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Original Article

The adaptations in muscle architecture following whole body vibration training

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Abstract

Objective: This study aims to investigate the effect of 8-week whole-body vibration (WBV) added to conventional training on muscular architecture, dynamic muscle strength and physical performance compared to controls in young basketball players. **Methods**: Sixteen young basketball players between the ages of 14-16 years were randomly assigned to whole body vibration group (VG) or control group (CG). Both groups were trained with a conventional program. Pennation angle (PeA), fascicle length and muscle thickness of Rectus Femoris (RF) and Vastus lateralis were measured by ultrasonography. Isokinetic dynamic muscle testing at 180 °/s and 60°/s, squat jump (SJ) and flexibility were evaluated before and after 8 weeks of training programs. Primary outcome measure was the fascicle length. **Results**: Fascicle length of RF, SJ height and flexibility increased significantly within VG compared to pretraining ($p<0.05$). SJ height increased in VG compared to CG significantly following training ($p<0.05$). PeA, fascicle length, muscle thicknesses, strength and flexibility did not differ between groups. **Conclusion**: Eight weeks of WBV training improved fascicle length of RF, SJ height, and flexibility compared to pre-training. Addition of WBV to conventional training did not cause improvement in muscle architecture, strength and flexibility compared to conventional training alone.

Keywords: Pennation Angle, Jump, Basketball, Vibration, Muscle

Introduction

Sport of basketball requires intermittent explosive actions including jumps, quick and repeated accelerations, and changes in movement direction[1]. The leg strength was found to be related with speed, jumping, agility, and flexibility that are the determinants of success in basketball[2]. Therefore, it is necessary to establish appropriate training programs to maximize muscle strength.

As one of exercise modalities to improve physical performance, exposure of the body to mechanical vibration under static or dynamic positions has emerged as a training method. Improvements after WBV training were achieved in vertical, squat[3-6] and counter movement jumps[3,4,7,8], dynamic muscle strength[3,5,9], sprint velocity, flexibility[4], and agility[1] and morphological characteristics of skeletal muscle, such as the muscle mass[7,10] in various sports[11] and in basketball[1]. The respecting biomechanical vibration components such as frequency, peak to peak displacement, and peak acceleration[12] offered through a vibrating platform or device, must be individually adjusted for the individual who is in contact with the base of the platform[13]. The neuromuscular responses are determined either in the loaded or unloaded positions. Generally, subjects can be exposed to WBV while performing exercises, hold postures, sitting, or lying down[14]. Gains in the power and strength following WBV could be essentially induced by neuromuscular activation[5]. WBV induces "tonic vibration reflex" that is carried from tendons by muscle spindle Ia afferent neurons resulting in activation of large motor neurons and the muscle fibers (Figure 1)[5,8,15].

The strength and power of the muscles are significantly

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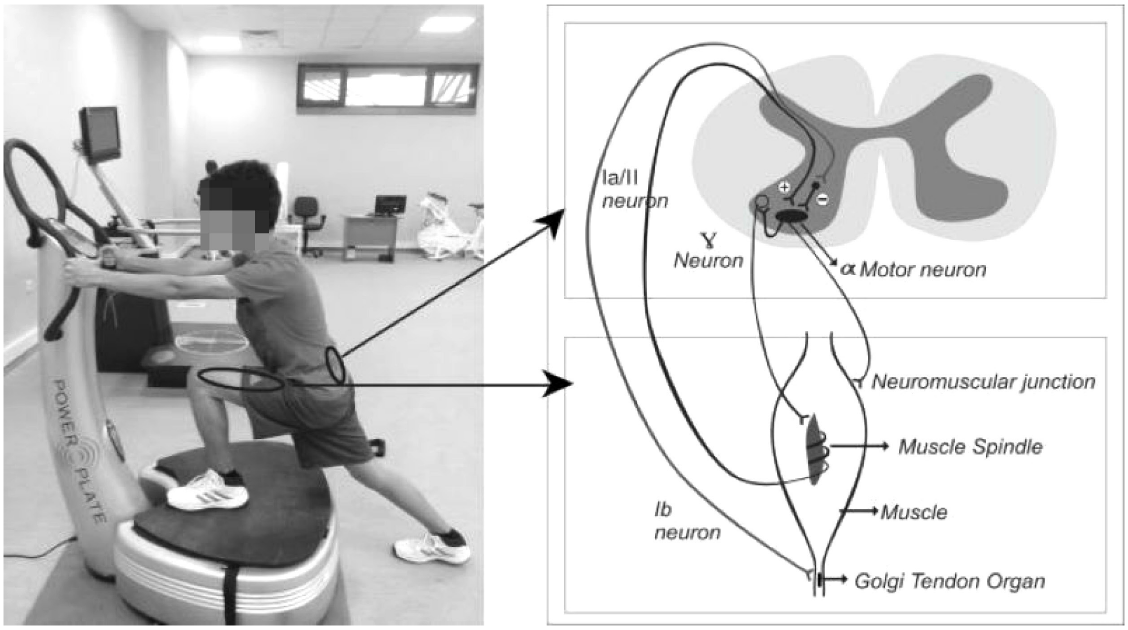

