ACUTE EFFECTS OF BILATERAL AND UNILATERAL WHOLE BODY VIBRATION TRAINING ON JUMPING ABILITY, ASYMMETRY, AND BILATERAL DEFICIT ON FORMER ARTISTIC GYMNASTS

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Abstract

Whole-body vibration (WBV) has been used to improve jumping ability, muscle strength, power, and performance in various sports. Bilateral deficit (BLD) is defined as the difference in the magnitude of the maximum force during single or double support. The present study investigated the effect of unilateral and bilateral whole-body vibration (WBV) exercise on jumping ability, asymmetry and BLD on former artistic gymnasts. Twenty-eight former artistic gymnasts volunteered to participate in this study. Participants performed 4 experimental protocols on nonconsecutive days in a random order. Each protocol included a 3-min-warm-up running on the treadmill at 2.22 m.s $^{-1}$, followed by a 2-min rest. The intervention protocols were: a) WBV with feet [bipedal] (WBVB), b) WBV with single foot [unilateral] (WBVU), c) WBVB with the device turn-off (NWBVB), and d) WBVU with the device turn-off (NWBVU). The dependent variables were the squat jump (SJ) and counter movement jump (CMJ) with both feet (bilateral) and with single leg (unilateral). Results showed a significant interaction effect between the condition and time on SJ on both condition (bilateral and unilateral) and CMJ, whereas significant main effect was found for the condition and for time on SJ. Conclusively, the WBV unilateral condition improves significantly lower limbs symmetry during SJ performance. Further, bilateral WBV (WBV B) was the most effective condition on bilateral and unilateral SJ and CMJ performance.

Keywords: *Bilateral deficit, Single leg vertical jump, Asymmetry.*

INTRODUCTION

Coaches use different types of training methods to enhance the muscle power of athletes on different sports. Plyometric training has been extensively applied using muscles' stretch reflexes and stretch-shortening cycles to enhance muscular function and power (Chelly, Ghenem, Abid, Hermassi, Tabka, Shephard, 2010; Park, Lee, Lee, 2014). Recently, whole-body vibration (WBV) has been used to improve jumping ability, muscle strength, power, and performance in various sports (Dallas, Kirialanis, 2013; Dallas, Paradisis, Mellos, 2013; Dallas, Paradisis, Kirialanis, Mellos, Argitaki, Smirniotou, 2015; Dallas, Tsopani, Papouliakos, Riga, Korres, 2016; Kim, et al., 2016; Petit, Pensini, Tessaro, Desnuelle, Legros, Colson, 2010; Tsopani et al., 2014). During vibration, the lower extremities of the subjects receive repeated alternating concentric – eccentric stimulations affecting the muscular and nervous system. Furthermore, during WBV training, subjects usually stand on both legs to improve leg strength and/or flexibility (Dallas, Kirialanis, 2013; Dallas, Paradisis, Mellos, 2013). Factors such as enhanced motor excitability (Cardinale, Bosco, 2003), recruitment of previously inactive motor units (Mischi, Cardinale, 2009), increased muscle temperature and blood flow (Bosco, Cardinale, Tsarpela, 1999) as well as facilitating neural functions resulting from tonic vibration reflex (Lapole, Perot, 2010) are responsible for the upcoming improvement. The difference in the magnitude of the maximum force during single or double support is referred to as the bilateral deficit (BLD) and is defined as the decrease in the magnitude of the force produced from bilateral movements of the limbs compared to the sum of forces produced by the right and left limbs when acting separately (Sale, 1992). Examining the lower limbs' strength during maximal or submaximal intensities (Kuruganti, Murphy, 2008) is subject to incorporating a simultaneous activation of numerus muscle groups. However, it is well known that the recruitment of motor units during bilateral contractions is lower compared to unilateral contractions, and that the uni-lateral training increases one's ability to generate maximal strength in relation to the bilateral training (Rejc, Lazzer, Antonutto, Isola, di Prampero, 2010). McCurdy et al. (2005) indicated that unilateral training was more effective during unilateral testing of vertical jump height compared to bilateral training, whereas during bilateral testing, the improvements in jumping ability were similar in both groups.

