Effects of Whole-Body Vibration and Resistance Training on Muscular Performance in Young Adults

Samah A Moawd[1], Nermeen M. Abdelhalem[1], Ahmed F. Samhan[1], Waleed S. Mahmoud [1]

[1.] Assistant Professor of Physical Therapy and Health Rehabilitation Department, College of Applied Medical Science, Salman bin Abdulaziz University, Saudi Arabia.
elbaze111@yahoo.com

Abstract: Whole body vibration (WBV) training is rapidly gaining in popularity in health and fitness centers, as an alternative method to improve muscle performance. The aim of this study was to investigate the effects of 12 weeks program of WBV in combination with resistance training on muscular performance on healthy untrained adults. **Subjects:** A group of 40 young male adults; age 21.6 ±1.5 yrs were assigned into two equal groups: WBV group performed a WBV plus resistance training program (WBV + RES) and placebo group, performed the same resistance training program in absence of vibration (PL + RES). **Methods:** Participants were evaluated for anthropometry, isokinetic dynamometry and counter-movement jump (CMJ). After the intervention The data were collected and analyzed using a paired and un-paired t-test to compare the difference between the results within each group pre test and post test and between the two groups. **Results**: Significant differences ($p<0.05$) were observed in isometric strength, in both groups**.** There were significant differences between post test of WBV and placebo groups. Concerning CMJ, there was significant improvement in whole body vibration group only. **Conclusion:** The addition of WBV to resistance training for 12 weeks, in healthy untrained adults result in a larger muscular performance improvement compared to an identical exercise program in absence of vibration. So vibration exercise may be more effective and low time consuming tool to enhance muscular performance.

[Moawd S, Abdelhalem N, Samhan A, Mahmoud WS. **Effects of Whole-Body Vibration and Resistance Training on Muscular Performance in Young Adults.** *J Am Sci* 2014;10(1):67-73]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 14

Keywords: Muscle strength, Whole-body vibration, Resistance training, Muscle performance

1. Introduction

Whole-body vibration (WBV) is a neuromuscular training method that has recently been developed. In WBV training, the subject is standing on a vibrating platform, where the person is standing in a static position or moving in dynamic movements, that generates vertical sinusoidal vibration at a frequency between 35 and 40 Hz. These mechanical stimuli are transmitted to the body where they stimulate in turn sensory receptors, most likely muscle spindles (1-3).

Whole-body vibration (WBV) training has been receiving attention in recent years in the area of musculoskeletal research. The potential advantage of a vibration stimulus is that it may potentiate muscle activity while avoiding the safety and compliance issues associated with high intensity resistance training programs (4,5).

Sedentary adults need to be persuaded to exercise regularly at a moderate intensity (6,7). The challenge however is to overcome barriers related to exercise participation, including lack of compliance, poor weather conditions, time constraints, work obligations, and low levels of motivation, confidence and self-esteem. WBV offers a way of training with practical, physical and psychological advantages (8).

Despite the increasing scientific interest, there is still no clear consensus on the mechanisms by which vibration may enhance neuromuscular performance, and the results widely vary between studies (9-12). WBV is a current neuromuscular training method, which even at a low intensity provokes muscle length changes that stimulate the sensory receptor of the muscle spindle, thereby eliciting a tonic vibratory reflex, which is defined as a sustained contraction of a muscle subjected to vibration. WBV intervention exploits the body's innate reflex response to disruptions in stability in order to stimulate and enhance muscle strength and performance. Practically, WBV training has the advantage of overcoming some of the cited obstacles to exercise because it decreases overall training time and takes place indoors. More importantly, it offers a host of physical benefits such as improved muscular strength, flexibility, range of motion, bone density, and improved blood circulation (13, 14).

There are a few theories of how vibration stimuli can have effect on the neuromuscular system, such as a stimulation of Ia afferents via spindle, resulting in facilitating homonymous a-motor neurons and/or perturbation of the gravitational field during the time course of intervention (15-17).

