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THE EFFECT OF PLYOMETRIC TRAINING ON THE EXPLOSIVE STRENGTH OF LEG MUSCLES OF VOLLEYBALL PLAYERS ON SINGLE FOOT AND TWO-FOOT TAKEOFF JUMPS

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Abstract. *In order to determine the effects of plyometric training on the explosive strength of cadet volleyball players, we studied the effects of a six-week plyometric training program during the second half of the preliminary period of the annual training cycle. The sample consisted of 46 subjects aged 16 (± 6 months). The experimental group consisted of 23 volleyball players, with an average height of 186.35 ± 8.52 and average weight of 70.57 ± 8.98. The control group consisted of 23 high school students, with an average height of 177.35 ± 4.80 and body weight of 68.91 ± 6.48, who had not been exposed to the plyometric method as part of their physical education classes. The sample of measuring instruments consisted of eight tests of explosive leg strength: the two-foot takeoff block jump, the right foot takeoff block jump, the left foot takeoff block jump, the two-foot takeoff spike jump, the right foot takeoff spike jump, the left foot takeoff spike jump, the standing depth jump and the standing triple jump. Using a multivariate and univariate statistical method, we were able to determine a statistically significant difference in explosive strength in favor of the experimental group. We determined an increase in explosive strength for the two-foot and single foot takeoff jumps.*

Key words: *plyometric training, explosive leg strength, the two-foot takeoff jump, the single foot takeoff jump, volleyball techniques*

INTRODUCTION

Modern-day volleyball is dominated by techniques which require two-foot takeoff jumps. Nevertheless, the speed of movement and the suddenness of the actions have forced volleyball players to use single foot takeoff jumps during serves, lifts, spikes, blocks and other techniques. Exercises involving two-foot takeoff jumps mainly domi-

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nate modern-day training techniques. Thus, there is a need to study to which extent exercises involving two-foot takeoff jumps affect the efficiency of single foot takeoff jumps.

Typical athletic movements are characterized by the occurrence of a special strength variant which is called explosive leg strength. Explosive strength is defined as the individual ability of the neuro-muscular system to manifest strain in the shortest possible time-span (Verhošanski, 1979). In his definition of explosive strength, Zatziorsky (1995) introduced the notion of reversible strength which consists of two phases: the eccentric (stretch) and concentric (shortening) phase. The concentric phase should follow the muscle extension phase that precedes it as soon as possible.

During training sessions and at competitions, the motor activities of volleyball players are characterized by muscular activity in which muscle shortening is preceded by muscle stretching. These kinds of muscle actions are used when hitting a ball, in a running start and during jumps (Stojanović, Kostić, & Nešić, 2006). The stretching and shortening cycles are characteristic of plyometric training. The elastic characteristics of muscles and the reflex function have a significant influence on the stretching of muscles. The muscle stretching reflex is included in the SSC (stretch shortening cycle). For a high quality eccentric-concentric contraction, three important conditions have to be satisfied: the timely activation of the musculature just prior to the eccentric contraction, the short duration of the eccentric contraction and the instant shift from the stretching phase to the shortening phase (Komi & Gollhofer, 1997).

Volleyball players can hurt themselves while using the plyometric method if they do not meet the requirements regarding the basic structures of the landing and the rebound (the anatomic, dynamic, rhythmic and other structures, according to Kostić, 2000).

During training sessions which include jump practice, it is necessary for the body of the volleyball players to be optimally prepared to carry out movements properly prior to reaction training, not merely for the prevention of injuries, but also because only an optimally innervated muscle can adapt to the effects of reaction training. Warm-ups prior to reaction training can be both general and specific (Weineck, 2000, 238).

The effects of prolonged training using this method for the development of reactive training were studied. It was concluded that the best results followed a six-week training period during the second phase of the preliminary period, following the development of general strength, with at least two training sessions a week (Hagl, 2003).

