

**Original empirical article**

## **THE EFFECTS OF PLYOMETRIC TRAINING ON THE DEVELOPMENT OF THE JUMPING AGILITY IN VOLLEYBALL PLAYERS**

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**Abstract.** *With the aim of evaluating the effects of plyometric training on the development of jumping agility, an experimental research program was carried out on a sample of 38 cadet volleyball players. Following the general principles of plyometric training, individual training programs were constructed. In order to evaluate the effects of plyometric training on the development of jumping agility, six variables were used. For the purpose of this research, all six tests for the evaluation of jumping agility were validated. The experiment was realized in the second part of the preliminary period, and lasted for six weeks with two to three training sessions per week. The training of the control group involved technical-tactical exercises. The data were processed with the help of a univariate and multivariate analysis of covariance. On the basis of the research results and the discussion, we can with great certainty conclude that the exercise model that was used, as the basic factor of the experimental group, made a statistically significant contribution to the difference in the increase in jumping agility in comparison to the control group which used technical-tactical exercises for the development of jumping agility.*

**Key words:** *plyometric training, jumping agility, experiment, volleyball players.*

### INTRODUCTION

When evaluating the anthropomotor skills of athletes, we may ask the following question: what kind of skill is speed? Starting from various aspects, most authors have

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emphasized one or another important feature in their definition of speed, which set it apart as a characteristic anthropomotor feature of athletes or non-athletes. "What we consider speed to be is the individual anthropomotor ability (capacity) to correctly and effectively, in as short a time span as possible (as fast as possible), perform a certain locomotion or movement." (Stojanović et al., 2005, 347).

The components of the multi-dimensionality of speed are one of its important components. "Speed is a multi-dimensional motor skill which primarily takes four different shapes: 1. the latency time of a motor reaction, 2. the speed of an individual movement, 3. the speed of frequent movements and 4. sprinting speed. "(Stojiljković, 2003, 135). Movement speed or the shifting of a body in space is a function determined by numerous factors (motor coordination, external conditions, strength, muscle endurance, the stretch-shorten cycle, relaxation skills, reaction skills and speed which includes reaction time and movement time). "Nevertheless, just speed, like an action without any additions has nothing in common with the speed necessary to perform complex movements in sport." (Siff, 2000, 137). In many definitions and studies on speed abilities, the connection between speed and the occurrence of force, strength, flexibility, precision, or balance is emphasized. "First and foremost, it is well-known that speed is basically the result of force acting on mass. Second, speed usually represents movement with a constant speed frequency. Body movement (be it a human body or any other kind) with constant speed frequency requires enough motor force to equal out the forces which oppose movement." (deVries, 1976, 346).

In regards to movement speed training in sport, it is important to know that explosive strength is at the same time a function of strength and muscle contraction speed. The athlete will be much faster if he uses a greater strength for the surface take-off. This strength must be a part of the technique for surface contact. For the purpose of developing movement speed, explosive strength training is of special importance to an athlete.

The plyometric method is used as an effective method for the development of explosive strength. It is dominated by the plyometric movement of the athlete during exercise. "Plyometrics is speed-strength training, a combination of strength and speed" (Marullo, 1999, 13). All types of plyometric movement occur during three consecutive phases: the first phase consists primarily of stretching or eccentric muscle activity, which is marked by a high concentration of elastic muscle energy, the second phase is known as the amortization phase and begins with the end of the first phase, and ends with the beginning of the concentric muscle action, and finally the third phase, the final phase of muscle contraction, which is primarily manifested as the jump, hit or throw. These phases in plyometric movement are known by one name: the stretch-shorten cycle of muscle work. This cycle is characterized by two patterns. The first is the mechanical pattern of movement which includes muscles, joints, and tendons which are elongated in the stretch cycle only to decrease in length during the shorten phase, in order to revert back to their original state after the action. The jump, hit or throw in this case are the components of the muscle-joint-tendon elastic component. The second pattern of plyometric movement is characterized by a neuro-muscular pattern and the role and function of the stretch reflex, the so-called "myotatic reflex" (Pašić, 1993, 179), which primarily has a protective function to help prevent injury. The mechanical component enables the elastic characteristics of movement and the neuro-physical component (the stretch reflex) to increase the level of generated strength during the plyometric exercise. For proper take-off technique during plyometric exercise, one of the important criteria is the maximum height at which the