2. Material and Methods

Study Design:

This study was a randomized controlled trial, performed over the period from December 2012 to

September 2013 at the physiotherapy outpatient clinic in college of applied medical sciences, Salman bin Abdullaziz University, Saudi Arabia

Subjects characteristics and general experimental design

A group of 40 young healthy male adults (age 21.6 ± 1.5 yrs; weight 64.8 ± 9.7 kg; height 174.0 ± 6.4 cm) volunteered to participate in the study. They were allocated into two equal groups; WBV group and placebo group. Subjects were excluded if they had any musculoskeletal, neurological problem or other chronic disease, involvement in a resistance-training program and any medication that could affect strength adaptations and adversely affect the results of the study.

Procedures:

Outcome measures:

All outcome measures were recorded pre and post intervention for both WBV and placebo groups. These were isometric strength of the knee and ankle extensor and flexor. In addition explosive strength was measured by means of a CMJ.

Evaluative procedures:

1. Physical examination

Weight was measured in underwear and without shoes with an electronic scale (SECA 861) to the nearest 0.1 kg, and height was measured barefoot with a telescopic height measuring instrument (SECA 225) to the nearest 0.1 cm. Body mass index was calculated as body weight in kg divided by the square of height in meters. All the anthropometric variables were measured in order, and then the same measurements were repeated one day after. The mean of the two measurements was used in the analyses (18).

2-Isokinetic dynamometry

Isometric muscle strength of the knee and ankle extensors and flexors was determined using a Cybex II (Lumex, Inc., Ronkonkoma, NY, USA) isokinetic dynamometer. A standardized warm-up of four submaximal muscle contractions was performed before each isokinetic test velocity. The angular velocity for the knee was 60°/s, and the ankle joint was tested at 30°/s. These tests were performed in the following order: knee and ankle and to improve clarity of the results and discussion, only the right leg was used for analysis. Isokinetic testing involved three cyclic (uninterrupted) maximal repetitions, performed twice. Between trials, Knee strength was assessed in the Cybex chair with the back positioned at 100°. The knees extended past the edge of the chair, with the lateral femoral condyle of the tested leg aligned with the axis of rotation of the dynamometer. The dynamometer arm was secured 5 cm above the medial malleolus. Knee-flexor and -extensor strength was measured from 85° to 10° of flexion. Ankle strength was measured with subjects lying prone with their knees were fully extended and stabilized. The tested foot was fixed to the dynamometer footplate, with the ankle maintained at 10° dorsiflexion. The lateral malleolus was aligned with the dynamometer axis of rotation with the tested leg was secured with a Velcro strap 5 cm below the patella. Ankle-flexor and -extensor strength was measured from 10° dorsiflexion to 20° plantar flexion. The Cybex was calibrated before testing, using known masses placed on the lever arm. A gravity correction factor (additional torque created by the mass of limb) was determined by measuring the mass of the limb through its range of motion before each test. The procedures for isokinetic testing were based on a review of literature and shown to be both valid and reliable (13). a 1-min rest period was imposed and participants were instructed before each trial to contract specific muscles as fast and as hard as possible and so verbal encouragement was provided during the test to help participants produce maximum efforts. Isokinetic testing of the knee and ankle flexors and extensors involved standardized body positioning. For all isokinetic tests, participants were strapped securely at the waist and chest and were instructed to fold their arms across their chest for each contraction and two stoppers were positioned to control joint range of motion (19, 20).

3-Countermovement jump test

A vertical counter-movement jump (CMJ) was used to assess lower-body explosive strength (also called power) after stretch shortening of the muscles [14]. 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 test was performed on an infrared light mat (ERGO JUMP Plus-BOSCO SYSTEM; Byomedic, SCP, Barcelona, Spain), recording the right time in milliseconds. The jump was repeated five times, and the mean value of the countermovement jump height (cm) was used for further analyses. The ICC for test-retest reliability of the power test was r = 0.96 (21, 22).