The results of studies of various authors have proved that explosive strength training leads to better adaptations of the CNS and a greater increase in strength and jumping ability (Wilson, Newton, Murphy, & Humphres, 1993; Harris, Stone, O Bryan, Proulx, & Johnson, 1999; Blakey & Southard, 1987; Hevett, Stroupe, Nance, & Noyes, 1996; Hagl, 2003; Paul, Jeffrey, Mathew, John, Michael, & Robert, 2003).

Both in volleyball theory and practice, there are several models for the development of explosive leg strength, such as the Chu Model (1991). The application of the plyometric model indicated the need to study the possibilities of its application in cadet training on the one hand, and the efficiency of a certain set of plyometric exercises for the development of jumping skills, if it is used after a technical-tactical training, on the other.

In order to compare the effects of three training programs (squatting, plyometrics and squatting and plyometrics) on the increase in the muscle strength of the upper legs and hips, measured by means of the vertical jump, Adams et al. (1992) carried out a study on a sample numbering 48 subjects, who were divided into four experimental groups. The subjects trained for a period of seven weeks, with two training sessions each week. The explosive strength of the upper leg and thigh muscles was tested at the beginning and end of the experiment. After the statistical processing of the data following the final measuring, they determined that there had been an increase in explosive strength in all three experimental groups. The average increase for the values of the vertical jump was greatest among the members of the group that trained using squatting and plyometrics, 10.67 cm, then for the group that trained using plyometrics 3.81 cm, and finally the group using squats, 3.30 cm.

In an attempt to present a six-week plyometric training program, Lori (1996) used six beginner jumping exercises, eight intermediate high jumps, four box jumps, and three depth jumps. In his conclusion about the realized training, the author concluded that plyometric training should be implemented two or three times a week, that jumping should be practiced before training sessions and including the use of weights and that the height of the trunk can be increased during the program in order to increase intensity. The program should be realized over a 6-8 week cycle, so that the final cycle could be completed before the onset of the competition season.

In order to study the plyometric training model for the development of explosive strength, a study was carried out on a sample of 33 cadet volleyball players. Guided by the general principles of plyometric training, individual training plans were devised. In order to evaluate the effects of training, Stojanović & Kostić (2002) used three variables. The experiment was realized during the second part of the preliminary period of the annual training cycle which lasted for eight weeks and included training sessions two to three times a week. The control group trained by using technical-tactical contents. The data was processed by means of the MANCOVA and ANCOVA. On the basis of the results and the discussion, the authors concluded that the used exercise model for the development of jumping skills as the basic factor of the experimental group led to a statistically significant difference in the increase of jumping skills in relation to the control group, which had used technical-tactical contents for the purpose of developing jumping skills.

Rajić, Dopsaj, & Abella (2004) carried out a study in order to determine the influence of a training model for the development of explosive strength on the change in the maximal indicators of the muscle mechanical characteristics of isometric force among the muscle groups which endure the greatest load during a volleyball game. They used a sample which consisted of 11 female volleyball players aged 19. The program lasted for four weeks, with training sessions three times a week. At the initial and final measuring, the following muscles were studied: the back extensors, leg extensors, ankle extensors and finger extensors of the hand. The following characteristics were monitored: maximum force, the time needed to achieve maximum force, explosiveness, force impulse and muscle activation speed. The data was processed by means of the MANOVA and the student t-test. The MANOVA test indicated that changes had taken place at the general level, while the student t-test indicated changes in the ankle flexors and force impulse, the time needed to achieve maximum strength and the index indicator of the speed of muscle activation.

The aim of the study carried out by Rahimi & Behpur (2005) was to compare the effects of three different training programs (plyometric training, load training and a combination of the two) on the vertical jump, anaerobic power and muscle strength. Their sample numbered 48 students aged around 19, who were divided into the following groups: those using plyometric training (13 subjects), those using load training (11 subjects), those using a combination of plyometric and load training (14) and the control group (10 subjects). The high jump, the 50-yard sprint and maximum strength were measured before and after a six-week training program. The subjects in the experimental groups did not participate in any of the activities. The data was analyzed by means of a univariate analysis of variance. All of the treatments had a statistically significant affect on all of the tested variables, and the combined program of plyometrics and load had a numerically greater effect in relation to the other two programs. This study supports the use of combined traditional training with load training and plyometric exercises for the improvement of high jumping skills and explosive leg strength.

