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Short-term effect of whole-body vibration training on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts

Tsopani Despina [a], Dallas George [a,*], Tsiganos George [a], Papouliakos Sotiris [b], Di Cagno Alessandra [c,d], Korres George [e], Riga Maria [f], Korres Stavros [e]

[a] *University of Athens, Department of Physical Education and Sport Science, Greece*
[b] *University of Athens, G. Gennimatas Hospital, Greece*
[c] *Department of Physical Education and Sport Science, University of Rome "Foro Italico", Piazza Lauro De Bosis, 15-00194 Rome, Italy*
[d] *Department of Medicine and Health Science, University of Molise, Via F. De Sanctis, Italy*
[e] *University of Athens, Hippokratio Hospital, Greece*
[f] *Democritus University of Thrace, University Hospital of Alexandroupolis, Greece*

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The purpose of this study was to examine whether whole-body vibration (WBV) training results in short-term performance improvements in flexibility, strength and balance tests in comparison to an equivalent exercise program performed without vibration. Eleven elite rhythmic gymnasts completed a WBV trial, and a control, resistance training trial without vibration (NWBV). The vibration trial consisted of eccentric and concentric squatting exercises on a vibration platform that was turned on, whereas the NWBV involved the same training protocol with the platform turned off. Balance was assessed using the Rhythmic Weight Shift (RWS) based on the EquiTest Dynamic Posturography system; flexibility was measured using the sit & reach test, and lower limb explosive strength was evaluated using standard exercises (squat jump, counter movement jump, single leg squat). All measurements were performed before (pre) immediately after the training program (post 1), and 15 minutes after the end of the program (post 15). Data were analyzed using repeated measures ANOVA was used with condition (WBV-NWBV) as the primary factor and time (pre, post 1, post 15) as the nested within subjects factor, followed by post-hoc pairwise comparison with Bonferroni corrections. Results confirmed the hypothesis of the superiority of WBV

* Corresponding author. Tel.: +30 2106643704; fax: +30 2107276028.
E-mail address: gdallas@phed.uoa.gr (D. George).

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training, especially in the post 15 measurement, in all flexibility and strength measures, as well as in a number of balance tests.

1. Introduction

Rhythmic gymnastics is a sport that combines elements of gymnastics, dance, and apparatus manipulation that require a great sense of balance. The integration of visual, vestibular and somatosensory components is used to maintain postural balance (Massion, 1994; Matheson, Darlington, & Smith, 1999). Postural control represents a complex interplay between the sensory systems, with the visual system to be the primary sensory information to maintain postural balance (Gaerlan, 2010; Gill et al, 2001). As one ages, the sensory systems used for balance decline (Cook & Woollacott, 2000; Ricci, Goncalves, Coimbra, & Coimbra, 2009). Although, optimal control of postural sway is achieved during late adolescence and maintained until about the age of 60 years (Liaw, Chen, Pei, Leong, & Lau, 2008), younger adults use distinct patterns of response and strategies to maintain their balance (Ricci et al., 2009), which are not the same as in other age groups (Choy, Brauer, & Nitz, 2003). The degree to which individuals rely on those information sources depends on task difficulty, cognitive load (Vuillerme & Nafati, 2007) and motor skill (Bressel, Yonker, & Kras, 2007; Schmit, Regis, & Riley, 2005). The suppression of one type of sensory information can be used to estimate the importance of that information to postural control and indicate how the central nervous system adapts and reorganizes information provided by the remaining sensory information (Teasdale, Stelmach, & Breunig, 1991).

A number of studies focused on the effects of whole-body vibration on postural control in Parkinson's disease. For example Haas, Turbanski, Kaiser, and Schmidtbleicher (2004) found that patients showed spontaneous improvements in balance depending on their postural disturbance and the test procedure. This is important in view of the findings by Buchman, Wilson, Luergans, & Bennett (2009) that vibratory thresholds are associated with mobility, supporting the link between peripheral sensory nerve function and mobility in the elderly. Finally in a meta-analysis conducted by Lau et al. (2011) it was concluded that whole body vibration is beneficial for enhancing leg muscle strength among older adults.

