater improvements in muscular performance were observed in BVB than in VB players. BVB players gain a greater increase in SJ, CMJ, 1RM regardless of WBV use. But also moderate to strong interaction time x group x discipline effects were found for SJ, CMJ, and 1RM. BVB players achieved the highest muscular performance when WBV was used in their training. This could be explained by an initial lower fitness level. Wilcock et al. determined that in non-athletic subjects the potential for neural adaptations may be even higher compared to well-trained athletes [3]. This is also supported by Delecluse, who stated that a WBV programme impacts more on untrained subjects [26]. Also, Manimmanakorn et al. [36] reported that a stronger positive effect of WBV training on CMJ (ES; 0.77) SJ height performance (ES; 0.68) could be expected when compared with non-exercise.

The BVB players generally achieved a lower jump height. During jumps on sand they slow down their movements, especially during the phase of transition from knee flexion to extension and during the extension phase [13]. This adaptation could have altered jumping measurements in tests. Turpin et al. [37] found that in real competitions, more jumps are made by beach volleyball players than volleyball players. It is likely that higher vertical jump height (spike and block) positively influences the performance of beach volleyball players and the team during a match. Nevertheless, transfer of increased jumping performance to BVB players' game performance was not analysed well.

The underlying mechanisms of the observed gains are probably related to neural adaptations [28]. Also, physiological adaptations are much debated. Experimental studies in mice also provide some evidence for muscular adaptation and muscle hypertrophy after vibration [38]. By activating muscle spindles WBV could stimulate alpha

motor neurons and promote stretch reflexes [5]. On the other hand, it was suggested that effects of the long-term WBV training gained via neural adaptation were similar to effects of resistance exercise training involving enhancement of motor unit firing, motor unit synchronization, synergist muscle contraction, antagonist muscle inhibition, and adaptation of the reflex response [39,40]. Higher synchronization of motor units and higher motor unit firing could favour more effective muscle contraction and greater force production. It is also proposed that increases in strength after WBV may be due to hormonal changes. It was documented that WBV resulted in elevating essential hormones for muscle hypertrophy and force production, i.e. growth hormone, testosterone, and insulin-like growth factor 1 [41]. It is supposed that hormonal secretion is affected by neural-hormonal regulation. Cardinal and Bosco suggested that higher brain or cerebral motor cortex activity stimulates the hypothalamic-anterior pituitary axis and autonomic system [5].

Still, there is a lack of consensus as to which training protocols allow the best results to be achieved. It is likely that vibration exercise can result in similar or greater strength improvements compared with conventional resistance training [32]. Petit et al. concluded that high-frequency/high peak-to-peak displacement was the most effective vibration setting to enhance knee extensor muscle strength and jump performance during a 6-week WBV training programme and that these improvements were not mediated by central neural adaptations [42]. Luo et al. [1] suggested that a higher amplitude (4 mm) induced larger effects than lower amplitudes. Adams et al. [43] found that to generate the greatest effect, a high amplitude (4–6 mm) should be applied with a high frequency (50 Hz), whereas a low amplitude (2–4 mm) should be applied with a low frequency (30 Hz). This study adopted lower loads, the vibration frequency range being 30–40 Hz and the amplitude 1.7–2.5 mm, and the positive effects also occurred. Several other factors are identified as moderators of WBV training effects on strength and power. The greatest improvements in performance tests occurred in the initial WBV phase and early phases of training [44]. It also depends on exposure time, exercise loading parameters, type of exercise and body positions, types of platforms and additional external loads [35,45].

Traditional strength training supplemented with WBV seems to improve muscle strength and jumping performance better than

a conventional exercise programme. This study provides evidence supporting the suitability of WBV training for beach volleyball and volleyball athletes to provide rapid performance gains in jump height. Improvements can be achieved in shorter periods of time (6 weeks) than reported in earlier studies. WBV has been shown to be a time-efficient method of improving strength and power indices, which are all vital physical fitness components that support beach volleyball players.

#### Study limitations

The effects of WBV observed in our study need, however, to be interpreted with caution. The study sample was quite small and groups differed at initial levels. Moreover, a placebo or sham vibration was not included, and the participants and investigators were not blinded, which could have affected the athletes' engagement and expectations. Although no injury was reported in the period of study, the vibration training is believed to be stressful. The investigators did not analyse muscle-damage indications that provide a good insight into the process of adaptation as the initial muscle damage may appear to have negative consequences in the short-term effects of resistance exercise [46].

Undoubtedly, the use of external load and individualized vibration frequencies and the subsequent effects on jumping performance deserve further research on WBV training. Further studies involving larger sample sizes and longer interventions are required to clarify whether the use of WBV, as a complement to resistance training, produces additional specific benefits.

The results of this study may encourage trainers to employ new training methodologies by incorporating WBV sessions into their training programmes in order to improve and maintain jump height and leg strength.

## CONCLUSIONS

It can be concluded that implementation of 6-week WBV training in routine practice in volleyball and beach volleyball players increases leg strength more and leads to greater improvement in jump performance than traditional strength training, but greater improvements can be expected in beach volleyball players than in volleyball players.

**Conflict of interest:** the authors declare no conflict of interests.

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