The subject matter of this study is to determine the effects of plyometric training exercises on the development of explosive leg strength among cadet volleyball players. The possible relations and differences between the quantitative indicators of jumping height in the case of the two-foot takeoff and single foot takeoff block and spike jumps stand out as a special point of interest. What would especially be beneficial for volleyball training is the study of whether the use of a plyometric program has the same effect on the effectiveness of explosive strength among volleyball-specific block jumps, spike jumps (in the case of both two-feet and single foot jumps), the depth jump and the triple standing jump.

The basic aim of this study was to determine the effects of plyometric training on the effectiveness of explosive leg strength in the case of two-foot and single foot jumps and to determine the relations of jump efficiency for two-foot and single foot volleyball jumps on the techniques for block and spike jumping. In order to achieve this aim, the following tasks were realized:

- the plyometric training method was realized
- the results were compared and differences determined between the initial and final measuring of the variables calculated for the experimental group
- the comparison of the results obtained for the experimental and control group at the final measuring with a partialization of the differences between them at the initial measuring.

THE METHOD

The sample of subjects

The sample consisted of 46 subjects aged 16 (±6 months). The control group consisted of the students of the vocational, mechanics high school "15.maj" in Niš, who had an average body height of 177.35 cm (SD ±64.80) and average body weight of 68.91 (SD ±6.48) and who did not train volleyball. The experimental group consisted of 23 members of the "Naissus '97" volleyball club in Niš, who had an average height of 186.35 cm (SD ±8.52) and body weight of 70.57 (SD ±8.98). The subjects of the experimental group had trained volleyball prior to the experimental program for a period of four to six years. During the testing, all of the subjects of the experimental and control group were healthy.

The sample of measuring instruments

The following measuring instruments were used to evaluate explosive leg strength:

– the two-foot takeoff block jump (SBLOO),
– the right foot takeoff block jump (SBLOD),
– the left foot takeoff block jump (SBLOL),
– the two-foot takeoff spike jump (SSMOO),
– the right foot takeoff spike jump (SSMOD),
– the left foot takeoff spike jump (SSMOL),
– the standing depth jump (SDM) and
– the triple standing jump (TRSM).

The validity of the SBLOO and the SSMOO tests was proven by Stojanović & Kostić (2002); the metric characteristics of the SBLOD, SBLOL, SSMOD and SSMOL tests were proven by Milić (2007); the predictive values of the SDM and TRSM tests were proven by Milanović (1981).

The description of the experimental program

Prior to the realization of the experimental program, the volleyball players trained for three weeks using a preliminary period training program, including a total of five training sessions a week for a duration of 90 to 120 minutes. The basic aim during this period was to increase the basic abilities for aerobic capacities, endurance and strength. During the preliminary period, within a seven-day micro-cycle, three training sessions were used for the development of endurance, and two for gym workouts. The initial measuring took place following the completion of this phase of the preliminary period. The final measuring took place three days after the completion of the experimental program.

After a three-week preliminary period, the experimental group, as part of the second part of the preliminary period, trained using a plyometric training model for a period of six weeks, which included the use of a plyometric training method for the development of explosive leg strength. A total of 15 training sessions took place. The number of training sessions per week was as follows: 2-2-3-2-3-3.

The set of models for the development of explosive leg strength consisted of five exercises which were realized during the first part of the training session, following a 30 min warm-up.

During this time, the control group took part in only two physical education classes a week.

The findings of Chu (1991) were used in the choice of exercise. Load dosing was done for every subject of the experimental group individually. As the starting values in load dosing for training, the values of the maximum attempts for all of the exercises contained in the explosive leg strength exercises were used. In creating the individual programs, we adhered to the principle that load during the first week should be 70% of the maximum, 80% during the second, 90% during the third, 80% during the fourth, 90% during the fifth and 100% during the sixth.

