EFFECTS OF PLYOMETRIC TRAINING ON SELECTED KINEMATIC PARAMETERS IN FEMALE VOLLEYBALL PLAYERS

Miroslav Hrženjak, Nebojša Trajković and Tomislav Krističević

Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia

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Abstract

Purpose: The biomechanical effects of plyometric training are inconsistent. The aim of this study was to determine the effects of plyometric training on kinematic parameters in junior female volleyball players. Method: Sixty female volleyball players participated in this study. Players were members of youth and junior squads from several Serbian volleyball clubs. The recordings of volleyball spike jumps were made with a Panasonic NV-MS1 camera, which recorded a rate of 50 frames per second. Recorded data were downloaded to a computer and coordinate data were digitized with the help of software for 2D kinematic analysis. Results: Both the plyometric and the control group showed significant improvement ($p < 0.05$) in joint kinematics from pre- to post-training on most of the measures for linear velocity. However, no significant differences were found between initial and final measurement for angular joint velocity. Conclusion: The use of a modified or different plyometric training program could potentially improve player's movement and performance, and lower the athlete's risk for injury. More research is needed to determine whether instructing athletes to use specific spike jump approach and landing techniques may help to improve kinematic parameters or reduce load on lower extremities.

Key words: *biomechanics, spike jump, velocity, plyometric drills*

Introduction

Volleyball is an intermittent sport that requires players to compete in frequent short bouts of high-intensity exercise, followed by periods of low intensity activity (Gabbett & Georgieff, 2007). Of all activities, the attack and block situations represent 45% of the total actions of the game and are also responsible for 80% of the points obtained within international matches (Voigt & Vetter, 2003). Due to the obvious importance of vertical jump in volleyball, sport scientists and coaches are seeking for the best way to improve it. Although various training methods have been effectively used for the enhancement of vertical jump performance, most coaches and researchers seem to agree that plyometric training is a method of choice when aiming to improve vertical jump ability (Markovic, 2007). Moreover, research studies indicate that plyometric training can be a safe and worthwhile method of conditioning for youth if appropriately prescribed and implemented. Nonetheless, there is the potential for injury or illness to occur if the intensity, volume, and/or frequency of plyometric training exceed the abilities of the participants (Faigenbaum et al., 2009). Newton, Kraemer, and Haekkinen (1999) reported an increase in vertical jump performances in elite volleyball players over an eight-week period. Results from Fatouros et al. (2000) also supported this finding concluding that plyometric training over twelve weeks significantly improved vertical jump performance. However, the combination of plyometrics and traditional weightlifting exercises produced significantly greater improvements than plyometrics alone (Fatouros et al., 2000). Plyometric exercises may increase performance and decrease injury risk in competitive female athletes (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett, Stroupe, Nance, & Noyes, 1996). However, despite the advantages of plyometric training, the principal issue of determining the optimal elements of a plyometric program remains inconclusive. With an understanding of how beneficial plyometric training can develop vertical jump, it is of great importance to female volleyball players to maximize results by conducting these exercises correctly. An elite volleyball athlete, practicing between 16 and 20 hours a week may perform 40 000 (or more) spikes in a single season (Ferretti, Papandrea, Conteduca, & Mariani, 1992). Jumping activities can include both horizontal approach movements (spike jumps), as well as movements without an approach but generally involving a countermovement (jump setting, blocking) (Polglaze & Dawson, 1992; Viitasalo, 1991). Early studies of volleyball biomechanics described the whole motor pattern of the spike (Coleman, Benham, & Northcott, 1993; Maxwell, 1981; Samson & Roy, 1976). Studies have demonstrated that female athletes have a higher rate of noncontact ACL injury than male athletes, particularly in the sports of volleyball (Hewett et al., 1996; Ireland, 2002). Nevertheless, previous research indicates that lower extremity biomechanics can be altered via appropriate interventions (Myer, Ford, McLean, & Hewett, 2006; Paterno, Myer, Ford, & Hewett, 2004) and programs using combinations of plyometrics, balance, and strength training. Myer et al. (2006) stated that neuromuscular training that includes both plyometric and dynamic stabilization/balance exercises alters biomechanics movement and reduces ACL injury risk in female athletes. Moreover, Lephart et al. (2005) investigated the effects of an 8 week plyometric and basic resistance training program on neuromuscular and biomechanical characteristics in female athletes. Both groups increased initial and peak knee and hip flexion, and time to peak knee flexion during the task. The vertical velocity of the center of gravity at the end of the takeoff phase is very important not only for maximum jump height in volleyball spikes but also to identify biomechanical differences in movement strategies which may help determine what type of landings have the greatest risk of injury. To our knowledge, no studies have reported the biomechanical characteristic changes following plyometric training programs in female junior volleyball players. Therefore, the aim of this study was to determine the effects of plyometric training on kinematic parameters in junior female volleyball players. It was hypothesized that plyometric training would have significant effects on kinematic parameters in female volleyball players due to similar movement patterns in volleyball spike.