Functional asymmetry (FA) or bilateral strength asymmetry (BSA) is a phenomenon that is often observed in sports and characterize the side-to-side differences in kinetics and/or kinematics during task performance (Newton et al., 2006). FA is responsible for the occurrence of injuries (Croisier, Ganteaume, Binet, Genty, Ferret, 2008; Murphy, Connolly, Beynnon, 2003) or re-injuries (Myer, Brent, Ford, Hewett, 2011), while also adversely affecting performance (Young, James, Montgomery, 2002). Possible reasons for FA / BSA might be specific motor demands of different sports and training methods (Mayer, Schlumberger, Van Cingel, Henrotin, Laube, Schmidtbleicher, 2003; Newton et al., 2005) and differences in neural control and/or how the body may learn to perform a motor skill as well. The concept of inter-limb asymmetries compares the performance of one limb in respect to the other (Keeley, Plummer, Oliver, 2011) quantifying these inter-limb differences between the dominant vs. non-dominant (Rouissi et al., 2016), the stronger vs. weaker (Sato, & Heise, 2012) the right vs. left (Atkins, Bentley, Hurst, Sinclair, Hesketh, 2016), showing that inter-limb asymmetries of about 10% result in reductions in jump height (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Lilley, Bradshaw, Rice, 2007). More specifically, as Ford and colleagues stated, uneven lower limb loading patterns during jumping and landing have been previously thought of as a mechanism of injury (Ford, Myer, Smith, Hewett, 2003). In another study, Newton et al. (2005) found a difference of 8% in force production during the single leg vertical jump between the dominant and non-dominant leg in college-level athletes, whereas Stephens, Lawson, De Voe, and Reiser. (2007) revealed a similar difference between legs in volleyball players. Furthermore, previous data by Ceroni, Martin, Delhumeau, Farpour-Lambert, 2012) showed a difference of 8.8% and 8.95% in force production in female and male teenagers, respectively.

Given the asymmetry of the lower limbs, it is possible that the amount of vibratory stimulation that each limb receives is different during body weight support, and the magnitude of this effect depends on the condition of each limb. Therefore, training using unilateral vibratory stimulation can be a suitable method of improving the functional ability of a weak lower limb and the asymmetry of functional ability between both lower limbs. There are not many studies concerning the effect of WBV on bilateral deficit or/and lower limbs asymmetry (Marin, Hazell, Garcia-Gutierrez, & Cochrane, 2014; Shin, Lee, Song, 2015; Yapicioglu, Colakoglu, Colakoglou, Gulluoglu, Bademkiran, Ozkaya, 2013). Some of them use 1RM test or isometric contractions to examine the BLD, whereas no study uses isotonic contraction during WBV protocols to examine the BLD (Costa, Moreira, Cavalcanti, Krinski, & Aoki, 2015; Shin, Lee, Song, 2015). Further, findings by Yapicioglu et al. (2013), who examined the short-term performance outcomes and neurological effects of three different warm-up methods (static stretching [SS]; dynamic warm-up [DW]; and tendon vibration combined with SS [TVSS]), found a significant improvement in jump height performance following the DW whereas TVSS did not yield negative effects. Additionally, Marin et al., examined if WBV exposure during one-legged static semi-squat would benefit muscle performance in the non-exposed contralateral leg and found that acute WBV bout augments cross-transfer in neuromuscular performance of explosive power parameters (Marin, Hazell, Garcia-Gutierrez, & Cochrane, 2014). It must be noted that bilateral training increases bilateral force production more than unilateral force production and reduces BLD, while unilateral training increases unilateral force production more than bilateral force production, therefore, increases the BLD (Hakkinen, Kallinen, Linnamo, Pastinen, Kraemer, 1996). To the author's knowledge there is paucity concerning the acute effect of unilateral and bipedal WBV training on jumping ability, asymmetry and BLD on the same sample that performed the same protocols with and without WBV exposure. Furthermore, no studies exist that examined lower limb asymmetry on gymnasts. The present study investigated the effect of unilateral and bilateral WBV exercise on jumping ability, asymmetry and BLD in former artistic gymnasts. It was hypothesized that a BLD would occur during the assessment of jumping testing when using both limbs simultaneously; and that a unilateral WBV exposure would reduce asymmetry between the lower limbs.

METHODS

Twenty-eight former artistic gymnasts with 12 years training experience, aged 22.43 ± 2.44 years; height: 168.73 ± 5.81cm; body mass: 61.66 ± 9.29kg volunteered to participate in this study. Body mass (kg) was measured to the nearest 0.01kg (Seca 770 UK), and body height was measured to the nearest 0.1cm using a stadiometer (Seca Leicester, UK). Former gymnasts who retired more than 4 years ago as well as those who had injury/ies problem in the last 3 months were excluded from the study.