Week 1 (08.01. - 14.01.2007), training sessions 1 and 2, 70% load

The hurdle jump	2 series, 6 hurdles, 50 cm in height
The depth jump	2 series, 10 reps; height of the box: 60 cm
The box jump sideways	2 series; height of the box: 30 cm; 30 sec.
Lunge jumps	2 series, 9 reps
Vertical jumps	2 series, 8 reps

Week 2 (15.01. - 21.01.2007), training sessions 3 and 4, 80% load

The hurdle jump	3 series, 6 hurdles, height of the hurdle: 50 cm
The depth jump	3 series, 10 reps; height of the box: 70 cm
The box jump sideways	3 series; height of the box: 30 cm; 30 sec.
Lunge jumps	3 series, 10 reps
Vertical jumps	3 series, 9 reps

Week 3 (22.01. - 28.01.2007), training sessions 5, 6 and 7, 90% load

The hurdle jump	4 series, 6 hurdles, height of the hurdle: 60 cm
The depth jump	3 series, 10 reps; height of the box: 80 cm
The box jump sideways	3 series; height of the box: 30 cm; 60 sec.
Lunge jumps	3 series, 12 reps
Vertical jumps	3 series, 11 reps

Week 4 (29.01. - 04.02.2007), training sessions 8 and 9, 80% load

The hurdle jump	3 series, 6 hurdles, height of the hurdle: 50 cm
The depth jump	3 series, 10 reps; height of the box: 70 cm
The box jump sideways	3 series; height of the box: 30 cm; 60 sec.
Lunge jumps	3 series, 10 reps
Vertical jumps	3 series, 9 reps

Week 5 (05.02. - 11.02.2007), training sessions 10, 11 and 12, 90% load

The hurdle jump	3 series, 6 hurdles, height of the hurdle: 60 cm
The depth jump	3 series, 10 reps; height of the box: 80 cm
The box jump sideways	3 series; height of the box: 30 cm; 90 sec.
Lunge jumps	3 series, 11 reps
Vertical jumps	3 series, 11 reps

Week 6 (12.02. - 18.02.2007), training sessions 13, 14 and 15, 100% load

The hurdle jump	4 series, 6 hurdles, height of the hurdle: 60 cm
The depth jump	3 series, 10 reps; height of the box: 90 cm
The box jump sideways	3 series; height of the box: 30 cm; 90 sec.
Lunge jumps	3 series, 13 reps
Vertical jumps	3 series, 12 reps

The statistical procedure

In order to determine the differences between the groups at the final measuring with a partialization of the difference between the groups at the initial measuring and to determine the effects of the experimental program on the development of explosive strength of the leg muscles, a multivariate analysis of covariance (MANCOVA) was used, while at the univariate level, a univariate analysis (ANCOVA) was used.

The data was processed by means of the STATISTICA 6.0 program for Windows.

THE RESULTS AND THE DISCUSSION

Table1 shows the basic descriptive statistical parameters of the studied variables.

Table 1. The means and standard deviation of the experimental and control group at the initial and final measuring

Test	The experimental group				The control group			
	Initial		Final		Initial		Final	
	Means	Std.Dev.	Means	Std.Dev.	Means	Std.Dev.	Means	Std.Dev.
SBLOO	290.43	14.89	293.96	15.33	264.57	9.08	264.61	9.35
SBLOD	281.78	14.85	285.22	15.08	255.96	10.79	256.65	9.67
SBLOL	278.30	12.71	282.35	13.35	252.87	9.31	253.39	9.63
SSMOO	296.00	14.23	301.22	14.60	272.57	9.10	272.78	9.26
SSMOD	283.96	15.14	288.30	15.35	269.39	10.53	269.13	10.96
SSMOL	293.65	12.56	299.04	12.94	269.96	9.15	270.26	9.44
SDM	239.96	20.26	257.91	21.82	224.43	10.51	224.13	10.22
TRSM	948.00	78.00	1020.00	80.00	883.00	69.00	885.00	75.00

On the basis of the determined intergroup differences at the initial measuring between the experimental and control group in the space of explosive leg strength, and with the aim of determining the efficiency of the used six-week experimental program of plyometric training, an analysis of the possible intergroup differences at the final measuring of explosive leg strength was carried out by means of the multivariate analysis of covariance (MANCOVA), while the individual univariate intergroup differences of certain variables were defined by means of a univariate analysis of covariance (ANCOVA). In fact, this analysis neutralizes the differences between the groups noted at the initial measuring, while partially altered means from the final measuring were used to determine the differences.