Testing took place in laboratory conditions in two sessions 48 h apart. Anthropometric measurements and isokinetic dynamometry were administered in the same day, while jumping performance was measured in the other session. The order was randomly chosen for each participant. In both testing sessions, prior to muscular assessment, participants completed a dynamic warm-up of 10 min composed of jogging, specific knee extension movements and stretching exercises. For each participant, all testing sessions were administered at the same time of the day and under the same environmental conditions. The subjects were asked to perform all the tests at maximal intensity.

Treatment procedures

The two groups trained for 12 weeks at a frequency of three times a week, with at least 1 day of rest between sessions. Each training session lasted 35–40 min, including warm-up, exercises, rest periods, and cool-down. At the beginning of each testing and training session, a 5-minute walking warm-up was performed. All participants completed a familiarization session for each test before the study began. All sessions were supervised and participation assessed. All participants were free to withdraw from the study at any time. If any adverse effects had occurred, the experiment would have been stopped and the Human Subjects Review Board would have been informed. However, no adverse effects occurred, and so the data of all the participants were available for analysis. The detailed training regimen was as follows:

A. Exercises on vibrating platform

In a standing position on a synchronous (also called vertical) vibrating platform (Fitvibe Excel; N.V. Gymna Uniphy, Bilzen, Belgium), holding on the device handle, participants performed several sets of exercise with rest intervals(table 1) The exercise time was distributed as follows: 16% of total exposure time isometric half squat, 16-50% of total exposure time dynamic half squat at a 1:1 cadence, 50-66% of total exposure time calf raise, 66-100% of total exposure time one-legged half-squat, alternatively with both legs. Therefore, we developed a 12-week WBV program with a low training load at the beginning but slowly progressive according to the overload principle. In WBV group, the frequency was increased from 35 to 40 Hz, peak-to-peak displacement from 2.5 to 5 mm, and number of sets from 6 to 10. Participants in PL group performed identical exercises on the vibrating platform without vibration. In the PL condition, the subjects, standing on the platform, could hear the motor and experienced tingles on their foot soles, but the acceleration of the platform was only 0.4 *g* with negligible amplitude. All the participants were asked to wear the same gymnastic shoes during all the sessions to standardize the damping of the vibration due to the footwear.

The training volume increased systematically over the 12-wk training period by increasing the duration of one vibration session, the number of series of one exercise, or the number of different exercises. The training intensity was increased by: shortening the rest periods or by increasing the amplitude (2.5–5 mm) and/or the frequency (35–40 Hz) of the vibration (20).

Table 1. Description of WBV program

	0 week	4 weeks	8 weeks
Volume			
Number of exercise	4	4	4
Duration of vibration exposure (s)	30	45	60
Intensity			
Rest period between exercise(s)	60	30	5
Amplitude (mm)	2.5	2.5-5	5
Frequency (Hz)	35	35-40	40

B-Resistance training

Immediately after the exercises on the vibrating platform, all participants performed moderate to high resistance training half-squat exercises on a Smith's machine, followed by poly metric jumping-type exercises. The load of the resistance training exercises (dynamic half-squat) was slowly progressive, starting at the 55% of one repetition maximum (1RM) and then was increased to 85% of 1RM. 1 RM loads were newly calculated after the first 6 weeks of the training program. After the half-squat exercises, participants performed poly metric exercises: (a) box jumps, landing on a 48 cm mat bench; and/or (b) resisted jumps with 5–10% 1RM. Participants were asked to perform all the exercises at the highest speed. The rest time between repetitions was 2–3 s, and 3 min between sets as well as between different exercises (23).

Testing took place in laboratory conditions in two sessions 48 h apart. Anthropometric measurements and isokinetic dynamometry were administered in the same day, while jumping performance was measured in the other session. The order was randomly chosen for each participant. In both testing sessions, prior to muscular assessment, participants completed a dynamic warm-up of 10 min composed of jogging, specific knee extension movements and stretching exercises. For each participant, all testing sessions were administered at the same time of the day and under the same environmental conditions. The subjects were asked to perform all the tests at maximal intensity.