The participants were physically active for 10-12 $h^{\cdot} w^{-1}$ because of the nature of their studies. During the study they were asked to abstain from any activity other than those they required in their university courses. All participants had experience in vertical jumping with one and two legs and were familiarized with the vibration equipment and with the measurements in a preliminary session. Furthermore, a written informed concept was obtained from each participant after an extensive explanation of the purpose and experimental design of the study. The study was approved by the local Institutional Review Board and all procedures were in accordance with the Declaration of Helsinki.

A randomized, counterbalanced, within-subjects experimental design was conducted in order to investigate the acute effects of unilateral and bipedal WBV training on jumping ability, asymmetry, and BLD. The study was carried out over the course of 4 sessions on nonconsecutive days. Participants performed 4 experimental protocols, at the same time of the day, in a random order. Each protocol included a 3-minute warm up running on the treadmill at 2.22m.s $^{-1}$, followed by a 2-minute rest. Participants attended a total of 5 data-collection sessions including a familiarization session. The intervention protocols were as follows: a) whole body vibration with both feet [bipedal] (WBVB), b) WBV with single foot [unilateral] (WBVU), c) WBVB but the device was turned-off (NWBVB), and d) WBVU but the device was turned-off (NWBVU). Participants in the WBV protocols were exposed to vertical sinusoidal mechanical WBV while standing on the Power Plate® Next Generation WBV platform (Power Plate North America, Northbrook, Illinois), whereas participants in the NWBV protocols performed the same protocol with the WBV device turned off. Vibration platform settings included a frequency of 50Hz with the peak-to-peak displacement of 2.51mm amplitude for a total time of 3 min. A schematic representation of the protocols is presented in Table 1. During performance of each protocol a 30 sec rest was mediated between each set. The rest period of 30 sec is supported by previous study that assessed jumping performance in high level gymnasts (Dallas et al, 2019).

During all conditions, subjects wore the same athletic shoes to standardize the damping of the vibration because of the footwear (Marin, Bunker, Rhea, Ayllon, 2009).

Table 1
A schematic representation of the intervention program (Protocols).

WBVB	WBVU	NWBVB	NWBVU
6 set * 30 sec SSQP	3 set * 30 sec for each leg SSQP	6 set * 30 sec SSQP	3 set * 30 sec for each leg SSQP

SSQP: static semi squat position

Jumping ability was evaluated by the jump height of squat jump (SJ) and counter movement jump (CMJ) with both feet (bilateral) and with single leg (unilateral). Testing was performed before intervention to determine the initial level of performance (baseline values), immediately after, and 8 minutes after the intervention. During the first session, 3 min after the warm-up, participants performed the SJ and CMJ with both legs and with single leg separately on a Chrono Jump platform, in a random order. During the testing, the arms were held on the hips and the participants tried to jump upward, leaving the platform with the knees and ankles extended and landing with straight knees in the upright position. Three trials were made with a 60 sec rest between them and the best trial of JH was recorded for further statistical analysis.

A common test to assess the functional performance ability of both power limbs is the jump test (Petschnig, Baron, Albrecht, 1998) and single leg vertical jump (SLVJ) (Kivlan, Martin, 2012), and the results can be represented using the limb symmetry index (LSI) (Marin, Hazell, Garcia-Gutierrez, & Cochrane, 2014). An LSI ≥ 90% should be considered in the normal range, therefore an asymmetry exists if there is > 10%

difference between the two lower limbs (O'Donnell, Thomas, Marks, 2006). The LSI is calculated by taking the average of any test scores for the affected limb divided by the unaffected limb multiplied by 100 to obtain a percentage difference between limbs.

Statistical analyses were performed using SPSS version 24 (IBM, New York, USA). A two-way (condition x time) ANOVA with repeated measures on the second factor was used for the statistical analysis. The Shapiro-Wilk method was conducted to check the normality of the data. Furthermore, a three-way (condition x time x gender) ANOVA was used to examine the effect of gender. Sphericity was checked using Mauchly's test, and the Greenhouse-Geisser's correction on degrees of freedom was applied when necessary. The Levene's test of equality of error variances was used to check the assumption of homogeneity of variances. In cases where interaction between the condition and time was detected, the simple effects were investigated, and the Bonferonni's correction was used. In the absence of interaction, the main effects of the two factors (condition and time) on the dependent variables were investigated. All statistical significances were tested at α = 0.05.