Methods

Participants

Sixty female volleyball players participated in this study. Players were members of youth and junior squads from several Serbian volleyball clubs. A few were candidates for youth and junior female national squad. General descriptive parameters are presented in Table 1. All the participants provided written consent after being informed of the test protocol. All volleyball players were participated to medical examination, to determine their health state, because in the research can participate only healthy athletes and those whose parents agreed that their children can take part in the research. The protocol of the study was approved by the Ethical Committee of the Faculty of sport and physical education, University of Niš and according to the revised Declaration of Helsinki. Each player had 3-5 years of training experience, corresponding to 2-hour training sessions, and at least 1 competition per week.

Table 1. General descriptive parameters of participants (Mean ± SD).

	Plyometric group (N=31)	Control group (N=29)
Age (years)	16.18±1.32	16.3±1.52
Body height	168.76±4.81	169.11±5.88
Body weight	61.76±8.43	61.21±7.61

Procedure

Before the study, the pre-season mesocycle was carried out for three weeks. Each week there were five training sessions lasting 90 to 120 minutes. The main objective of this period was to improve the aerobic endurance and strength. In the microcycle of seven days, three sessions were designed to develop endurance, and two sessions in the gym. After completing the preparatory phase the initial measurement was carried out while the final measurement was implemented within three days after the end of the experimental program. The experimental group (EG) conducted six weeks of plyometric training for developing explosive leg power. The number of training sessions was 15. Set model for developing of explosive leg power consisted of five exercises, and exercises will be done in the first part of the training, after a 30-minute warm up. Number of training sessions per week, starting the first week, would be as follows: 2-2-3-2-3-3. The control group did not include plyometric training or strength training in their program besides technical and tactical training.

Measurements

Although it is believed that 3D analysis is more detailed, the way in which feedback is provided to the athlete is essential (Guadagnoli, Holcomb, & Davis, 2002). The recordings were made with a Panasonic camera (50 Hz, Panasonic NV-MS1 HQ S-VHS; Panasonic, Paris, France). The camera was placed on a tripod at the height of 5 feet on the right angle i.e. perpendicular to the side-line at a distance of 5 meters away from the point of jump.
The reflective markers were placed on the right side, on the leg that makes first contact with the ground. The movement lasted from the moment when the heel touches the ground to the time when foot of the same leg left the ground. The movement of spike was divided into land and bounce, eccentric phase (lower center of gravity, flexion of the joints feet) and concentric phase (raising the center of gravity, the extension of the leg joints). For each of the 100 movies, the digitization of six segmentation models was made with the following markers on joints: shoulder, hip, knee, ankle, the top of the foot and heel.