By analyzing the data in Table 2, which shows the results of the multivariate analysis of covariance of the used variables of explosive leg strength among the subjects of the experimental and control group at the final measuring, with the partialization and neutralization of the noted differences at the initial measuring, we can conclude that the present statistically significant intergroup difference is at the .00 (p=.000) level. The noted difference occurs under the influence of the applied experimental factor, by means of which we can conclude that the used experimental program of plyometric training had a positive effect on the transformation of explosive leg strength of the subjects in the experimental group.

Table 2. The test of significance of the effects of the jump skills program at the multivariate level

Wilk's Lambda	F	Effect df	Error df	p
.141	22.16	8	29	.000

Legend : Wilks' Lambda – value of the coefficient of the Wilk's test for the equality of group centroids; F – the value of the F-test coefficient for the significance of Wilk's Lambda; Effect df; Error df – degree of freedom; p – the coefficient of the significance of the difference between the centroids;

The greatest contribution to the difference found at the final measuring (Table 3), with the neutralization of the differences at the initial measuring, came from the two-foot takeoff spike jump, which had an F value of 86.62, followed by the left foot takeoff spike jump, with a F=82.01, while the smallest contribution came from the standing triple jump, F=5.55. The contribution made to the difference between the groups is statistically significant for all of the dependent variables at the p=0.05 level, and can be assumed to be the consequence of the use of the experimental program consisting of a set of plyometric exercises which the experimental group used for a period of six weeks.

Table 3. The test of significance of the effects of the jumping skills program at the univariate level

	Adjusted Means experimental	Adjusted Means control	MS effect	MS error	F (1. 36)	p
SBLOO	280.79	277.77	26.66	.82	32.49	.000
SBLOD	272.91	268.96	45.75	5.25	8.72	.006
SBLOL	270.10	265.64	58.41	4.26	13.70	.001
SSMOO	289.54	284.46	75.82	.88	86.62	.000
SSMOD	280.90	276.54	55.84	1.68	33.31	.000
SSMOL	287.47	281.84	92.89	1.13	82.01	.000
SDM	247.79	234.25	537.03	89.62	5.99	.019
TRSM	976.00	930.00	62.00	11.00	5.55	.024

Legend: MS Effect – the average sum of the squares of the intergroup means; MS Error – the average sum of the squares of intra-group means; Adjusted means

In the discussion section of the statistical analysis, what can be noted is that the use of the set of plyometric exercises by the experimental group led to an increase in the explosive strength of the leg muscles, while no increase in the explosive leg muscle strength was noted for the members of the control group. Explosive strength had an effect on the increase in the ability for the high jump, as well as for the depth jump. Similar results were obtained in a study carried out by Chu (1991). A considerable increase in the jumping skills was found among the members of the experimental group, and so it is quite justified to use this type of plyometric exercises in cadet training. Nevertheless, many questions still remain unanswered. One of these questions has to do with determining which of these exercises led to the changes between the experimental and control group. The second question has to do with the share of the speed component which, to a great extent, is dependent on innate abilities.

The experimental group achieved an increase in the jumping abilities of volleyball players for the block and spike jumps from 3.44 up to 5.39 cm. This increase does not numerically differ from the two to six cm that Hagl (2003) found in the study he carried out on a sample of 8 subjects, or the 4.60 to 4.47 cm difference measured by Stojanović & Kostić (2002).

In their study of the development of jumping abilities, Polhemus & Burkherdt (1980) noted an increase among volleyball players of 8.12 cm, while the greatest values for the increase of the vertical jump (10.67) was noted by the authors Adams, O'Shea, O'Shea, & Climstein (1992), who used a combined plyometric training on a sample of 48 to 103 subjects, and which took place following seven weeks of training. The statistical analyses have determined the significant nature of the achieved coefficients of the increase in the vertical jump.