RESULTS

Table 2.
Descriptive statistics in dependent variables among different intervention methods.

		WBV B	WBV U	NWBV B	NWBV U
SJ (cm)	Pre	26.59 ± 4.83	26.30 ± 3.93	27.18 ± 4.47	26.69 ± 4.88
	Post 1	28.86 ± 5.80 ↑	26.55 ± 5.46	28.50 ± 5.45	26.26 ± 5.11
	Post 8	27.43 ± 5.08 ↓	26.22 ± 5.93	27.72 ± 5.37	25.01 ± 4.94 #
RLLLSJ (cm)	Pre	26.25 ± 4.73	25.82 ± 5.29	27.22 ± 3.93	27.54 ± 6.33
	Post 1	27.85 ± 6.47 ↑	25.73 ± 8.70	26.39 ± 6.80	25.43 ± 5.95 ↓
	Post 8	27.51 ± 6.06	24.89 ± 5.75	26.29 ± 5.55	24.75 ± 6.17
CMJ (cm)	Pre	27.56 ± 4.35	27.29 ± 4.81	28.10 ± 4.13	27.72 ± 5.34
	Post 1	28.91 ± 5.99 ↑	27.70 ± 5.77	30.10 ± 5.63	27.54 ± 5.36
	Post 8	28.88 ± 5.83 #	28.14 ± 5.57 #	28.10 ± 5.11	25.92 ± 5.16 #
RLLLCMJ (cm)	Pre	28.02 ±4.85	26.29 ± 5.47	27.63 ± 4.10	27.16 ± 4.82
	Post 1	29.42 ± 7.01	26.15 ± 5.60	28.81 ± 6.16	27.53 ± 5.87
	Post 8	28.84 ± 6.80	26.61 ± 5.88	28.32 ± 5.45	25.73 ± 5.26

WBV B: Whole body vibration bilateral; WBV U: Whole body vibration unilateral;
NWBV B: No Whole-body vibration bilateral; NWBV U: Whole body vibration unilateral; RLLLSJ: Right Leg plus Left Leg Squat Jump;
RLLLCMJ: Right Leg plus Left Leg Counter Movement jump
↑ significant increase between pre- and post-1
↓ Significant reduction between pre and post 1
Significant increase between pre- and post-8

Table 3
Changes in single leg SJ and CMJ performance.

		WBV B	WBV U	NWBV B	NWBV U
RLSJ (SLL)	Pre	13.39 ± 2.56	13.16 ± 2.47	14.23 ± 2.27	14.23 ± 3.22
	Post 1	14.45 ± 3.56 ↑	12.29 ± 3.03 ↓	13.44 ± 3.24	13.14 ± 3.14 ↓
	Post 8	14.05 ± 3.40	12.56 ± 3.10	13.37 ± 2.72	12.79 ± 3.51 ¥
	Post 1 – Pre	1.05 ± 1.54	0.870 ± 1.51	0.78 ± 2.49	1.08 ± 1.16
	Post 8 - Pre	0.66 ± 1.49	0.60 ± 1.52	0.68 ± 1.09	0.34 ± 1.30
LLSJ (WLL)	Pre	13.20 ± 2.07	12.62 ± 2.96	13.06 ± 1.83	13.30 ± 3.27
	Post 1	13.75 ± 3.31	12.28 ± 2.81	13.31 ± 3.33	12.37 ± 2.89 ↓
	Post 8	13.45 ± 2.70	12.32 ± 2.91	13.11 ± 2.69	11.95 ± 2.78
	Post 1 – Pre	0.54 ± 2.35	0.34 ± 1.04	0.24 ± 2.52	0.93 ± 1.07
	Post 8 - Pre	0.24 ± 1.81	0.29 ± 1.92	0.20 ± 0.91	1.35 ± 1.17
RLCMJ (SLL)	Pre	14.60 ± 2.53	13.52 ± 2.67	13.96 ± 2.53	14.03 ± 2.64
	Post 1	15.01 ± 3.24	13.34 ± 3.13	14.72 ± 3.12	14.20 ± 2.90
	Post 8	14.75 ± 3.38	13.80 ± 3.06	13.37 ± 3.08	13.13 ± 2.69 ¥
	Post 1 – Pre	0.41 ± 1.32	0.18 ± 1.47	0.76 ± 1.85	0.17 ± 1.35
	Post 8 - Pre	0.15 ± 1.67	0.45 ± 1.23	1.35 ± 1.17	1.07 ± 1.30
LLCMJ (WLL)	Pre	13.42 ± 2.51	12.76 ± 2.91	13.66 ± 1.92	13.09 ± 2.39
	Post 1	14.40 ± 3.89 ↑	12.80 ± 2.58	14.08 ± 3.26	13.31 ± 3.12
	Post 8	13.81 ± 2.72	12.81 ± 3.01	14.16 ± 3.73	12.59 ± 2.86 ¥
	Post 1 – Pre	0.98 ± 2.33	0.03 ± 0.93	0.42 ± 2.45	0.22 ± 1.19
	Post 8 - Pre	0.38 ± 1.58	0.01± 1.07	0.07± 1.31	0.50 ± 1.16