At each stage of the movement mean values of the parameters of linear kinematics (linear velocity of the hip, knee and ankle joint) and angular kinematics (angle at the hip, knee and ankle, and on the basis of angular velocity in these joints) were calculated. The data were than fitted in a Butterwort digital filter. Transient muscle contraction was determined based on the minimum value of the angle of the knee joint, the moment when flexion exceeds the extension. The obtained mean values of the linear and angular velocities of the joints in both phases are further used in order to determine the statistically treated difference. The 9-body segment model of asymmetrical launchers with 23 reference points was digitalized. Prior to acquiring data each participant was asked to warm-up for at least 15 minutes by stretching all major muscle groups for performance and practicing several normal spike jumps. After the warm-up participants were asked to perform volleyball spike jump. A setter was used to set the ball for spike. Every player performed spikes at an interval of 2-3 minutes and their performance was recorded. Data were collected from the onset of movement until the peak of the spike jump. The videotapes were digitalised with Human software (Human, version 6.0, HMA Technology Inc., 2005, Canada) at a frequency of 50 Hz. The variables for this study were taken as the LBKUek- linear velocity in hips during eccentric phase, LBKOek- linear velocity in knee during eccentric phase, LBSZek - linear velocity in ankle during eccentric phase, LBKUko- linear velocity in hips during concentric phase, LBKOko- linear velocity in knee during concentric phase, LBSZko - linear velocity in ankle during concentric phase; UBKUek- angular velocity in hips during eccentric phase, UBKOek- angular velocity in knee during eccentric phase, UBSZek - angular velocity in ankle during eccentric phase, UBKUko- angular velocity in hips during concentric phase, UBKOko- angular velocity in knee during concentric phase, UBSZko - angular velocity in ankle during concentric phase.

Training programme

The experimental program (Table 2) was conducted for the purposes of this research during the preparation and as part of the competition period during the 2010/2011 season. Before the experimental programme, preparatory period of three weeks was carried out. The main objective of this period was to prepare athletes for high intensity plyometric program. The microcycle of seven days consisted of four strength training sessions and two training sessions of technical and tactical training. After this preparatory period, initial testing was conducted. Final measurement was carried out within three days after the experimental program was finished.

Table 2. Plyometric training programme

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Hurdle jumps	Sets x repetitions	2 x 6	3x6	4x6	3x6	3x6	4x6
	Box height	50 cm	50 cm	60 cm	50 cm	60 cm	60 cm
	Intensity	moderate	moderate	high	moderate	high	high
Depth jumps	Sets x repetitions	2x10	3x10	3x10	3x10	3x10	3x10
	Box height	40 cm	50 cm	60 cm	50 cm	60 cm	70 cm
	Intensity	moderate	moderate	high	moderate	high	high
Lateral jumps over box	Number of umps	2x30 sec	3x30 sec	3x60 sec	3x60 sec	3x90 sec	3x90 sec
	Box height	30 cm	30 cm	30 cm	30 cm	30 cm	30 cm
	Intensity	moderate	moderate	high	moderate	high	high
Lunge jumps	Sets x repetitions	2x9	3x10	3x12	3x10	3x11	3x13
	Intensity	moderate	moderate	high	moderate	high	high
Vertical jumps	Sets x repetitions	2x8	3x9	3x11	3x9	3x11	3x12
	Intensity	moderate	moderate	high	moderate	high	high

Results

Table 3. Differences between experimental and control group for linear velocity

	Plyometric group (*n*=31)		Control group (*n*=29)	
	Initial (Mean ±	Final (Mean ±	Initial (Mean ±	Final (Mean ±
LBKU	4.1941±.58	4.5519±.459	4.1174±.46	4.3850±.38
LBKO	3.5444±.53	3.4681±.707	3.5280±.63	3.6187±.56
LBSZ	2.3615±.46	2.6428±.492	2.2730±.46	2.3519±.60
LBKU	4.8538±.74	5.4408±.858	4.4813±.73	5.1533±.90
LBKO	3.1210±.71	3.6445±1.07	3.4037±.86	3.4619±1.0
LBSZ	3.3097±.98	3.4971±1.03	2.8121±.82	3.3164±.88

* - statistically significant differences between initial and final measurement; LBKUek- linear velocity in hips during eccentric phase, LBKOek- linear velocity in knee during eccentric phase, LBSZek - linear velocity in ankle during eccentric phase, LBKUko- linear velocity in hips during concentric phase, LBKOko- linear velocity in knee during concentric phase, LBSZko - linear velocity in ankle during concentric phase

The Kolmogorov-Smirnov tests showed that the data were normally distributed and no violation of homogeneity of variance was found using Levene's test. The experimental and control groups were well matched on the pre-training tests with no significant differences found for any variable between the two groups.