Fig. 1. Single foot takeoff jump

Fig. 2. Two-foot takeoff jump

Figure 1 shows the most common single foot takeoff spike jump, in which explosive strength plays an important part, especially that of the left leg. The results of the study indicate that plyometric exercises lead to a numerical increase in the averages of right and left foot jumps. This leads us to the conclusion that the use of two-foot takeoff jumps in the plyometric method does have an effect on the increase in explosive strength for the spike jump (both in the case of single and two-foot takeoff jumps).

Figure 2 shows the two-foot takeoff lift jump. Apart from the players who are supposed to block, those whose job it is to lift usually use two-foot takeoff jumps the most. The results of this study have confirmed the claim that plyometric exercises give a significant contribution to the differences in the average values of the experimental group. The results of this research could not be used to determine whether the increase in single foot or two-foot takeoff jumps would have been the same in the case of plyometric training including exercises of single foot takeoff jumps.

Common principles of muscle work regime in dealing with load exist in plyometric training, but it is necessary to construct individual programs for individual volleyball players. Jumping skills are an individual-specific characteristics, and the intensity and extent of the exercise should be determined in relation to this. The results and the discussion of this study indicate the need for a study which would test the relation between exercises involving single and two-foot takeoff jumps in the plyometric method and whether they should be used one at a time.

CONCLUSION

The plyometric training exercise program which included exercises involving primarily two-foot takeoff jumps, used on a sample of cadet volleyball players, contributed to the increase in the average jumping height in single foot and two-foot takeoff block and spike jumps.

A statistically significant difference was noted between the experimental and control group on the basis of which we concluded that the plyometric model can be recommended for the training of cadet volleyball players.

It has been proven experimentally that a six-week plyometric training model (with an increase in exercise intensity from 70% to 100%) influences the statistically significant increase in explosive strength of the leg muscles, and thus increases the jumping skills for the block jump, spike jump, depth jump and triple standing jump. In addition, we have determined that the regular physical education program used in schools does not have an effect on the development of explosive strength. By an analysis of covariance we have proven that the differences in the obtained values for jumping skills are significant, and are in favor of the experimental group. For this reason we can recommend the individual use of the plyometric model as a more effective method for the development of jumping skills among players at the cadet level.

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UTICAJ PLIOMETRIJSKOG TRENINGA NA EKSPLOZIVNU SNAGU NOGU ODBOJKAŠA U OBENOŽNIM I JEDNONOŽNIM SKOKOVIMA

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Sa ciljem da se istraži uticaj pliometrijskog treninga na eksplozivnu snagu kadeta – odbojkaša – istraživana je primena pliometrijskog treninga u toku šest nedelja u drugom delu pripremnog perioda godišnjeg trenažnog ciklusa. Uzorak je brojao 46 ispitanika starih 16 godina (± 6 meseci). Eksperimentalnu grupu je činilo 23 odbojkaša, telesne visine 186,35 ± 8,52) i telesne mase 70,57 ± 8,98. Kontrolnu grupu je činilo 23 učenika srednje škole telesne visine 177,35 ± 4,80 i telesne težine 68,91 ± 6,48) koji nisu primenjivali pliometrijski metod na časovima fizičkog vaspitanja. Uzorak mernih instrumenata je činilo osam testova eksplozivne snage nogu: Skok u bloku odrazom obenožno, Skok u bloku odrazom desne noge, Skok u bloku odrazom leve noge, Skok u smeču odrazom obenožno, Skok u smeču odrazom desne noge, Skok u smeču odrazom leve noge, Skok u dalj s mesta i Troskok iz mesta. Multivarijantnom i univarijantnom statističkom metodom utvrđena je značajna razlika u eksplozivnoj snazi nogu u korist eksperimentalne grupe. Utvrđen je prirast eksplozivne snage za skokove sa obenožnim i jednonožnim odražavanjem.

Ključne reči: *pliometrijski trening, eksplozivna snaga nogu, obenožni skok, jednožni skok, odbojkaške tehnike*