WBV B: Whole body vibration bilateral; WBV U: Whole body vibration unilateral;
NWBV B: No Whole-body vibration bilateral; NWBV U: Whole body vibration unilateral; RLSJ: Right leg squat jump; LLSJ: Left leg squat jump;
RLCMJ: Right leg counter movement jump; LLCMJ: Left leg counter movement jump
↑ significant increase between pre- and post-1
↓ Significant reduction between pre and post 1
¥ Significant decrease between pre- and post

Table 4
Changes in symmetry.

		WBV B	WBV U	NWBV B	NWBV U
	Pre	97.47 ± 10.28	95.06 ± 8.74	92.54 ± 8.84	94.34 ± 10.82
LSI (%)	Post 1	94.89 ± 7.04	100.55 ± 6.62 *	99.06 ± 5.67 *	95.26 ± 13.47
USJ	Post 1 – Pre	2.57 ± 11.45	-5.49 ± 9.58	-6.52 ± 9.04	-0.91 ± 8.54
	Pre	91.10 ± 6.29	94.08 ± 8.26	99.17 ±12.00	93.40 ± 10.37
LSI (%)	Post 1	94.84 ± 10.02	96.97 ± 8.86	95.99 ± 10.20	93.62 ± 10.06
UCMJ	Post 1 – Pre	3.74 ± 11.47	-2.89 ± 8.28	3.17 ±13.34	-0.21 ± 10.95

Values are expressed as the mean ± standard deviation
LSI: Limb symmetry index; USJ: Unilateral Squat Jump;
UCMJ: Unilateral Counter Movement Jump; WBV B: Whole body vibration bilateral;
WBV U: Whole body vibration unilateral; NWBV B: No Whole-body vibration bilateral; NWBV U: Whole body vibration unilateral;
*Significant difference between the pre- and post-intervention values

Significant interaction effect between condition and time was found on: **SJ**: $F_{(6)} = 5.454$, $p = .001$, $n^2 = .168$, power = .996; **CMJ**: $F_{(6)} = 13.788$, $p = .001$, $n^2 = .168$, power = 1.000; **RLSJ**: $F_{(6)} = 9.987$, $p = .001$, $n^2 = .270$, power = 1.000; **LLSJ:** $F_{(6)} = 3.929$, $p = .001$, $n^2 = .127$, power = .966; **RLCMJ**: $F_{(6)} = 5.308$, $p = .001$, $n^2 = .164$, power = .995.

Furthermore, significant main effect was found for condition on: **SJ**: $F_{(3)} = 6.125$, $p = .001$, $n^2 = .185$, power = .954; **CMJ**: $F_{(3)} = 4.008$, $p = .01$, $n^2 = .129$, power = .821; **RLSJ**: $F_{(3)} = 5.569$, $p = .002$, $n^2 = .171$, power = .933; **LLSJ**: $F_{(3)} = 4.342$, $p = .006$, $n^2 = .141$, power = .860; **RLCMJ:** $F_{(3)} = 10.626$, $p = .001$, $n^2 = .282$, power = .998, and **LLCMJ**: $F_{(3)} = 8.978$, $p = .001$, $n^2 = .250$, power = .994.