Data Analysis:

All statistics were calculated by using the statistical package of social sciences (SPSS) version 16. Descriptive statistics (mean and standard deviation) were computed for all outcomes measures which are isometric strength of the knee and ankle extensor and flexor *in* (n ·m) and CMJ in (mm). Paired t- test was applied to determine changes between pre and post test for isometric of strength the knee and ankle extensor and flexor in both groups. Unpaired t-test was applied for age, weight, and height of patients between WBV and placebo groups. A value of $P < 0.05$ was considered statistically significant.

3. Results

There were no significant differences between patient characteristics (age, weight, and height) between two groups of the study before the program. WBV group the mean age, weight and height of the subjects was 21.8± (2.3) years, 65.4± (7.4)1kg, and 174.2 ± (3.8)cm respectively as shown in table 2. For placepo group the mean age, height, and weight of the subjects was 21.4± (4.7)years, 64.2 ± (8.3) kg, and 173.8 (5.9)cm respectively as shown in table 2:-

Table 2: Demographic characteristics of WBV and PL groups.

Parameter	WBV group Mean± (SD)	PL group Mean± (SD)	P-value
Age (yrs)	21.8± (2.3)	21.4± (4.7)	0.702
Weight (kg)	65.4± (7.4)	64.2 ± (8.3)	0.639

1- Knee extension isometric strength:

There were significant differences between pre and post test in WBV and PL groups for Knee extension isometric strength also there were significant differences of knee isometric strength between post test of both groups as shown in table 3.

Table 3: Isometric strength of knee extension (Mean±SD) between two groups

Isometric strength (n.m)	Knee extensor		
	Pre	**Post**	**P-value**
WBV group	155.4± 40.4	186.3±36.9	0.000
PL group	153.4± 43.2	180. 2± 39.5	0.003
P value	P>0.05	0.03	

* Level of significant p< 0.05

2- Knee flexion isometric strength:

There were significant differences between pre and post test in WBV and PL groups for Knee flexion isometric strength also there were significant differences of Knee isometric strength between post test of both groups as shown in table 4.

3- Ankle planter-flexion isometric strength:

There were significant differences between pre and post test in WBV and PL groups for ankle planter-flexion isometric strength also there were significant differences between post test of both groups as shown in table 5.

Table 4: Isometric strength of knee flexion (Mean±SD) between two groups

Isometric strength (n.m)	Knee Flexor		
	Pre	**Post**	**P-value**
WBV group	120.4 ± 29.30	130.7 ± 22.9	0.000
PL group	127.3 ± 30.8	133.2 ± 34.6	0.02
P value	P>0.05	0.02	

* Level of significant p< 0.05

Table 5: Isometric strength of ankle planter-flexion (Mean±SD) between two groups

Isometric strength (n.m)	Ankle planter-flexion		
	Pre	**Post**	**P-value**
WBV group	114.3± 20.8	133.2±21.2	**0.000**
PL group	115.5±24.2	128.1± 27.3	**0.003**
P value	P>0.05	0.03	

* Level of significant p< 0.05

4- Ankle dorsi- flexion isometric strength:

There were significant differences between pre and post test in WBV and PL groups for ankle dorsi-flexion isometric strength also there were significant differences between post test of both groups as shown in table 6.

Table 6: Isometric strength of ankle dorsi- flexion (Mean±SD) between two groups

Isometric strength (n.m)	Ankle dorsi- flexion		
	Pre	**Post**	**P-value**
WBV group	44.3± 6.4	48.4± 4.7	0.000
PL group	43.3± 9.3	45.1± 8.0	0.002
P- value	P>0.05	0.001	

* Level of significant p< 0.05

5- Counter-movement jump

There were significant differences of score between pre and post test in WBV group regarding CMJ but no significant differences of score between pre and post test in PL group. Also there were significant differences between post test of both WBV and PL groups for CMJ as shown in table 7.