Both the plyometric and the control group showed significant improvement ($p < 0.05$) in joint kinematics from pre- to post-training on most of the measures for linear velocity, except for the LBKOek (p=.669 for plyometric group, p=.595 for control group) where none of the group showed significant improvement (Table 3).

In both groups the ANOVA showed, however, no significant differences between the first and second measurement for angular joint velocity (Table 4).

The only significant improvement was in ankle angular velocity during concentric phase for experimental group (p=.001).

Table 4. Differences between experimental and control group for angular velocity

	Plyometric group		Control group	
	(*n*=31)		(*n*=29)	
	Initial	Final	Initial	Final
	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)
UBKUek	174.53±86.918	212.22±107.821	202.96±110.917	181.09±117.329
UBKOek	323.88±130.867	301.26±135.168	287.21±91.336	292.75±125.462
UBSZek	263.18±152.865	291.41±134.720	256.85±152.141	252.57±145.640
UBKUko	583.94±182.149	593.43±169.527	527.16±178.849	607.97±234.823
UBKOko	368.85±144.890	375.27±139.984	330.88±171.777	395.94±167.951
UBSZko	270.72±96.034	393.34±134.880*	362.41±147.853	332.31±101.970

* - statistically significant differences between initial and final measurement; UBKUek- angular velocity in hips during eccentric phase, UBKOek- angular velocity in knee during eccentric phase, UBSZek - angular velocity in ankle during eccentric phase, UBKUko- angular velocity in hips during concentric phase, UBKOko- angular velocity in knee during concentric phase, UBSZko - angular velocity in ankle during concentric phase

Discussion and conclusion

This study has shown that 6 weeks of plyometric training had positive effects on linear velocity in female volleyball players, but has no significant effects on angular velocity. Players in the experimental group improved their linear kinematics significantly. However, players in the control group have also improved in some parameters of linear velocity, especially in the concentric phase. Significant improvement in control group can be explained by the fact that players were involved in skill training with numerous repetitions of volleyball spike which is in contrast to the EG that was involved in plyometric training and had less time for skill training. Specificity is a key concept in planning a plyometric training program. The sport and the skill which need to be developed must be analyzed so proper exercises could be emphasized (Chu, 1998). Moreover, it was found that skill based conditioning can significantly improve physical fitness and skill in junior elite volleyball players (Gabbett, 2008). Plyometric training increased linear velocity in hips (p=.020) and ankles (p=.044) during eccentric phase and linear velocity in hips (p=.013) and knees (p=.048) during concentric phase. Findings could be attributed to the fact that the plyometric training improves neuromuscular adaptations such as increased inhibition of antagonistic muscles as well as activation and contraction of synergistic muscles (Lachance, 1995). Myer et al. (2006) found that plyometric training reduced initial contact (P = .002), maximum hip adduction angle (P = .015), and maximum ankle eversion angle (P = .020). In addition, plyometric training increased initial contact knee flexion (P = .047) and maximum knee flexion (P = .031) during the vertical drop jump. Hip flexion at initial contact and peak knee and hip flexion were increased during the 8 weeks of plyometric training (Lephart et al., 2005). For vertical jumping, optimizing the combination of joint linear speeds caused by ankle plantar flexion, knee extension, and hip extension will result in the largest sum of joint linear speeds and will maximize the jumper's linear speed when leaving the ground. A combination of ankle plantar flexion, knee extension, and hip extension will sum to create greater linear motion at the hip and at all joints above the hip.