Figure 1. A basic scheme for the mechanism of vibration reflex.

influenced from the distribution of fiber type, neural drive, and muscle architecture[16]. The geometrical arrangement of the structural components of the muscle substantially affects its functional properties[17]. As the size and quality of muscle, moment arm, length of fascicles, and pennation angle (PeA) increase, greater force and power are produced[17-19]. Vertical jump and sprinting performances were found to be related with architectural properties[19].

Ultrasonography has been used widely for the determination of muscles architecture. Furthermore, it helps to quantify the training induced changes in muscle architecture such as the muscle thickness, pennation angle, fascicle length and echogenicity[20]. Musculoskeletal ultrasonography is a safe and low-cost method. It was found to be reliable and valid, as compared with some superior techniques, such as magnetic resonance imaging and computerized axial tomography.

It was demonstrated that the resistance training raised fascicle thickness and PeA, as well as it increased force production[6,17,21]. However, the properties of optimal mechanical stimuli that influence the fascicle length remain as a question. Although WBV training has been widely used for explosive athletes, the effect of WBV training on muscle architecture has not been investigated so far. The aim of this study is to detect changes in extensor muscles of the lower limb with respect to muscle thickness, fascicle length and PeA measured by ultrasonography and dynamic muscular strength and physical performance with respect to controls when WBV training is added to conventional strength training in young basketball players.

Materials and methods

The study was conducted as a parallel designed, randomized controlled single-blinded study. Two groups were formed, WBV group (VG) and the control group (CG). Random allocation was made by the computer-generated random numbers and sequenced by non-transparent sealed envelopes. Participants were allocated 1:1 ratio. Participants were enrolled and assigned to trainings. Participants were trained for 8 weeks. These groups were dependent variables. Participants were evaluated at the beginning and the end of the training in Faculty of Sports Sciences of Pamukkale University. PeA, fascicle length, and muscle thickness were used to detect architectural changes. Fascicle length was the primary outcome measure. Additionally, muscle strength, squat jump height, and flexibility were considered as independent variables, all of which were the secondary outcome measures.

Subjects

Sixteen young male Caucasian licensed amateur basketball players between 14-16 years old participated voluntarily in this study. They were randomly and equally distributed into 2 groups, VG and CG. The mean training ages of the players were 5.88±1.25 years for VG, and 4.63±1.77 years for CG. The age, height, body mass, body mass index, squat jump height and lower extremity strength were not significantly different between groups at the beginning of the study ($p>0.05$) (Table 1). Exclusion criteria were the presence of

Table 1. Characteristics of basketball players.

	Vibration Group (n:8)	Control Group (n:8)	p
Age (years)	15.25±0.46	15.88±0.35	0.734
Height (cm)	175.5±8.55	174.0±13.06	0.790
Weight (kg)	72.24±6.25	76.55±13.70	0.431
Body mass index (kg/m^2)	23.51±2.13	25.49±5.13	0.248
Training Age (Year)	6.25±1.03	6.25±1.04	0.980

p<0.05

Table 2. Whole body vibration training programme.

	Exercise Type	Time (sets x s)	Frequency (Hz)	Amplitude (mm)	Rest (s)
1st week	1,2	2x30	35	2	30
2nd-3rd week	1,2	2x30			
	3	1x30			
4th week	1,2,3	2x30			
5th-6th week	1,2,3	2x30			
	4	1x30			
7th week	1,2,3,4,5	2x30			
8th week	1,2,3,4,5	2x30			

Exercises 1: lunge 2: squat 3: quadriceps strech 4:deep squat 5: wide stance squat.

lower limb injury, inflammatory conditions, cardiovascular diseases, or any other health problems that would prevent training. All the subjects completed the trainings and were evaluated for outcome measures.