dismount starts, according to Schmidbleicher & Gollhofer (1985, 280). It should match that height from which the heels do not touch the ground prior to take off during a dismount. The concept of "border height" from which one can "drop jump" (Schmidbleicher in Berger et al., 1984, 170) has been accepted as the logical height of dismount in the research of Bosco & Pittera (1982) and Letzler & Letzler (1990). According to the conditions cited by Komi & Gollhofer (1997), we can conclude that the amortization phase during dismount must be as short as possible. The duration of the amortization phase of top athletes ranges from 120 to 150 ms. Except for the regularity of movement during take-off, it is important that the body be optimally prepared prior to reactive training, not only to prevent injury, but also because only optimally enervated muscles can adapt to the influence of "reactive" training. Preparation prior to reactive training can be general and specific (Weineck, 2000, 238).

Special "volleyball" warm-up exercises have been experimentally proven to be appropriate for reactive training (Baum & Essfeld, 1989). In volleyball, plyometric exercise conditions the neuro-muscular system, using great levels of energy over a short period of time. Nevertheless, if basic strength is missing, its effectiveness will be limited. The following basic motor abilities are responsible for situational-motor effectiveness: coordination, explosive strength, precision, movement frequency, balance, movement speed, force and strength (Strahonja & Prot, 1983).

The primary aim of our experimental research program was to evaluate the effectiveness of a plyometric exercise model on the development of the jumping agility in the case of cadets, that is, to combine the technical-tactical program (TTP) with the plyometric method. Regarding the set aims, the basic assumption is that the experimental group, which used the plyometric training model and the TTP, would achieve a statistically more significant increase in jumping agility in comparison to the control group, which did not use the plyometric exercise model.

## METHOD

### Participants

The sample for our research numbered 38 volleyball players, all of them cadets. The basic criterion for selection was that they: were all 16 years old ( $\pm$  6 months); were all members of the VC "Niš" and VC "Naissus '97" volleyball clubs in Niš; that they had all been training volleyball for a period of four to six years; that they had all had five training sessions per week during the preliminary period, and that the sessions lasted from 90 to 120 minutes; that they were all tested at the beginning and end of the experiment; that they were all healthy, since that the data for the injured volleyball players were not used in the statistical analyses. The non-random sample method was used to divide the participants into an experimental group (E) numbering 19 volleyball players and a control group (K) also numbering 19 volleyball players.

### The variables

The development and determination of the state of jumping agility at the initial and final measuring was carried out using six measuring instruments which covered the space of movement frequency speed. These measuring instruments were termed: 1. jumping – feet

apart (SKRASK), 2. the jump and turn (SKOOKR), 3. quick jumps sideways (BRKBO), 4. quick jumps – with both hands touching (BROBSK), 5. jumps to the side (SKOSTR) and 6. hop steps – scissor legs (POUISK).

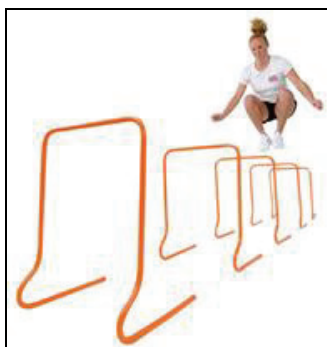
The validity of all the tests was proven by calculating the measuring characteristics by means of the factor procedure for proving predictive possibilities (Stojanović et al., 2010). The procedure was carried out by the authors of the research.

### **The testing procedure and research description**

The preliminary period for the 2006/2007 competitive season lasted for a period of 12 weeks, starting from July 31, 2006 until the start of the competition (October 21, 2006). The first phase of the preliminary period lasted for a period of three weeks. During each week, five training sessions were held, lasting from 90 to 120 minutes. The basic aim during this period was to increase the basic abilities for aerobic endurance and strength. During a micro-cycle of seven days, three training sessions were aimed at developing endurance, while two training sessions involved gym exercise. Following the completion of the first phase of the preliminary period, the initial measuring was carried out, while the final measuring was realized three days following the end of the experimental program, that is, following the completion of the second phase of the preliminary period. The experimental group (E) used a technical-tactical program in its training along with a special plyometric program for the development of explosive leg strength, during a period of six weeks in the second part of the preliminary period. A total of 15 training sessions were held. The model set for the development of explosive leg strength consisted of five exercises, which took up the first part of the training session, following a 30-minute warm-up period. The number of training sessions per week, starting from the first one, was the following: 2-2-3-2-3-3. At the same time, the control group (K) training used a technical-tactical program (TTP).