According to Kioumourtzoglou et al expert gymnasts can control their balance better than inexperienced athletes or novices and they relied mainly on visual cues to perform accurate complex movements (Danion, Boyadjian, & Marin, 2000; Kioumourtzoglou, Derri, Mertzanidou, & Tzetzis, 1997). Furthermore, the lateral sway of the center of pressure was smaller in dancers than in untrained subjects during unilateral leg movements performed while standing (Mouchnino, Aurenty, Massion, & Pedotti, 1992). Whole-body vibration (WBV) training requires standing on a vibration platform that generates to side to side alternating vertical sinusoidal mechanical vibration, and has been reported to be an effective method to enhance athletic performance (Cardinale & Wakeling, 2005; Rittweger, Beller, & Felsenberg, 2000) and improve muscle strength during a short time period (Cardinale & Bosco, 2003). However, Torvinen, Kannus, Sievanen, et al. (2003) reported that WBV training had no effect on the dynamic or static balance of the young subjects after either a 4-month or an 8-month treatment (Torvinen et al., 2002b). Despite the benefits on muscle strength, the efficacy of WBV on balance ability is still uncertain, and may be dependent on age (Ferber-Viart, Ionescu, Morlet, Froehlich, & Dubreuil, 2006) and physical conditions (Schuhfried, Mittermaier, Jovanovic, Pieber, & Paternostro-Sluga, 2005; van Nes, Geurts, Hendricks, & Duysens, 2004). Previous studies have suggested that WBV induces several neural and muscular changes, such as stimulation of human spindle endings (Burke, Hagbarth, Lofstedt, & Wallin, 1976a,b), and changes in biogenic amines (Ariizumi & Okada, 1985), which might lead to the improvement of contractile properties and muscle strength, and hence the balancing ability. It is therefore believed that the positive effects of WBV on the muscle performance (Bautmans, Van Hees, Lemper, & Mets, 2005; Schuhfried et al., 2005; van Nes et al., 2004) should help to improve balance (Okada, Hirakawa, Takada, & Kinoshita, 2001; Rudd, 1989). Further, previous studies showed that WBV training resulted in improved muscle strength or muscle performance (Bosco, Iacovelli, & Tsarpela, 2000; Delecluse, Roelants, & Verschueren, 2003; Gerodimos et al., 2010; Roelants, Delecluse, Coris, & Verschueren, 2004), increased explosive strength of lower limbs (Cochrane & Stannard, 2005; Cormie, Deane, Triplett, & McBride, 2006), and flexibility with or without stretching (Jacobs & Burns, 2009; Kinser, Ramsay, O'Bryant, & Ayres, 2008; Sands, McNeal, Stone, Russell, & Jemni, 2006; Sands et al., 2008). Most studies have examined either the vibration effect on flexibility in elite gymnasts (Kinser, Ramsay, O'Bryant, & Ayres, 2008; Sands et al., 2006, 2008) or the acute effect of a WBV program on muscle performance on female athletes (Sands et al., 2008). However, there are no reports on the efficacy of vibration training in elite rhythmic gymnasts. The purpose of this study was to examine whether WBV training results in acute improvements on balance, flexibility and lower limb explosive strength performance in elite rhythmic gymnasts as compared to a control, resistance training program performed without vibration.

2. Methods and materials

2.1. Subjects

Eleven elite rhythmic gymnasts, members of National teams competing at the 2012 Olympic Games in London (age 17.54 ± 0.52 years, body mass 51.27 ± 2.24 kg, height 170.54 ± 3.48 cm, and percent body fat 15.29 ± 1.22) volunteered to participated in the study. All participants had 10–12 years of training and competition experience, trained 6 days per week for 4 h per day, and had no previous experience with WBV.

2.2. Design

All participants performed two trials under two different conditions on two separate days, once with whole body vibration (WBV) and the other without WBV (NWBV). In order to compensate for any habituation due to intervention six subjects were measured in the order WBV-NWBV and the other five in the reverse order. One hour prior to the first trial, a familiarization session and anthropometric measurements were performed. The order of the trials was not randomized to avoid cross-contamination of the results.

The WBV trial was consisted of a single bout of WBV on the Galileo 900 platform (Galileo Fitness, Novotec, Germany). Before the trial, members of the research team introduced these participants to the protocol and safety features of Galileo 900. The amplitude of the device was controlled by adjusting the foot position from 1 to 3, with the higher the position, the greater the amplitude and the frequency of the vibration was set at 30 Hz and 2 mm amplitude.