Each subject was informed about the study and written consent was taken from their families. The study was approved by the clinical research ethics committee of Pamukkale University with number 20.10.2019/29187 and followed Declaration of Helsinki.

Intervention

The control group received conventional basketball training in 2 days a week. VG training was performed 2 days a week with 5 different unloaded positions for lower limb by the use of WBV device (*Power Plate, Performance Health Systems, IL-USA*) in addition to conventional training made in other 2 days of the week. WBV was applied with vertical vibrations at 35Hz and with 2mm amplitude for sets of the 30s interspersed with a rest of 30s (1:1 ratio), as given in Table 2. The calculated acceleration was 4.93g. WBV training was performed on a platform generating vertical/linear vibrations in unloaded static position with isometric muscular contractions while wearing sports shoes.

Procedures

All the participants were evaluated for muscle architecture by ultrasonography, dynamic leg strength by isokinetic test, and physical performance tests by SJ height and flexibility before and after the training period of 8 weeks from February to May 2020. The trial was ended after the completions of trainings and evaluation for outcome measures.

Ultrasound Measurement

Images were taken from the RF and VL muscles of the dominant leg. A two-dimensional B mode ultrasonography with a 12 MHz linear array transducer (*General Electric LOGIQ P5, Wauwatosa, WI-USA*) was utilized. The probe was placed without depressing the dermal layer. The participants were placed supine on an examination table for RF measurements with the legs extended and relaxed with 10° of knee bending. The participants were positioned on the lateral recumbent position and relaxed with a 10° bend in the knee for VL measurements. A measurement of the RF was taken close to the axial plane in parallel with the muscle fascicles at 50% of the distance between the anterior inferior iliac spine and the proximal border of the patella. VL was measured at 50% of the distance from the most prominent point of the greater trochanter to the lateral condyle of the femur. The

Table 3. Comparison of pennation angle, fascicle length and muscle thickness.

	Vibration Group (n:8)	Control Group (n:8)	Between Groups *p*	Time x Group Effect *p*	Main effect of group *p*
RF Pennation Angle (degree)					
Baseline	9.36 ± 1.64	9.92 ± 2.03	*0.555*	*0.910*	*0.555*
8th week	11.44 ± 2.58	10.66 ± 2.84	*0.577*		*0.577*
Main effect of time p	*0.117*	*0.305*	-	-	-
RF Fascicle Length (mm)					
Baseline	8.43 ± 0.39	8.62 ± 1.26	*0.694*	*0.769*	*0.694*
8th week	8.83 ± 0.41[#]	8.90 ± 1.11	*0.698*		*0.871*
Main effect of time p	***0.02***	*0.225*	-	-	-
RF Muscle Thickness (mm)					
Baseline	1.95 ± 0.30	1.98 ± 0.36	*0.871*	*0.855*	*0.833*
8th week	2.13 ± 0.55	2.02 ± 0.40	*0.873*		*0.678*
Main effect of time p	*0.275*	*0.731*	-	-	-
VL Pennation Angle (degree)					
Baseline	13.53 ± 3.26	12.00 ± 2.45	*0.833*	*0.349*	*0.307*
8th week	13.60 ± 3.59	12.51 ± 2.01	*0.835*		*0.467*
Main effect of time p	*0.941*	*0.204*	-	-	-
VL Fascicle Length (mm)					
Baseline	8.59 ± 0.83	9.42 ± 1.32	*0.678*	*0.335*	*0.153*
8th week	9.21 ± 1.01	9.57 ± 1.66	*0.671*		*0.613*
Main effect of time p	*0.09*	*0.421*	-	-	-
VL MuscleThickness (mm)					
Baseline	2.14±0.37	2.40±0.47	*0.307*	*0.190*	*0.238*
8th week	2.26±0.21	2.50±0.43	*0.309*		*0.184*
Main effect of time p	*0.198*	*0.349*		-	-

RF: Rectus femoris. VL: Vastus lateralis
#: comparison between baseline and 8th weeks. (Paired t test) ($p<0.05$)
**: comparison between WBV and control group. (T test) ($p<0.0.5$)*

measurements were made 3 times and the average value was taken. Fascicle length was measured along the length of the fascicle extending between superficial and deep aponeurosis. The fascicles were followed up to the attachment point by the probe if the fascicle extends off the image. Distance between superficial and deep aponeuroses is the muscle thickness, the angle of the fascicles relative to the attached aponeurosis is the PeA and the length of the fascicle extending between aponeuroses is defined as the fascicle length[16].