### **The contents of the training model for the development of explosive leg strength**

The set of the specialized model for explosive leg strength in this study consisted of five exercises based on the plyometric [reversible – Zatsiorski (1995)] method. In the selection process of these exercises, we relied on the information obtained by Chu (1991, 77).



**Fig. 1.** The hurdle jump

Props: six hurdles (the height of the hurdles was determined for each individual in turn).

Starting position: the participant stands in a mid-high squat position in front of the row of hurdles.

Action: the jump is with both feet, and over the first hurdle. During the landing, the participant takes off again quickly and jumps over the second hurdle, repeating the sequence for all the remaining hurdles.



**Fig. 2.** The drop jump.

Props: a box

Starting position: the participant stands upright on the box, closer to its front edge.

Action: the participant dismounts from the box, moving forward, and using both feet at the same time. While landing, he uses both feet to take off moving upwards, as fast as possible, and tries, during the jump, to touch a mark placed at the height of the maximum reach for a block or spike jump.

For proper take-off technique, the maximum height of the dismount is usually determined, according to Schmidbleicher & Gollhofer (1985, 280). It should match the height from which, during the dismount, the heels do not touch the ground prior to take-off. The concept of "border height" from which one can "drop jump" (Schmidbleicher in Berger et al., 1984, 170) has been accepted as the logical height of a dismount in the research of Bosco & Pittera (1982) and Letzler & Letzler (1990).



**Fig. 3.** Side-to-side bench vaults.

Props: a Swedish bench 30 cm high, 30 cm wide.

Starting position: the participant stands sideways next to the Swedish bench with his feet shoulder-width apart. Action: the participant jumps sideways over the Swedish bench with both feet and during the landing quickly takes off again and jumps to the opposite side of the bench, continuing to do so in an alternating fashion until the end of the exercise. Touching the floor surface on one side of the bench counts as one touch. The following instructions were given: 30 touches over a period of 30 s at the beginning of the training session, 60 touches over a period of 60 s during the middle of the training session and 90 touches over 90 s at the end of the training session.



**Fig. 4.** Vertical jumps beneath a vertical jump height indicator.

Props: a vertical jump height indicator.

Starting position: the participant stands with feet apart below the height indicator. The feet are at shoulder-width.

The action: the participant swings his arms forward and up, jumps upward and tries to make contact with the rod of the indicator with his right hand at the position which indicates the highest possible value, lands in the starting position and repeats the jump, only now trying to make contact with the rod of the indicator using his left hand.

Props: no props are required.

Starting position: the participant lunges forward, forming a 90 degree angle between the hip joint and the knee of the forward leg.

Action: swinging his arms forward, the participant jumps off the ground high as possible, lands in the starting position, and immediately repeats the jump.

Load dosing for each of the participants in the experimental group was carried out individually. The values of the maximum repetitions of all the exercises in the explosive leg strength training program were used as the starting points for dosing the load during training. The principle that load during the first week was 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 was used in the creation of individual programs. For example: cadet S. Z. is 197.0 cm high, and at the initial measuring was assigned a maximum hurdle height of 70 cm. The maximum height of the box used in the drop jump was 90 cm, and the maximum number of jumps over a Swedish bench was 42. The maximum number of jumps beneath the vertical jump height indicator was 12, and the maximum number of lunge jumps was 13.