According to other studies (Bosco et al., 2000; Cochrane & Stannard, 2005; Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006; Jacobs & Burns, 2009; Mahiu et al., 2006; Torvinen et al., 2002a,b) low frequencies and amplitudes are most effective in improving balance and muscular performance. The participants were exposed in WBV training using different execution forms of five exercises each one lasting for 15 s for a total time of 75 s. During all trials participants wore the same gymnastics shoes to avoid bruises and to standardize the damping of the vibration caused by the footwear. As there is evidence based WBV programs the training program in the present study was chosen based on similar protocols previously found to result in performance improvements (Delecluse et al., 2003; Torvinen et al., 2002a). The NWBV trial consisted of the same exercises used during WBV trial also on the Galileo platform but with the devices turned off. Participants wore similar sport shoes during both trials.

2.3. Measurements

A battery of tests was performed at baseline (pre), immediately after the end of the trial (Post1) and 15 min after the end of the trial (Post15). The participants were informed about the test procedures and were asked to perform all tests at maximum intensity. The participants had one familiarization session before each test. The maximum duration of the test battery was seven minutes.

2.3.1. Postural control

Postural Control was examined using the EquiTest computerized dynamic posturography system (NeuroCom International. Balance Master operator's manual. Clackamas, 2001). The Limits of Stability (LOS), and Rhythmic Weight Shift test (RWS) available on the EquiTest system were used in the present study. The LOS is a dynamic balance test performed in bipedal stance that measures the stable support in a controlled manner and quantifies the percentage of the maximum distance a person can intentionally displace their Center of Gravity (COG) without losing balance, stepping, or reaching for assistance (Nallegowda et al., 2003). In this test, each participant must shift COG from the center to each of the 8 peripheral targets: (forward (F), forward right (FR), right (R), backward right (BR), backward (B), backward left (BL), left (L), and forward left (FL). On command, the subject moves the COG cursor as quickly and accurately as possible forward 1 of the targets located on the limits of stability perimeter and then holds a position as close to the target as possible. The measured parameters are described in detail in Table 1.

The RWS test quantifies the subject's ability to rhythmically move the COG from left to right (lateral) and from forward to backward (anterior/posterior) between 2 targets at three distinct speeds: slow, medium, and fast, with the subject's COG displayed on a screen as a cursor providing visual feedback. With the COG cursor, the subject is asked to follow an on-screen cue as it moved between the endpoints. The 2 measured parameters were the on-axis (intentional) COG velocity (the average speed (deg/sec) of the rhythmic movement along the specified direction) and the directional control (DCL) (comparison the amount of movement in the intended direction (toward the end line) to the amount of extraneous movement (away from the end line).

2.3.2. Flexibility and explosive strength test

Flexibility was assessed with the sit and reach test (S&R) using a Flex-Tester box (Cranlea, UK). Participant, sitting barefoot on the floor with legs out straight ahead, were instructed to lean forward slowly as far as possible, toward a graduated ruler held on the box from −25 to +25, without bending their knees and held at the greatest stretch for 2 s (Fagnani et al., 2006). The test was repeated twice with a rest period of 10 s (Cochrane & Stannard, 2005), and the best of the two trials was recorded to the nearest 1.0 cm for statistical analysis.

Explosive strength of lower limbs was assessed using the squat jump (SJ), the counter movement jump (CMJ) and single leg squat (right leg (RL) and left leg (LL). Vertical jump tests were conducted on the Optojump device (Microgate, Italy), which allows the measurement of contact and flying times as previously described by Bosco, Luhtanen, and Komi (1983). Before this test participants did two familiarization trials to ensure proper performance technique. The participants were instructed to perform two maximal trials, in all tests, with a rest period of 10 sec between trials and the best jump was considered for further statistical analysis.