Isokinetic Test

The isokinetic muscle torque was assessed using the isokinetic dynamometer (Cybex, Humac Norm, USA). Participants warmed up on an unloaded cycle before the isokinetic test. The isokinetic test was made in the sitting position with backrest at 90° while the hands gripping the handles. Velcro straps were used to stabilize the trunk, waist, and distal part of the tested leg during movements. Gravitational corrections were not taken into account. The most prominent point of the femoral epicondyle was oriented with the rotational axis of the dynamometer. The shin pad was secured approximately two finger breadths above the lateral malleolus. The movement was restricted between the range of 10° and 90° for the knee extension. The subjects were familiarized with the device with 2 sets of submaximal contractions at low and high velocities. Peak torque (Nm) values were obtained for concentric flexor and extensor muscles at 60°/s and 180°/s angular velocities with 5 repetitions for the dominant leg separated with 2 mins of rest in between two sets.

Squat Jump Test

Squat jumps were performed with the participant flexing the knee to approximately 90° with the hands on the hips to reduce the contribution of the upper extremity to power production. Participants remained stabilized in the

Table 4. Comparison of isokinetic strength tests.

	Vibration Group (n:8)	Control Group (n:8)	*Between Groups p*	*Time x Group Effect P*	*Main Effect of Group p*
Torque for Quadriceps at 60°/s (Nm)					
Baseline	141.17±28.68	168.83±36.46	*0.225*	*0.240*	*0.225*
8th week	138.71±44.78	155.63±47.47	*0.312*		*0.312*
Main effect of time p	*0.185*	*0.490*	-	-	-
Torque for Hamstrings at 60°/s (Nm)					
Baseline	80.63±16.60	96.25±19.01	*0.102*	*0.216*	*0.102*
8th week	83.29±22.71	87.75±11.70	*0.633*		*0.633*
Main effect of time p	*0.428*	*0.284*	-	-	-
Torque for Quadriceps at 180°/s (Nm)					
Baseline	116.75±24.65	120.0±24.26	*0.787*	*0.845*	*0.787*
8th week	117.63±41.03	119.63±26.35	*0.909*		*0.909*
Main effect of time p	*0.948*	*0.909*	-	-	-
Torque for Hamstrings at 180°/s (Nm)					
Baseline	63.71±11.79	69.14±14.98	*0.449*	*0.469*	*0.449*
8th week	66.28±20.65	69 ±14.81	*0.576*		*0.576*
Main effect of time p	*0.900*	*0.868*	-	-	-

RF: Rectus femoris. VL: Vastus lateralis
#: comparison between baseline and 8th weeks. (Paired t test) (p<0.05)
**: comparison between WBV and control group. (T test) (p<0.0.5)*

90° position for 3 seconds before performing the jump. Participants were asked to jump explosively to fly as high as possible and best score of two repetitions was recorded. The jump height of the subjects was measured with the iPhone application of My Jump[22], which is found to be valid and reliable as compared with those from the force plate.

Flexibility

The test measures the flexibility of the lower back and hamstring group of muscles that were measured by using a sit-and-reach box with a scale. Before the test, shoes were removed, and participants were instructed to slowly achieve forward as far as possible with their knees completely extended. It was scored as the highest distance was attained on the ruler with the fingertips in cm and carried out two times, where the best score was taken.

Statistical analysis

Data were analyzed using SPSS 17.0 (IBM, NY-USA) software. Continuous variables were given as mean ± standard deviation. The distribution of data was tested with the Shapiro Wilk test. The distribution and the variance of data were normal satisfying parametric test conditions. T test was used for comparisons of independent variables. Paired t-test was utilized for comparison of dependent variables. Repeated measures of ANOVA were used to show the time * group interaction and main effects of time or group. Related confidence intervals were presented. $p<0.05$ was accepted as significant. Since there are not any similar articles to calculate the power and the number of the participants, effect size and post hoc analysis was calculated. Effect size tells us how meaningful the difference between or within groups is. Effect size was 0.99 for RF concerning fascicle length and indicated a large effect size. Power of a study represents the probability of finding a difference that exists in a population. Power analysis calculated for RF fascicle length change for 16 participants with α:0.05 indicated a power of 0.95.