This greater sum of linear motion will be the linear speed of the jumper's center of mass when it leaves the ground. The greater the jumper's linear speed, the greater the vertical jump height (Dapena & Chung, 1988). No significant differences were found between initial and final measurement for angular joint velocity. The only significant improvement was in ankle angular velocity during concentric phase for plyometric group (p=.001). This could be explained by the fact that women have low force-velocity characteristics of the knee-hip extension movement (Yamauchi & Ishii, 2007). Häkkinen (1991) also reported that male basketball players record higher maximum forces of the knee-hip extensor and hip flexor muscles, shorter times required to produce maximum isometric force, and higher maximum vertical jumping heights than female basketball players. One previous research has also reported that female athletes land with less knee flexion, less time to peak knee flexion, greater knee valgus, greater vertical ground reaction forces, and less hamstring activation than male athletes (Pincivero, Gandaio, & Ito, 2003; Rozzi, Lephart, Gear, & Fu, 1999). Lower extremity kinematics is very important in order to accommodate the impact during landing. By using joint moments of force and joint kinematics of the lower extremity, landing mechanics describe the efficiency of absorption of the kinetic energy from the jump (Richards, Ajemian, Wiley, & Zernicke, 1996). From a biomechanical point of view, no specific benefit of one technique can be postulated for maximum jump height in volleyball spikes. These results lead to the assumption that the technique of spike jumps seems to be highly individual in top level athletes (Singh & Rathore, 2013). This is in line with Tokuyama, Ohashi, Iwamoto, Takaoka, and Okubo (2005), who showed in a laboratory-study, that intra-individual variation was significantly smaller than inter-individual variation for female attackers. More research is needed to determine whether instructing athletes to use specific spike jump approach and landing techniques may help to reduce load on lower extremities. The current study has some limitations. Firstly, the control group may have achieved similar neuromuscular adaptations due to skill training in volleyball. Secondly, the 6 week plyometric training may not have sufficient time to induce an additional biomechanical benefit.

In conclusion, completion of a 6 week plyometric training program improved selected linear kinematic measures and changed movement patterns during jumping tasks in female junior players. However, there were no significant changes in angular kinematic measures except for the ankle joint. Therefore, the results of our study could partially support our hypothesis. Research that analyzes kinematics of jumping and landing in volleyball could identify biomechanical differences in movement strategies which may help determine what type of landings have the greatest risk of injury. This kind of information could help coaches to lower the risk of injury and instead use movements that are safer.

The use of this plyometric training program could potentially modify volleyball player's motion strategies, improve performance, and lower the athlete's risk for injury.

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UČINAK PLIOMETRIJSKOG TRENINGA NA ODREĐENE KINEMATSKE PARAMETRE KOD ODBOJKAŠICA

Sažetak

Svrha: Biomehanički efekti pliometrijskog treninga su nedosljedni. Cilj ovog istraživanja bio je odrediti efekte pliometrijskog treninga s kinematskim parametrima kod odbojkašica juniorki. Metoda: Šezdeset odbojkašica sudjelovalo je u ovom istraživanju. Igračice su bile članice odjeljenja za mlađe igrače i juniore iz nekoliko srpskih odbojkaških klubova. Snimke smeč skoka napravljene su pomoću Panasonic NV-MS1 kamere, koja je snimila podatke u 50 sličica po sekundi. Snimljeni podaci su preuzeti na računalo i koordinirani podaci su digitilizirani uz pomoć programa za 2D kinematičku analizu. Rezultati: I pliometrijska i kontrolna grupa pokazale su značajan napredak (p<0,05) u zajedničkoj kinematici od prije do poslije treninga za većinu mjera za linearnu brzinu. Međutim, nisu pronađene značajne razlike između početnih i završnih mjerenja za brzinu kutnog zgloba. Zaključak: Korištenje promijenjenog ili drugačijeg pliometrijskog programa treninga potencijalno može poboljšati igračevo kretanje i izvedbu, te smanjiti sportašev rizik za ozljede. Potrebno je više istraživanja za utvrđivanje može li upućivanje sportaša na korištenje specifičnog pristupa smeča i tehnika slijetanja pomoći da se poboljšaju kinematski parametri ili smanji opterećenje na donje ekstremitete.

Ključne riječi: *biomehanika, smeč, brzina, pliometrijski trening*

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Correspondence to:
Assist. Prof. Tomislav Krističević, PhD.
University of Zagreb
Faculty of Kinesiology
Zagreb, Croatia 10 000, Horvaćanski zavoj 15
Tel: +385 (1) 3658 666
e-mail: tomislav.kristicevic@kif.hr