**Fig. 5.** The lunge jump.

<b>1. week (21.8.2006- 27.8.2006), training sessions 1 and 2, 70% load</b>	
The hurdle jump	2 sets, 6 hurdles, hurdle height 50 cm
The drop jump	2 sets, 10 repetitions; box height 60 cm
The side-to-side Swedish bench vault	2 sets; bench height 30 cm; 30 sec.
The lunge jump	2 sets, 9 repetitions
Vertical jumps	2 sets, 8 repetitions
<b>2. week (28.8.2006. - 03.9.2006.), training sessions 3 and 4, 80% load</b>	
The hurdle jump	3 sets, 6 hurdles, hurdle height 50 cm
The drop jump	3 sets, 10 repetitions; box height 70 cm
The side-to-side Swedish bench vault	3 sets; bench height 30 cm; 30 sec.
The lunge jump	3 sets, 10 repetitions
Vertical jumps	3 sets, 9 repetitions
<b>3. week (04.9.2006. - 10.9.2006.), training sessions 5 – 7, 90% load</b>	
The hurdle jump	4 sets, 6 hurdles, hurdle heights 60 cm
The drop jump	3 sets, 10 repetitions; box height 80 cm
The side-to-side Swedish bench vault	3 sets; bench height 30 cm; 60 sec.
The lunge jumps	3 sets, 12 repetitions
Vertical jumps	3 sets, 11 repetitions
<b>4. week (11.9.2006. - 17.9.2006.), training sessions 8 and 9, 80% load</b>	
The hurdle jump	3 sets, 6 hurdles, hurdle height 50 cm
The drop jump	3 sets, 10 repetitions; box height 70 cm
The side-to-side Swedish bench vault	3 sets, bench height 30 cm; 60 sec.
The lunge jump	3 sets, 10 repetitions
Vertical jumps	3 sets, 9 repetitions
<b>5. week (18.9.2006. - 24.9.2006.), training sessions 10 - 12, 90% load</b>	
The hurdle jump	3 sets, 6 hurdles, hurdle height 60 cm
The drop jump	3 sets, 10 repetitions; box height 80 cm
The side-to-side Swedish bench vault	3 sets; bench height 30 cm; 90 sec.
The lunge jump	3 sets, 11 repetitions
Vertical jumps	3 sets, 11 repetitions
<b>6. week (25.9.2006. - 01.10.2006.), training sessions 13 – 15, 100% load</b>	
The hurdle jump	4 sets, 6 hurdles, hurdle height 60 cm
The drop jump	3 sets, 10 repetitions; box height 90 cm
The side-to-side Swedish bench vault	3 sets; bench height 30 cm; 90 sec.
The lunge jump	3 sets, 13 repetitions
Vertical jumps	3 sets, 12 repetitions

### Statistical analysis

Due to the nature of the experiment, it was necessary to gather data on the experimental and control group at the initial and final measuring. In order to analyze the results for the dependent variables at the initial and final measuring for both groups at the multi-

variate level, a multivariate analysis of variance was used for the repeated measures (MANOVA – repeated measures), while the significance of the conclusions was determined at the  $p < 0.05$  level. In order to determine the inter-group differences at the final measuring with a partialization of the possible inter-group differences at the initial measuring, and to determine the effects of the experimental program on the development of jumping agility, a multivariate analysis of covariance (MANCOVA) was used. The following parameters were calculated: Wilks' Lambda – the value of the coefficient for Wilks' test of group centroid equality; F – the value of the F-test coefficient for the significance of Wilks' Lambda; Effect df and Error df – the degrees of freedom; p – the significance of the coefficient of the differences between the centroids; MS Effect – the average sum of squares of the inter-group means; MS Error – the average sum of squares of the intra-group means; Adjusted means – the adjusted (modified) means. The data were processed using the STATISTICA 8.0 for Windows.

### THE RESULTS

In order to determine how much progress the group made during the six-week experimental treatment in terms of the used variables, a multivariate analysis of variance of repeated measures (MANOVA - repeated measures) was used, which tested the differences between the initial and final state at the multivariate level. Only the differences whose significance was at the  $p < .05$  level were considered significant.

**Table 1.** The multivariate inter-group differences from the initial and final measuring of the subjects in the Experimental group.

Wilk's Lambda	F	Effect df	Error df	p
.002	899.95	6	13	.000*

Wilk's Lambda – the value of the coefficient for Wilks' test of the of group centroid equality;  
 F – the value of the F-test coefficient for the significance of Wilks' Lambda; Effect df and Error df – the degrees of freedom; p – the significance of the coefficient of the differences between the centroids

Table 1. shows the results of the multivariate analysis of variance for repeated measures of the experimental group, which was used to test the difference between the results for their initial and final state. By testing the values of Wilk's Lambda coefficient (.002) with the help of the F test (899.95), and with the degrees of freedom Effect  $df=6$  and Error  $df=13$ , we can conclude that a statistically significant difference between the results from the initial and final state can be noted. On the basis of the obtained data, we can conclude that, following the six-week experimental program, statistically significant changes in the space of jumping agility of the participants in the experimental group were found at the  $p=.000$ .