Table 1
Description of the measured parameters.

a/a	Parameter	Description
1	Reaction Time (RT) (sec)	RT was defined as the time in seconds between the signal to move and the initiation of movement
2	COG velocity (MVL)	MVL was defined as the average speed of COG movement (expressed in degrees per second) between 5% and 95% of the distance to the primary endpoint
3	Directional Control (DCL)	DCL is a comparison of the amount of movement in the intended direction (toward the target) to the amount of extraneous movement (away from the target)
4	End Point Excursion (EPE)	EPE was defined as the distance of the 1est movement toward the designed target, expressed as a percentage of maximum LOS distance. The endpoint is considered to be the point at which the initial movement toward the target ceases
5	Maximum excursion (MXE)	MXE is the maximum distance achieved during the trial

2.3.3. Statistical analyses

According to the protocol described above the participants were tested under two different conditions on two separate days, the one including training with whole body vibration (WBV) and the other without WBV (NWBV). The test battery was the same in each condition and was repeated three times, (Pre, Post 1, Post 15 respectively). Data were analyzed using repeated measures ANOVA was used with condition (WBV-NWBV) as the primary factor and time (pre, post1, post15) as the nested within subjects factor The interaction between the two factors (condition X time) was also considered in the model. Significant effects of the factors or their interactions were tested through their *F*-values with the appropriate degrees of freedom that yield the corresponding *p*-values. The estimates of effect size are also reported through the corresponding η^2 values. This is an approximate measure of the proportion of the overall parameter variability attributable to the effect of the factor. If significant effects are detected then post-hoc pairwise comparisons with Bonferroni correction were performed. These involve comparisons of the three measurements within each condition as well as comparisons of the two conditions within each time point.

3. Results

All dependent variables were found with the Kholmogorov-Smirnov test not to deviate from normality. This allowed for the employment of parametric statistical tests and comparisons.

3.1. Balance tests

In the RWS test, there was a significant condition X time interaction effect on directional control slow in Forward Backward direction (RWSFB) ($F_{(2,20)} = 3.5$, $p = 0.05$, $\eta^2 = 23.2\%$). As shown in fig. 1, the participants had the same RWS performance in the pre measurement at both conditions (85.6 ± 1.4% vs 85.3 ± 3.3% for the WBV and NWBV conditions respectively, p = NS). In the WBV condition, participants retain their RWS at both post measurements, while in the NWBV condition RWS gradually decreased in both post measurements. As a result, at the post15 measurement the RWS performance was significantly higher in the WBV as compared to the NWBV condition (post 1: 84.0 ± 5.4% vs 82.5 ± 5.8%, p = NS post 15: 86.6 ± 1.2% vs 80.7 ± 9.6%, $p < 0.05$).

In terms of the LOS test, there was a very significant time effect on the Limits of Stability at End Point Excursion (LOSEPE) Left Forward variable ($F_{(2,20)} = 12.0$, $p < 0.001$, $\eta^2 = 54.5\%$). As fig. 2 shows, this effect is totally attributable to the significant decrease (↓) in the performance of the participants at the post 1 measurement in comparison to the pre measurement and a further significant decrease in the post 15 measurement. However this significant decrease was observed only in the NWBV condition (pre: 99.7 ± 10.5%, post 1: 92.9 ± 9.2%, $p < 0.05$, post 15: 86.1 ± 11.1%, $p < 0.05$) while in the WBV condition gymnasts managed to retain their performance (pre: 98.0 ± 11.2%, post 1: 94.8 ± 9.3%, p = NS, post 15: 92.1 ± 9.2%, p = NS).

In the LOS Maximum Excursion in Backward direction (LOSMXE B) there was a significant time effect ($F_{(2,20)} = 3.58$, $p = 0.046$, $\eta^2 = 23.1\%$), a significant condition X time interaction effect ($F_{(2,20)} = 3.51$, $p = 0.040$, $\eta^2 = 21.2\%$). In both conditions participants performed equally at the pre and post1 measurements. At the pre measurement the mean values for the WBV and NWBV conditions were 90.7 ± 8.4% and 90.0 ± 7.6% (p = NS) and at the post 1 measurement they were 90.2 ± 7.9% and

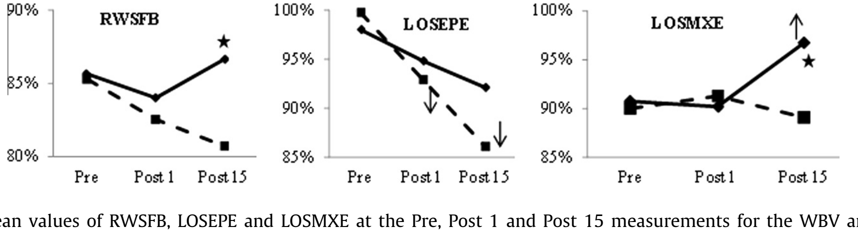

Fig. 1. Mean values of RWSFB, LOSEPE and LOSMXE at the Pre, Post 1 and Post 15 measurements for the WBV and NWBV conditions (*$p < 0.05$ between conditions. Significant differences between measurement times are shown with up (↑) or down (↓) arrows).