Data availability

The data associated with the paper are not publicly available but can be obtained from the corresponding author on reasonable request.

Results

The mean age, height and body mass of the players were listed in Table 1. All the participants completed the trainings. None of the players smoke or use anabolic steroids.

PeA, fascicle length, and muscles thickness of RF and VL were not significantly different between groups at the beginning and the end of 8 weeks of training ($p>0.05$). There was no time and group interaction ($p>0.05$).

Table 5. Comparison of squat jump. and flexibility tests.

	Vibration Group (n:8)	Control Group (n:8)	*Between Groups p*	*Time x Group Effect p*	*Main effect of group p*
Squat Jump height (cm)					
Baseline	38.29±8.64	33.5±5.83	*0.301*	*0.072*	*0.301*
8th week	47.82±7.11#*	39.11±5.38	***0.028***		***0.028***
Main effect of time p	***0.009***	*0.062*			
Flexibility (cm)					
Baseline	20.73±7.34	25.9±8.59	*0.270*	*0.593*	*0.270*
8th week	24.63±7.13#	26.0±8.13	*0.769*		*0.769*
Main effect of time p	***0.047***	*0.061*			

RF: Rectus femoris. VL: Vastus lateralis. VG:Vibration group. CG:control group
#: comparison between baseline and 8th weeks. (Paired t test) ($p<0.05$)
**: comparison between WBV and control group. (T test) ($p<0.0.5$)*

The fascicle length of RF increased significantly from 8.43±0.39 mm (%95 CI, 8.10-8.76) to 8.83±0.41 mm (%95 CI, 8.49-9.17) only within VG group but not within CG (8.62±1.26 mm (%95 CI, 7.56-9.67) vs 8.90±1.11 mm (%95 CI, 7.97-9.83)) which was supported by the main effect of time ($p<0.05$) (Table 3).

The results of isokinetic strength testing performed at 60°/s and 180°/s for knee flexors and extensors were not significantly different between groups and within each group before and after training ($p>0.05$). This was confirmed by the absence of any time and group interaction and other main effects, (Table 4).

SJ height was significantly different between groups, 47.82±7.11 cm (%95 CI, 42.85-52.78) in VG vs 39.11±5.38 cm (%95 CI, 33.38-44.85) in CG. This finding was supported by the main effect of group ($p>0.05$). SJ height (38.29±8.64cm (%95 CI, 31.06-41.87) vs 47.82±7.11 cm (%95 CI, 41.87-53.76)) and flexibility (20.73±7.34 cm (%95 CI, 14.59-26.87) vs 24.63±7.13 cm (%95 CI, 18.67-30.58)) increased after training only in VG. This finding was supported by the main effect of time ($p<0.05$), (Table 5).

Discussion

We have studied the contribution of the WBV training on the muscle strength, SJ height, flexibility, and architectural adaptations of RF and VL in young basketball players. SJ height increased in VG compared to CG. Fascicle length of RF, SJ height and flexibility increased significantly in following WBV training performed with isometric contractions in static position compared to pretraining. However, addition of WBV training to conventional training did not improve muscle thicknesses, strength, architectural features, and flexibility compared to controls.

Ultrasound Imaging

Fascicle Length

Fascicle length is related with force-length relationship, muscle power, and muscle excursion range[23]. Increase in fascicle length that indicates an increase in number of sarcomeres added in series. The adaptation of sarcomere was found to occur in exercises made through large excursions. This might suggest that muscle excursion range is a stimulus for increasing the fascicle length. In this study, WBV training comprised the constant knee flexions up to 130° in the squatting position. Isometric training made at long muscle lengths of 90° of knee flexion was shown to produce larger isokinetic strength and pennation angle than isometric training made at shorter lengths of 50° of knee flexion[24]. Another factor related to fascicle length is the type of contraction. Some of the studies reported that fascicle length extended after applying chronic eccentric training. On the other hand, other studies found decreased or unchanged[23] fascicle length after concentric training. As for WBV training, the isometric contractions at constant joint angle were performed under vibration. Movement velocity might be another factor concerning with fascicle length. Static isometric contractions used in WBV training might be a factor the non-significant increase in fascicle length.