**Table 2.** The univariate differences between the results from the initial and final measuring of the participants in the Experimental group.

Variable	Mean Initial	Mean Final	Growth	Growth %	MS effect	MS error	F	p
SKRAS	29.47+5.51	31.36+4.83	1.88	6.38	33.70	.90	37.60	.000*
SKOKR	13.11+2.02	14.04+2.17	.94	7.17	8.32	.01	796.02	.000*
BSKBO	3.78+0.41	3.65+0.39	-.13	3.44	.16	.00	612.80	.000*
BOBSK	31.37+3.15	33.61+3.37	2.24	7.14	47.69	.03	1886.10	.000*
SKSTR	19.21+2.57	21.29+2.19	2.08	10.83	41.06	1.08	37.89	.000*
POISK	33.79+4.45	36.20+4.77	2.41	7.13	55.34	.05	1093.27	.000*

Mean – the means; MS Effect – the average sum of squares of the inter-group means; MS Error – the average sum of squares of the intra-group means; p – the coefficient of the significance of the differences of the means.

Table 2. shows the results of the univariate analysis of variance for the repeated measures of the experimental group, which was used to test the differences between the results of the initial and final state for each variable individually. By testing the values of the variability around the intra-group (MS effect) and inter-group (MS error) means with the help of the F-test, we obtained a significant difference for all of the variables. We can note that the statistically significant differences in the test for quick jumps-both feet (BROBSK), whose F value was 1886.10, made the greatest contribution to the difference between the initial and final state in the jumping agility space, which gives a statistically significant difference at the  $p=.000$  level. In the case of the remaining jumps, a statistically significant difference between the results was also noted at the  $p=.000$  level of significance, but the growth of the results is somewhat smaller in comparison to the quick jump with both feet. In the case of the hop step (POUIISK) the values for the F-test are somewhat smaller (1093.27) in comparison to the quick jump with both feet, and in the case of the jump and turn (SKOOKR) and quick jumps sideways (BRKBO) we found approximately equal values of the F-test (796.02 and 612.80), while the smallest values were found for the jumping-feet apart (SKRASK) ( $F=49.72$ ) and jumps to the side (SKOSTR) ( $F=26.19$ ).

In the further discussion, we can comment that under the influence of the experimental program of plyometric training, the growth of the average value of jumping agility is, in terms of percentages, highest in the case of the jumps to the side (SKOSTR) and has a value of 10.83 %, is somewhat lower (7.17 %) for the jump and turn (SKOOKR), is 7.14 % in the case of quick jumps-both feet (BROBSK), for the hop step (POUIISK) is 7.13 %, and for jumping-feet apart is (SKRASK) 6.38 %. The smallest growth was registered for the quick jumps sideways (BRKBO) with 3.44 %. The smallest growth, in terms of percentages, can be found for the quick jumps sideways (BRKBO) test and it can be explained, since it was only in that test that we measured the duration of the test performance. The test consisted of 5 successive jumps sideways over hurdles in one and 5 successive jumps sideways in the other direction, and not the number of jumps during a 20-second period. The distance between the hurdles, which was 60 cm, limited the growth in jumping agility in comparison to the other tests which were performed as standing jumps over a single hurdle, or in one test, even without the hurdle. These results indicate the significant influence of the plyometric training program on the development of explosive leg strength, which in turn influenced the development of jumping agility.

**Table 3.** The multivariate differences between the results from the initial and final measuring of the subjects in the Control group.

Wilk's Lambda	F	Effect df	Error df	p
.112	7.12	6	13	.000*

Wilks' Lambda – the value of the coefficient for Wilks' test of the of group centroid equality;  
 F – the value of the F-test coefficient for the significance of Wilks' Lambda; Effect df and Error df – the degrees of freedom; p – the significance of the coefficient of the differences between the centroids

Table 3. shows the results of the multivariate analysis of variance for the repeated measures of the control group, which was used to test the difference between the results of their initial and final state. By testing the values of Wilk's Lambda coefficient (.112) with the help of the F-test (7.12), and along with three degrees of freedom Effect df=6 and Error df=13, we can conclude that a significant difference between the results from the initial and final state can be noted. On the basis of the obtained results, we can conclude that following a six-week program of technical-tactical training, statistically significant changes were found in the space of jumping agility in the case of the control group (p=.000).