Also, significant main effect was found for time on: **SJ:** $F_{(2)} = 8.296$, $p = .001$, $n^2 = .235$, power = .953; **CMJ:** $F_{(2)} = 12.055$, $p = .001$, $n^2 = .309$, power = .993; **RLSJ**: $F_{(2)} = 4.911$, $p = .011$, $n^2 = .154$, power = .784; **RLCMJ**: $F_{(2)} = 5.290$, $p = .008$, $n^2 = .164$, power = .816.

Pairwise comparison revealed statistically significant differences on: **(i)** SJ: condition 1: pre vs post 1 (p = .001), and post 1 vs post 8 (p = .001); and condition 4 pre vs post 8 (p = .001), and post 1 vs post 8 (p = .001); **(ii)** on CMJ: condition 1: pre vs post1 (p=.027), pre vs post8 = .018; condition 2: pre vs post 8 (p =.022); condition 3: pre vs post1 (p = .001), post1 vs post8 (p = .001); condition 4: pre vs post 8 (p = .001), post1 vs post8 (p = .001), **(iii)** on RLSJ: condition 1: pre vs post 1 (p = .004); condition 2 pre vs post 1 (p = .016), and condition 4: pre vs post 1 (p = .001), pre vs post8 (p = .001), **(iv)** on RLCMJ: condition 3: post1 vs post8 (p = .001), condition 4: pre vs. post 8 (p = .001); and post1 vs post8 (p = .001), **(v)** on LLSJ: condition 4: pre vs post1 (p = .001) and pre vs post8 (p = .001), and (**vi)** on LLCMJ: condition 4: post1 vs post8 (p = .020).

The mean and standard deviation for each dependent variable is presented in table 2.

In addition, the RLSJ showed significant improvement in the WBV B protocol (p < .05) (table 3).

The LSI (%) significantly improved only in unilateral condition immediately after the intervention protocols (p < .05) (table 4).

DISCUSSION

The results revealed that bilateral WBV (WBV B) was the most effective condition on bilateral and unilateral SJ and CMJ performance. Specifically, a statistically significant improvement was revealed between the pre-test and post 1 measurement with percentage improvement of 8.54%, 4.90% on SJ and CMJ respectively, (p <.05) (Table 2). Further, an increase by 7.91% and 7.30% on RLSJ, and LLCMJ performance respectively on WBV B (p <.05) (Table 2). Consequently, our hypothesis that a BLD would occur during the assessment of jumping testing when using both limbs simultaneously was rejected. Also, it is mentioned that although a trend appeared in the rest of examined parameters (2.80%, 4.16% on RLCMJ and LLSJ, respectively), the improvement was obvious.

Unilateral WBV (WBV U) produced statistically significant improvement only on CMJ after a rest period of 8 min (Table 2). In contrast, the NWBVU showed a statistically significant reduction (p >.05) in CMJ on post 8 (Table 2). In addition, in WBV U there was a significant reduction in post 1 measurement during RLSJ performance - a finding that contradictsthe study of Taniguchi. (1998). However, it should be mentioned that WBV U group had much lower percentage reduction compared to the NWBV group.

A great number of studies have investigated the potential of WBV to enhance subsequent performance. During the stance on the vibration platform, the subject was under the effect of bilateral vibratory stimulation which transmitted through both lower limbs. The results of our study reinforce data by previous studies that reported an enhancement of bilateral SJ performance (Rhea, Kenn, 2009) and CMJ performance (Cormie, Deane, Triplett, McBride, 2006) following acute WBV power and strength performance, and also those byTorvinen et al. (2002) and Jacobs and Burns (2009) that found an increase in unilateral isometric knee extension force and unilateral knee isokinetic torque, respectively. Our results are in contrast with those of Dallas et al. (2014) who examined young competitive gymnasts and found that the jump height was improved in the vibration group during the CMJ and unilateral (single leg) SJ. Maybe the training status of our participants, and other factors such as the type of measurement, participants' level of physical activity, contraction type, etc., may be responsible for these discrepancies (Botton et al, 2015; Hakkinen et al, 1996; Howard & Enoka, 1991; Kuruganti et al, 2005; McCurdy et al, 2005; Ramirez-Campillo et al, 2015; Speirs et al, 2016). Further, our results failed to support data by Rejc et al. (2010) that favour unilateral training as a way to increase one's ability to generate maximal strength.