Pennation Angle

The PeA is another factor for force production as it allows attachment of a greater amount of contractile tissue to aponeurosis[25]. As the PeA rises, the packing of muscle fascicles within the same anatomical cross-section increases proportional to the sine of PeA. PeA was found to increase after 14-16 weeks of resistance training[18,23,26]. A 10-week of eccentric training was shown to increase the PeA of VL[27]. It was reported that the PeA strongly depends on muscle size[23,26,27]. The PeA of VL did not display any change after training in this study. The calculations from the geometric parallelogram method indicates that a 13% increase in the quadriceps strength and a 5% increase in anatomical cross-sectional area corresponded to increase of 0.6° in PeA, which could be very small to detect[28]. Similar to this finding, PeA measured in this study grew a little which is proportional to the modest increase in isokinetic muscle strength.

Muscle Thickness

The muscle thickness, the anatomical and the physiological cross-sectional area, and the muscle volume were reported to increase after concentric and/or eccentric type of resistance training in the VL and gastrocnemius muscle[16]. However, the increment of the muscle thickness in youngsters trained with WBV was non-significant in this study. It is not known clearly that the constituent muscles in a synergistic group adapt to the same stimulus. Housh et al.[29] found a 23.2% hypertrophy of RF in comparison with a 7.5% hypertrophy of VL. A study investigating architectural changes in four heads of quadriceps femoris presented that adaptation to cross-sectional area, PeA and thickness were consistent among vasti muscle groups that were significantly different in RF[30]. Furthermore, PeA was found to vary along the length of the muscle in RF by Narici et al.[31] The response of each component might depend on the amount of loading and activation related with the biomechanics, such as length-tension relationship. Findings of this study indicate that the fascicle length but not the muscle thickness and the PeA showed different adaptations in RF and VL muscles in their response to WBV training.

Effect of WBV Training on Muscle Architecture

Rubio-Arias et al.[6] studied the effect of 6 weeks of WBV on muscle architecture. WBV was applied by starting with 30 Hz and 2 mm in the first week up to 40 Hz and 4 mm in the last week for 30 min, 3 times/week. Participants made static exercises without loading. PeA, fascicle length, and muscle thickness were not found to be different, but jump height increased before and after WBV training and compared with those of the control group. Similarly, PeA and muscle thickness and fascicle length didn't increase with respect to controls in this study.

Whole Body Vibration Training and Muscle Strength

WBV is a method which has been widely used and was shown to increase muscle strength and power[32]. Effect of WBV was investigated in skiers and untrained women who were trained for 6 and 12 weeks, respectively. They report that increases in the isokinetic leg extensors were found[5]. A short term WBV program for moderately active young women (25 Hz, 6 mm amplitude, 2 sets x 5 min, 16 sessions) was found to improve isokinetic knee extensor muscle strength, vertical jump and flexibility, as compared with the values of pretraining and controls[33].

It has been thought that the effects of WBV training on isokinetic muscle strength are prominent at high angular velocities, such as 240°/s[9], as supported by the study of Martinez-Pardo et al.[5]. They achieved major improvements in muscle strength after 6 weeks of WBV training with 50 Hz vibration, 4 mm peak to peak displacement and 2 sessions/week at a high velocity of 270°/s[5]. Moreover, Rittweger et al.[34] proposed that fast twitch fibers were activated by WBV training. As these fibers took place in short-lasting activities with intense energy, isokinetic testing at high velocities could detect the changes. As for our study, muscle strength was measured at 60°/s and 180°/s which were lower than the velocities mentioned. This could be a factor preventing the detection of changes in muscle strength.

Karatrantou et al. didn't obtain any improvement in the extensor muscles of the knee by following WBV training at 25 Hz of frequency, 6 mm peak to peak displacement, 2 sets of 5 mins, 3 sessions/week in their study in which the training load was not adopted during training[33]. We increased the types of exercise gradually in this study. However, the improvements appearing in muscle by isokinetic testing did not reach a statistical significance, which is confirmed by the study in which 11 weeks of WBV training did not induce an increase in knee extensor muscle strength[35]. Moreover, another study with a shorter duration of 5 weeks of WBV added to conventional sprint training program did not obtain any development in knee extensor muscles at the start velocity, start accelaration, and sprint running velocity[36]. Gains in muscle strength with WBV training were provided by the study adding resistance exercises to WBT or using dynamic exercises[9]. The athletes worked with body body mass in a static position in our study, which might contribute to insufficient improvement.