Table 7: Counter-movement jump (Mean± SD) between two groups.

CMJ (mm)	Pre	Post	P- value
WBV group	249.3±25.5	267.8±28.3	0.000
PL group	246.1±23.4	250.6±22.7	0.06
P- value	P>0.05	0.001	

* Level of significant p< 0.05

4. Discussions

This study was designed to test whether the combination of WBV and resistance training has any additional effect on muscular performance compared to an identical exercise program without vibration. The results of this study clearly indicate that there were statistically significant differences between groups, pre and post test with superiority improvement in WBV group more than the PL group. This confirms the effectiveness of the WBV interventions on muscular performance and explosive strength.

Regarding the Descriptive statistics for the participants' demographic data in the WBV and PL groups; the insignificant differences between patient characteristics (age, weight, and height) between two study groups may be attributed to the homogeneity of the sample. It was observed that the WBV group was superior regarding Isometric strength of both knee (extension – flexion) and ankle (planter- dorsi flexion). These results may be attributed to the use of vibration exercise. It is likely that WBV elicits a biological adaptation that is connected to the neural potentiation effect, similar to that produced by resistance and explosive strength training. Recently, it was suggested that resistance training might alter the connectivity between corticospinal cells and spinal motoneurons. Interneurons in the spinal cord receive input from afferent fibers, descending fibers, and the fibers of other interneurons and ultimately influence the activity of motoneurons. The interaction of these various inputs onto interneuronal circuitry determines which motor units are recruited during movement. The activation of motoneurons via both corticospinal cells and spinal reflex pathways is partly determined by the manner in which supraspinal and segmental elements interact to set the excitability states of interneuronal circuits. An important consequence of this arrangement is that the same corticospinal output can activate different populations of motoneurons dependent on the state of circuitry within the spinal cord (23,24).

Sale (25) suggested that full activation of the muscle may lead to motor unit fatigue and consequently to strength gain. EMG recordings show the impact of WBV on muscle activity, it is likely that a prolonged period of standing on the WBV platform results in full motor unit activation. However, a 4-min WBV session could be too short to induce motor unit fatigue. Generally, the adaptations that occur in the neuromuscular system with chronic levels of physical activity can be assessed in a variety of ways. The most common approach is to distinguish between the neural and intramuscular mechanisms that influence muscle power and strength. It is well known that the input of proprioceptive pathways (Ia, IIa, and probably Ib afferents) is used in the production of force during isometric contractions. During WBV, these proprioceptive pathways are strongly stimulated. The vibratory stimulus is activating the sensory receptors that results in reflexive muscle contractions. The increase in isometric strength after 12 wk of training, and thus after extensive sensory stimulation, might thus be the result of a more efficient use of the positive proprioceptive feedback loop in the generation of isometric force (26, 27).

In agreement with Ronnestad (28) who concluded that vibration group showed significant improvement in CMJ, but there was no significant difference between groups in. relative jump height increase.Several studies have investigated the long-term effect on muscle strength in healthy persons after WBV training with a variety of results. In one study by Torvinen et al. (29) isometric muscle strength and vertical jump height increased after 4 months of WBV training, but after 8 months of WBV training only vertical jump height increased but not muscle strength. The reason to the lack of increase in muscle strength after 8 months could be that the vibration intensity was too low to get further neuromuscular adaptation and that the control group also performed better in the repeated strength test. While De Ruiter et al. (30) could not find any improvements in muscle strength after 11 weeks of WBV training in healthy physically active students. More marked effect on muscle strength after WBV training was shown when the training intensity was progressive. Delecluse et al. (31) compared WBV training with RT in a placebo controlled study in young healthy women and found that WBV training could increase muscle strength to the same extent as resistance training. This was later confirmed in several studies including postmenopausal women (32, 33).