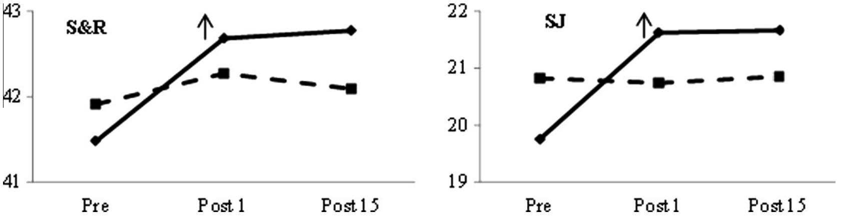

Fig. 2. Mean values of Sit & Reach (S&R) and Squat Jump (SJ) in cm at the Pre, Post 1 and Post 15 measurements for the WBV and NWBV conditions (*$p < 0.05$ between conditions. Significant improvements between measurement times are shown with up (↑) arrows).

91.3 ± 4.7% (p = NS). However, at the post 15 measurement the mean values were 96.7 ± 5.1% and 89.1 ± 5.3% ($p < 0.01$). This significant difference between the two conditions was due to the significant increase ($p < 0.01$) in the WBV condition between the post 1 and post 15 measurement (see fig. 1).

3.2. Sit & Reach (S&R) and Squat Jump (SJ)

In Sit & Reach test (S&R), there was a significant time effect $F_{(2,20)} = 30.8$, $p < 0.001$, $\eta^2 = 75.5\%$), and a significant condition X time interaction effect ($F_{(2,20)} = 15.6$, $p < 0.001$, $\eta^2 = 60.9\%$). The mean values for the WBV and NWBV conditions were: at the pre measurement 41.5 cm ± 3.4 cm vs. 41.9 cm ± 3.2 cm, at the post 1 measurement 42.7 cm ± 3.1 vs. 42.3 cm ± 3.3 and at the post 15 measurement 42.8 cm ± 3.6 vs. 42.1 cm ± 3.5 cm. Although there were no significant differences between the two conditions, there was a significant improvement of the WBV condition from the pre to the post 1 and post 15 measurements ($p < 0.05$).

Likewise, in Squat Jump (SJ), there was a significant time effect ($F_{(2,20)} = 11.5$, $p < 0.001$, $\eta^2 = 53.4\%$), and a significant condition X time interaction effect ($F_{(2,20)} = 5.9$, $p < 0.01$, $\eta^2 = 37.1\%$). The mean values for the WBV and NWBV conditions were: at the pre measurement 19.7 cm ± 3.8 cm vs. 20.8 cm ± 3.7 cm, at the post 1 measurement 21.6 cm ± 3.0 vs. 20.7 cm ± 4.3 and at the post 15 measurement 21.7 cm±3.0 vs. 20.8 cm ± 4.4 cm. Although there were no significant differences between the two conditions, there was a significant improvement of the WBV condition from the pre to the post 1 and post 15 measurements ($p < 0.05$).

In the WBV condition the athletes significantly improved at the post 1 and post 15 measurements. In contrast, the NWBV results showed that the participants' performance remained static in all tests.