According to Shin et al. (2015) the positive effect of WBV, either bilateral or unilateral, may be attributed in the fact that WBV stimulates the Ia afferent tendency of muscle spindles. A continued stimulation of the stretch reflex mechanism activates motor neurons, increasing the sensitivity of primary endings. In addition, more muscles are recruited via the muscle spindles and neuron bundles (Ronnestad, 2004). As Cochrane and Stannard stated, the mechanism by which a higher jump height occurs in SLVJ height is due to the fact that each joint of the lower limbs is flexed for instant extension for a jump, and the stretch-shortening cycle of extended muscles activate the spinal reflex for a burst of concentric contraction, in which the stretch receptors are activated in the eccentric loading phase (Cochrane & Stannard, 2005).

Baseline values showed that there was no BLD under any of the conditions, neither on SJ nor on CMJ. However, on post 1 test, a significant improvement was found in jump height to the sum of the RL and LL in CMJ (RLLLCMJ) by WBV B ($p < .05$) (Table 2) with a percentage improvement of 4.99%. In contrast, there was a slight reduction in the aforementioned parameter on WBV U (-0.34% and -0.53% for RLLLSJ and RLLLCMJ, respectively). It is noteworthy that an improvement was observed only in the RLLLCMJ, as was the case with the execution of the bipedal CMJ under the WBV U condition (table 2). This finding partially supports findings by Shin et al. (2015) who found that SLVJ in both the unilateral and the bilateral group revealed a considerably larger improvement than that in the no vibration group. In addition, our results are in agreement with previous data by Bogdanis et al. (2019) who found that CMJ performance with both legs significantly improved equally when following a 6-week unilateral or bilateral lower limb plyometric training, and that unilateral plyometric training of the lower limbs may be more effective when exercises were performed with each limb separately. However, this finding is in contrast with the principle of specificity which states that unilateral training primarily enhances unilateral performance whereas bilateral training improves bilateral performance (Ramirez-Campillo et al, 2015; Speirs et al, 2016).

According to Bobbert el al. (1996), a possible explanation for this improvement on CMJ may be the fact that the countermovement jump provides the ability to participants to achieve greater joint moments at the start of push-off. Therefore, joint moments were greater over the first part of the range of joint extension in CMJ, so that more work could be produced than in SJ. According to simulation results, storage and reutilization of elastic energy could be ruled out as an explanation for the enhancement of performance in CMJ over that in SJ. The crucial contribution of the countermovement seemed to be that it allowed the muscles to build up a high level of active state (fraction of attached cross-bridges) and force before the start of shortening, so that they were able to produce more work over the first part of their shortening distance.

In our study there was no obvious asymmetry between the two lower limbs (<10%). An LSI ≥ 90% should be considered in the normal range, therefore an asymmetry exists if there is > 10% difference between the two lower limbs (O'Donnell, Thomas, Marks, 2006). However, asymmetry decreased significantly with WBV U at USJ but not in the WBV B (Table 4), while there was an improvement trend in UCMJ. In addition, an improvement trend was observed in UCMJ with both WBV B and WBV U. This finding adds to the previous data by Shin et al. (2015) who stated that WBV U improved symmetry. The magnitude of the asymmetry may be affected by the type and volume of activity in which the athlete is involved (Hart et al, 2016), which was not taken into account in the present study. In addition, the lack of obvious asymmetry is probably due to the fact that our sample consisted of former gymnasts and also to the fact that the vast majority of exercises performed with the lower limbs are performed using both legs, with the sole exception of a small number of exercises on the balance beam. Nevertheless, this finding is in agreement with the data provided by Bailey et al. (2015) who reported that the presentation of asymmetry is related to be task specific particularly in weaker athletes. However, our results could not be generalized because they refer only to former gymnasts. In this concept, further study is recommended in active gymnasts so that other parameters such as dominant foot, level of sport, etc. could be considered.

CONCLUSION

WBV brings significant improvement in jump height on bilateral and unilateral squat jump and counter movement jump. Bilateral whole-body vibration was the most effective condition on bilateral and unilateral squat jump and counter movement jump performance. In contrast, the unilateral whole-body vibration condition significantly improves lower limbs symmetry during SJ performance.

The findings of the present study have practical applications. Gymnasts should engage in lower extremity training mainly with bipedal exercises, while in cases where technical exercises are performed with one leg, strengthening the other limb using the method of vibration is recommended.

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