Komi [34] showed the involvement of the stretch reflex and thus Ia afferent input in the force potentiation during a stretch-shortening contraction (SSC) in the CMJ. The stimulation of the sensory receptors and the afferent pathways with WBV might thus lead to a more efficient use of the stretch reflex. It is suggested that the tonic vibration reflex induced a reflex sensitization of the muscle spindles and increased a facilitation of the reflex action on the motor neuron pool. The sensory stimulation that is the basis of muscle activity in WBV training seems hereby crucial in the facilitation of the SSC as resistance training with little sensory stimulation did not improve the CMJ (35). Whatever may be the behind mechanisms behind, it is clear that WBV elicits muscle contraction involuntarily and it induces strength gain in previously untrained subjects within a short period of time and without much effort. The subjects did not experience the WBV training as exhausting training sessions. This suggests that WBV has a great potential in a therapeutic context where it may enhance muscular performance in patients and elderly, who are not attracted to or who are not able to perform standard exercise programs. It may also enhance performance of athletes in a stretch-shortening cycle as suggested by the results on the CMJ [36-39]. In conclusion, the data in this study suggest that 12 weeks of intervention of WBV in addition to resistance training can increase muscle performance and the explosive strength. The data also suggest that intervention with resistance training alone can increase muscle strength without significant effect on explosive strength.

Acknowledgment

The authors express their thanks to the Deanship of Scientific Research, Salman bin Abdulaziz University, Alkharg, Saudi Arabia for sponsoring this study, project number /9S/33.

Corresponding Author:
Dr. Samah Alsaid
Assisstant Professor of physical therapy and health rehabilitation department College of Applied Medical Science, Salman bin Abdulaziz University, Saudi Arabia
E-mail: elbaze111@yahoo.com

References

1. LANCE, J. W., D. BURKE, and C. J. ANDREWS. The reflex effects of muscle vibration. In: New Developments in Electromyography and Clinical Neurophysiology, J. E. Desmedt (Ed.). Basel: Karger, 1973;pp. 444–462.
2. Ahlborg L., Andersson C. and Julin P. Whole-Body Vibration Training Compared with Resistance Training: Effect on Spasticity, Muscle Strength and Motor Performance in Adult with Cerebral Palsy. J Rehabil Med 2006 ; 38: 302-308.
3. Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003; 31: 3 _7
4. Dolny DG, Reyes GFC. Whole body vibration exercise: training and benefits. Curr Sports Med Rep 2008; 7:152–7.
5. Cecilie Fjeldstad, Ian J. Palmer, Michael G. Bemben, Debra A. Bemben. Whole-body vibration augments resistance training effects on body composition in postmenopausal women. Maturitas 2009; 63: 79–83
6. Rees S., Murphy A. and Watsford M.Effects of Whole-Body Vibration Exercise on Lower-Extremity Muscle Strength and Power in an Older Population: A Randomized Clinical Trial. Phys Ther. 2008 Apr;88(4):462-70.
7. Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. Sports Med 2005;35(1):23–41.
8. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole body vibration exercise in man. Clin Phys 2000;20:134-142.
9. Rehn B, Lidstrom J, Skoglund J, Lindstrom B. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. Scand J Med Sci Sports 2007;17(1):2–11.
10. Cardinale M, Rittweger J. Vibration exercise makes your muscles and bones stronger: fact or Wction? J Br Menopause Soc 2006; 12(1):12–18.
11. Harris CM. Introduction to the handbook. In: Harris CM, editor. Shock and vibration handbook. New York: McGraw-Hill,: 1996: 1.1-1.27
12. Cardinale M, Bosco C (2003): The use of vibration as an exercise intervention. Exerc Sport Sci Rev.; 31(1) : 3-7.
13. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. Int J Sports Med 2004; 26:662-668.
14. Aayesha Kholvadia, Maryna L Baard. Whole body vibration improves body mass, flexibility and strength in previously sedentary adults. S Afr J SM 2012; 24(2):60-64.
15. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003; 35(6):1033–1041.
16. Cardinale, M. and Wakeling, J. Whole body vibration exercise: Are vibrations good for you? British Journal of Sports Medicine 2005; 39, 585-589.
17. Marı´n, PJ and Rhea, MR. Effects of vibration training on muscle strength: A meta-analysis. J Strength Cond Res 2010; 24(2): 548–556.