3.3. Counter movement Jump, right leg (RL) and left leg (LL)

There was a significant effect of condition ($F_{(1,20)} = 13.6$, $p = 0.004$, $\eta^2 = 57.6\%$), and time ($F_{(2,20)} = 4.8$, $p = 0.020$, $\eta^2 = 32.5\%$) on CMJ. Furthermore, there was a significant condition X time interaction effect ($F_{(2,20)} = 5.3$, $p = 0.014$, $\eta^2 = 34.7\%$). As fig. 3 shows, the pre measurements were equal in the WBV and NWBV conditions (22.4 cm ± 3.4 cm vs. 21.6 cm ± 3.8, p = NS). Subsequently there was a significant improvement in the post 1 measurement for the WBV condition (23.5 cm ± 3.4 cm, $p < 0.05$), while for the NWBV condition there was no improvement (21.5 cm ± 3.8 cm, p = NS). As a

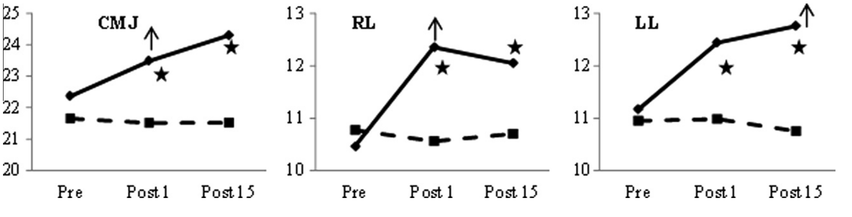

Fig. 3. Mean values of Counter Movement Jump (CMJ), Right Leg (RL) and Left Leg (LL) in cm at the Pre, Post 1 and Post 15 measurements for the WBV and NWBV conditions (*$p < 0.05$ between conditions. Significant improvements between measurement times are shown with up (↑) arrows).

result in the post 1 measurement there was a significant difference between the two conditions ($p < 0.05$). This difference is even greater in the post 15 measurement (24.2 cm ± 2.8 cm vs. 21.5 cm ± 3.8, $p < 0.01$).

For RL, there was also a significant effect of condition ($F_{(1,20)} = 7.4$, $p = 0.022$, $\eta^2 = 44.2\%$), time ($F_{(2,20)} = 14.4$, $p < 0.001$, $\eta^2 = 59.0\%$) and condition X time interaction ($F_{(2,20)} = 25.9$, $p < 0.001$, $\eta^2 = 72.2\%$). The pre measurements were equal in the WBV and NWBV conditions (10.5 cm ± 1.3 cm vs. 10.8 cm ± 1.7, p = NS). Subsequently there was a significant improvement in the post 1 measurement for the WBV condition (12.4 cm±1.7 cm, $p < 0.05$), while for the NWBV condition there was no improvement (10.6 cm ± 2.0 cm, p = NS). As a result in the post 1 measurement there was a significant difference between the two conditions ($p < 0.01$). The same pattern is revealed in the post 15 measurement (12.1 cm ± 1.8 cm vs. 10.7 cm ± 1.6, $p < 0.01$).

The same significant effects of condition ($F_{(1,20)} = 12.1$, $p = 0.006$, $\eta^2 = 54.8\%$), time ($F_{(2,20)} = 4.4$, $p = 0.026$, $\eta^2 = 30.6\%$) and condition X time interaction ($F_{(2,20)} = 13.2$, $p < 0.001$, $\eta^2 = 57.0\%$) was found in LL. The pre measurements were equal in the WBV and NWBV conditions (11.2 cm ± 1.3 cm vs. 10.9 cm ± 1.3, p = NS). For the post 1 the values were (12.4 cm±2.1 cm vs. 11.0 cm ± 1.7 cm, $p < 0.01$). In the post 15 measurement there was a significant difference between the two conditions (12.8 cm ± 1.9 cm vs. 10.8 cm ± 1.7, $p < 0.01$). There was a significant improvement in the post 15 measurement in comparison to the pre measurement ($p < 0.05$).

In contrast to the continuous improvement during the WBV condition resulting in the above significant differences, the performance in these three tests remained consistently low during the NWBV condition

4. Discussion

This is one of the first studies to examine potential beneficial effects of WBV on balance, flexibility and lower limb explosive strength in elite rhythmic gymnasts.

4.1. Balance

The only significant difference was revealed in LF directions, where the non-vibration condition resulted in significantly lower post-trial performances. Further, all subjects improved EPE irrespective of the intervention condition, which suggests a longer distance during the first movement toward the designated target. In addition, the only significant difference between the two conditions was in post 15 for the direction b (backward), where the vibration condition revealed an improvement compared to the non-vibration condition. However, all subjects improved the distance covered toward the designated target during each trial irrespective of the intervention condition. The only significant difference between the two conditions of Rhythmic Weight Shift (RWS) was in post 15, where an improvement was appeared after the WBV in contrast to the NWBV that reduced their ability to be "near the moving target".