**Table 4.** The univariate differences between the results for the initial and final measuring of the participants in the Control group

Variable	Mean Initial	Mean Final	Growth	Growth %	MS effect	MS error	F	p
SKRAS	27.26+3.94	27.68+3.68	.42	1.54	1.68	.85	1.98	.176
SKOKR	10.37+2.03	10.74+1.76	.37	3.57	1.29	.46	2.83	.110
BSKBO	4.24+0.34	4.20+0.34	-.04	.94	.02	.00	93.53	.000*
BOBSK	28.11+3.26	28.63+3.09	.53	1.89	2.63	1.13	2.33	.145
SKSTR	17.53+1.71	18.11+1.70	.58	3.31	3.18	.46	6.89	.017*
POISK	29.89+4.08	30.32+3.62	.43	1.44	1.68	1.07	1.57	.226

Mean – the means; MS Effect – the average sum of squares of the inter-group means;  
 MS Error – the average sum of squares of the intra-group means;  
 p – the coefficient of the significance of the differences of the means.

Table 4. shows the results of the univariate analysis for the repeated measures of the control group, which was used to test the difference between the results of the initial and final state for each variable individually. By testing the values of the variability around the intra-group (MS effect) and inter-group (MS error) means with the help of the F-test, we obtained a significant difference for two tests of jumping agility, while in the case of four tests, no significant difference between the results from the initial and final measuring was noted. We can determine that the greatest differences could be found for the quick jumps sideways (BRSKBO), whose value for the F-test was 93.53, which gives a statistically significant difference at the p=.000 level, and in the case of the jump to the side (SKOSTR), whose value for the F-test was 6.89, which gives a statistically significant difference at the p=.017 level. Much smaller and statistically not significant differences between the results from the initial and final measuring were noted for the jump and turn test (SKOOKR), whose F-test value was 2.83, where p=.110, then in the case of quick jumps-both feet (BROBSK) whose F-test value was 2.33, where p=.145. In the case of the jumping-feet apart (SKRASK) and the hop step (POUISK) the smallest differences between the results for the initial and final state were noted, since their values for the F-test were low (1.98 and 1.57), where p=.178 and p=.226.

In our further discussion we can comment that under the influence of technical-tactical training, the growth of the means was, in terms of percentages, the greatest for the jump and turn (SKOOKR) with a value of 3.57%, and was somewhat smaller for jumps to the side (SKOSTR), 3.31 %. In the case of quick jumps-both feet (BROBSK) and jumping-feet apart (SKRASK) the growth was approximately the same and had a value of 1.89% and 1.54%, and was somewhat smaller in the case of the hop step (POUISK) with a value of 1.44%. The smallest growth was noted in the case of quick jumps sideways (BRKBO) which had a value of 0.94%. These results unambiguously indicate that the technical-tactical programs as part of the training sessions carried out five times a week, as well as their contents and the effectiveness of their performance, are at a satisfactory level and that they had significant effects on the increase in jumping agility speed, but only for the two mentioned variables.

On the basis of the determined inter-group differences at the initial measuring between the experimental and control group in the space of jumping agility, with the aim of determining the effectiveness of the applied six-week experimental program based on the plyometric training method, we carried out an analysis of the possible inter-group differences at the final measuring of the jumping agility by means of the multivariate analysis of covariance (MANCOVA), while the individual univariate intergroup differences for certain variables were determined by means of the univariate analysis of covariance (ANCOVA). Actually, this analysis is used to neutralize the possible differences at the initial inter-group measuring, and the determination of the differences was carried out through the partialized modified means at the final measuring (Adjusted means).

**Table 5.** The test of the significance of the effects of the plyometric training program at the multivariate level – the MANCOVA model.

Wilk's Lambda	F	Effect df	Error df	p
.121	30.28	6	25	.000*

Wilks' Lambda – the value of the coefficient for Wilks' test of the of group centroid equality; F – the value of the F-test coefficient for the significance of Wilks' Lambda; Effect df and Error df – the degrees of freedom; p – the significance of the coefficient of the differences between the centroids.