18. Prabhdeep K., Radhakrishnan E., Sankarasubbaiyan S., Rao R., Kondalsamy-S., Venkata T.; Digamber G. A comparison of anthropometric indices for predicting hypertension and type 2 diabetes in a male industrial population of chennal south india. Ethn Dis 2008.;18: 31–36.
19. Perrin DH. Isokinetic Exercise and Assessment.(1993): Champaign, Ill: Human Kinetics.
20. Rees SS, Murphy AJ, Watsford ML. Effects of whole-body vibration exercise on lower-extremity muscle strength and power in an older population: a randomized clinical trial. Phys Ther 2008; 88:462–470.
21. Markovic G., Dizdar D., Jukic I. and Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. J Strength Cond Res 2004; 18(3):551–555.
22. Osawa Y., and Oguma Y. Effects of whole-body vibration on resistance training for untrained adults: Journal of Sports Science and Medicine 2011;10, 328-337.
23. Artero EG, Espada-Fuentes JC, Argüelles-Cienfuegos J, Román A, Gómez-López PJ, Gutiérrez A. Effects of whole-body vibration and resistance training on knee extensors muscular performance. *European* Journal of Applied Physiology 2012*; 112(4):1371–1378.*
24. Carroll T., Riek S., and Carson R. The sites of neural adaptation induced by resistance training in humans. J. Physiol. 2002; 544:641–652.
25. Sale D. Influence of exercise and training on motor unit activation. Exerc. Sport Sci. Rev. 1987; 15:95–151.
26. Carroll T., Riek S., and Carson R. Neural adaptations to resistance training: implications for movement control. Sports Med. 2001; 31:829–840.
27. Enoka R. Neural adaptations with chronic physical activity. J. Biomech. 1997; 30:447–455.
28. Ronnestad BR. Comparing the Performance Enhancing Effects of Squats on a Vibration Platform with Conventional Squats in Recreationally Resistance-Trained Men. J Strength Cond Res 2004; 18(4):839-845.
29. Torvinen S, Kannus P, Sieva¨nen H, Ja¨rvinen TAH, Pasanen M, Kontulainen S, et al. Effect of four-month vertical whole bodyvibration on performance and balance. Med Sci Sports Exerc 2002; 34: 1523 _1528.
30. de Ruiter CJ, van Raak SM, Schilperoort JV, Hollander AP, de Haan A. The effects of 11 weeks whole body vibration training on jump height, contractile properties and activation of human knee extensors. Eur J Appl Physiol2003; 90: 595 -600.
31. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003; 35: 1033 -1041.
32. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sports Med 2004 ; 25: 1 -5.
33. Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J Bone Miner Res 2004; 19: 352 -359.
34. Komi P. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. J. Biomech. 2000; 33:1197–1206.
35. Abercromby AF, Amonette WE, Layne CS, Mcfarlin WE, and Layine CS. Variation in neuromuscular responses during acute whole-body vibration exercise' Medicine and Science in Sports and Exercise 2007; 39: 1642-1650.
36. Romaiguere P., Vedel J., and Pagni S. Effects of tonic vibration reflex on motor unit recruitment in human wrist extensor muscles. Brain Res. 1993; 602:32–40.
37. Fagnani F., Giombini A., Di Cesare A., Pigozzi F. & Di Salvo V. The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. American Journal of Physical Medicine and Rehabilitation. 2006; 85(12). 956-962.
38. Roelants M., Delecluse C., Goris M. and Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. International Journal of Sports Medicine. 2004; 25(1): 1-5.
39. Cochrane D.J. & Stannard S.R. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. British Journal of Sports Medicine.2005; 39(11) 860-865.

1/12/2014