Our results confirm previous finding of Mahieu et al. (2006) who examined the effect of WBV training in young skiers and found that most postural control values did not increase significantly except for the directional control during the limits of stability test and the left-right excursion of the RWS test. Further, the present results are in part congruence with those of Torvinen et al. (2002a,b), which found that 4 months of WBV training had no effect on the static or dynamic balance of young, healthy subjects. In addition, the present findings are in congruence with the results by Runge, Rehfeld, and Resnicek (2000), who found that WBV training has a beneficial effect in postural control in geriatric patients, and those by van Nes et al. (2004) in stroke patients with unilateral impairment, who found that WBV training improved their weight-shifting speed at the balance assessment. Therefore, it appears that WBV is effective for different ages and different groups of people.

4.2. Flexibility and explosive strength

A 3.64% increase was found in the flexibility of elite rhythmic gymnasts after the end of the vibration treatment. In addition, the benefits of vibration training last for at least 15 minutes after the end of vibration, whereas the NWBV did not increase the baseline (pre) values. This study showed that an acute bout of WBV induced a significant 9.52% and 9.73% mean increase in SJ performance immediately after and 15 min after the end of the vibration program, respectively. These values are significant higher from those of NWBV (−0.38% & 0.09%, respectively). It is evident that vibration was more proper method to increase explosive strength of lower limbs, compared to the traditional training method. Further, the improvement immediately after the end of vibration on CMJ in WBV was significant higher from those of NWBV (5.01% & −0.65%, respectively), whereas the percent improvement 15 minutes after the end of vibration was 8.63% and -0.60% between the WBV and NWBV, respectively. Similar results were found for single leg test (RL and LL test) immediately after the end of vibration. WBV revealed percent improvement by 18.06% & 11.37% whereas NWBV revealed percent improvement by −1.95% & 0.36%.

Explosive strength is an important factor in rhythmic gymnastics, and various stretch-shortening cycle (SSC) exercises (eg. jumping or plyometric exercises) have been used to improve this performance trait. Results of the present study support previous finding showing that an acute bout of WBV can improve athlete's flexibility (Cochrane & Stannard, 2005; Fagnani et al., 2006) and Jump height (Cochrane & Stannard, 2005; Fagnani et al., 2006; Kinser, Ramsay, O'Bryant, & Ayres, 2008). Specifically, the 3.42% improvement in the sit and reach test to those of Cochrane and Stannard (2005) and Fagnani et al. (2006) who found an improvement of 8.7% and 13% respectively. Further, our finding is in agreement with results of Kinser, Ramsay, O'Bryant, and Ayres (2008) who examined split flexibility in young gymnasts using a local vibration device. This flexibility's improvement following WBV suggests that the vibration exposure may have activated the Ia inhibitory interneurones of the antagonist muscle (Rothmuller & Cafarelli, 1995). We also found a significant 9.52% improvement in SJ performance.

Further, an improvement in all examined strength variables was observed in post-vibration treatment in VG (CMJ: 5.01%; RL: 18.06%; LL: 11.37%) whereas the corresponding percentage improvement in NVG were −0.65%, −1.95% and 0.36% respectively. The jump height of WBV during the CMJ and single leg squat jump (RL and LLg in the present study increased and was significantly different from that observed in NWBV immediately after and 15 min after the end of the trial. Our findings verify previous data which reported an improvement by 8.1–8.7% (Cochrane & Stannard, 2005; Fagnani et al., 2006). Further, the current finding of enhanced explosive strength of lower limbs is consistent with previous results that found acute improvements in vertical jump ability (Armstrong, Grinnell, & Warren, 2010; Bosco et al., 2000; Cormie et al., 2006; Dabbs, Munoz, Tran, Brown, & Bottaro, 2011).

5. Conclusions

The present findings confirm the hypothesis of the superiority of single bout whole body vibration in comparison to an equivalent exercise program performed without vibration in the short-term effect on performance in flexibility, strength and a number of balance tests in a sample that comprised high level rhythmic female gymnasts.

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