WBV training load is determined by the variation of several factors, such as the frequency and amplitude of vibration, duration of sessions, the number and type of exercises, the training period, the body position and the type of platform[15]. Martinez-Pardo et al. studied the effect of 4 mm vs 2 mm amplitudes with high frequency on the semi-squat position. Increases in isokinetic muscle strength measured at 60°/s, 180°/s and 270°/s were found to be different irrespective of the WBV amplitude[5]. On the other hand, Marin et al. reviewed the studies on the effects of vibration on muscle strength and indicated that the higher gains in muscle strength were generated with the higher amplitudes of WBV[37]. The higher amplitudes were assumed to transfer the higher acceleration to the human body which might cause the greater tension, which reflects the greater gains in muscle strength. Another explanation is the activation of fast-twitch fibers by WBV that are responsible for explosive movements and can cause an increase in isokinetic muscle strength at high angular velocities[38,39]. A previous study investigated the effect of different frequency and amplitudes, i.e. high frequency and high amplitude versus low frequency and low amplitude on the knee extensor muscle strength. It was found that the most effective setting was the high frequency and high amplitude for the knee extensor muscle strength and jump performance[32]. We used WBV with high frequency and low amplitude in this study. Relatively lower duration and amplitude might be related with the lower gains in isokinetic muscle strength in this study. On the other hand, gains in muscle strength were found to be proportional to the baseline muscle strength of athletes[40]. As we concentrated in our study, young athletes who are adapted to regular exercise and acquired a muscular strength might have been improved less. WBV training supported by body mass was found to stimulate muscles less than training made at maximal voluntary contraction[15]. The exercises performed without external loads in our study might be another factor for insufficient strength gain.

Field Tests

Muscle power assessed by vertical jump height was shown to increase after WBV training[32]. Results of a meta-analysis about the effect of WBV training on CMJ and SJ indicated a positive difference, as compared with those of without exercise[40]. Issurin et al.[41] and Rehn et al.[42] reported the improvements in jump height after WBV training in their review studies. Similarly, we found that the squat jump heights were increased after WBV compared to controls in this study. Long term effects of WBV has been proposed to occur by motor unit firing and synchronization, contraction of agonists and inhibition of antagonists[43,44].

The gain in muscle power was found to be positively correlated with higher frequency, or amplitude, or longer session, or training period. High frequencies ranging between 30-50 Hz were notified to stimulate tonic vibration reflex more than the results of motor unit synchronization[45]. Ronnestad et al. show that counter movement jump performance increased further after squat exercises on the WBV platform with 40 Hz, as compared with those on the land. In this study, we used 35 Hz for WBV training[46]. It was found to rise SJ height significantly. Similarly, WBV training with high amplitude (>3 mm) was reported to cause a higher jump height than that with lower amplitudes[45]. On the other hand, Hortobagyi et al. reviewed long term findings of WBV and evaluated that jump height changed inconsistently in competitive and/or elite athletes[47]. There are other studies that did not show beneficial effects. These might be due to study design and fitness level of athletes[32,48,49].

We have obtained that the flexibility has increased only in the WBV group. An increase in flexibility following WBV was occurred in short term and long term studies. Issurin et al., reported that leg split of athletes raised, after 3 weeks of WBV flexibility training at 44 Hz[50].

To the best of our knowledge, this study is the first to use the ultrasonography for evaluating the change in muscle morphology as a response to whole body vibration. In this was not only the muscle thickness but also the other components of muscle architecture namely PeA and fiber length could be measured. The limitation of this study is that the participants involved in this study were adolescents who have not completed the bone epiphyseal development. Therefore, the training intensity and duration were lowered to reduce the risk of injury, as we compared with the studies performed with adults.

Practical applications

In conclusion, this study found that 8 weeks of WBV training performed in unloaded position and with isometric contractions added to conventional training in young basketball players did not improve ultrasonographic architectural features, muscle thicknesses, strength and flexibility compared to controls in contrast to an increase in SJ height. On the other hand, significant increases in fascicle length of RF, SJ height and flexibility were found following WBV training compared to pretraining. One must take into consideration that parameters related with vibration (frequency and peak-to-peak displacement), loading status or the volume of training (number and duration of the sessions) could effect the results. This new training modality was shown to have an effect on the muscle fascicle length which necessitates the acquisition of newer and better muscle parameters by ultrasonography. Training induced muscular architectural changes getting closer to the ideal structure would possibly contribute to better performance parameters of the athletes.

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