Table 5. shows the multivariate analysis of covariance of the applied variables for jumping agility between the subjects of the experimental and control group at the final measuring, with a partialization and neutralization of any possible differences at the initial measuring. By testing the values of the Wilk's Lambda coefficient (.121) with the help of the F-test (30.28), along with the degrees of freedom Effect df=6 and Error df=25, we can conclude that a statistically significant inter-group difference can be noted at the .000 level (p=.000). The noted difference occurs under the influence of the applied experimental factor, which is helpful to our conclusion of whether the applied experimental program of plyometric training had a more significant influence on the transformation of the jumping agility of the participants in the experimental group than the technical-tactical training on the participants in the control group.

**Table 6.** The test of significance of the effects of the jumping program at the univariate level – the ANCOVA model.

	Adj. Mean EKS	Adj. Mean KO	MS effect	MS error	F (1, 30)	p
SKRAS	30.39	28.65	11.12	1.26	8.83	.006*
SKOKR	12.92	11.86	4.11	.48	8.50	.007*
BSKBO	3.88	3.98	.03	.00	128.21	.000*
BOBSK	31.93	30.31	9.45	1.30	7.26	.011*
SKSTR	20.89	18.50	20.84	1.36	15.33	.000*
POISK	33.75	32.77	3.52	.74	4.77	.037*

Adj.mean – the mathematically adjusted means; MS Effect – the average sum of squares of the inter-group means; MS Error – the average sum of squares of the intra-group means; p – the coefficient of the significance of the differences of the means.

The greatest contribution to the inter-group difference at the final measuring (Table 6), with a neutralization of the differences at the initial measuring, was made by the quick jump sideways test (BRSKBO), whose F value was 128.21 at the  $p=.000$  level of significance, followed by the jumps to the side test (SKOSTR), whose F value was  $F=15.33$  at the  $p=.000$  level of significance. A somewhat smaller contribution to the difference between the experimental and control group at the final measuring was made by the tests of jumping-feet apart (SKRASK), whose F value was  $F=8.83$  at the  $p=.006$  level of significance and the jump and turn (SKOOKR), whose F value was  $F=8.50$  at the  $p=.007$  level of significance. The smallest contribution to the inter-group difference was made by the tests for quick jumps-both feet (BROBSK) was, whose F value is  $F=7.26$  at the  $p=.011$  level of significance and the hop step – scissor legs (POUIISK), whose F value was  $F=4.77$  at the significance level of  $p=.037$ . The contribution to the inter-group difference is statistically significant for all of the dependent variables at the  $p=.05$  level, so we can assume that it is a consequence of the experimental program of plyometric exercise which was used by the experimental group for a period of six weeks.

## DISCUSSION

In the discussion of the statistical analysis we can point out that by using the set of plyometric exercises for the development of explosive leg strength in the case of the experimental group, an increase in jumping agility was noted. In addition, an increase was noted for the control group as well, but the increase was significantly greater for the participants of the experimental than the control group of volleyball players. It is important to point out that the increase in explosive leg strength by means of the plyometric training method had an influence on the increase in jumping agility. The experimental group achieved a jumping agility increase which ranged from 3.44% to 10.83%. The noted increase is numerically different from the research results which dealt with the development of the jumping ability, primarily because of the growth in the results for the height of the vertical jump which were given in cm. But if these results were to be transformed into growth in terms of percentage, they could easily be compared to the results in this research. Similar results were obtained by Chu (1991). The results noting a growth in the jumping ability from two to six cm which Hagl (2003) found on a sample of 8 participants, in terms of percentages correspond to the increase in jumping agility obtained in

this research. Similar results were found in the studies on the development of the jumping ability by Blattner & Noble (1979), whose participants increased their jumping ability by 5.2 cm following an eight-week plyometric training program. In the study carried out by Polhemus & Burkhardt (1980) this increase was 8.12 cm, while the greatest values of the vertical jump (10.67 cm) were recorded by Adams, et al. (1992), who used a combined plyometric training program on a sample of 48 to 103 participants, following a seven-week training program. Statistical analyses were used to determine the significance of the achieved coefficients for the increase of the high jump. Hewett et al. (1996) in their research confirmed the increase in the height of the vertical jump by around 10%. Stojanović & Kostić (2002) reported that an increase in jumping ability in a range from 4,47 to 4,60 cm, that is, between 7.72% and 9.52% growth followed an eight-week plyometric training program on a sample of cadet volleyball players. Milić (2007) reported an increase in the jumping ability in a range from 3.44 to 5.39 cm for specific volleyball jumps with both feet and on one foot.

It is important to mention that the results of this research are in accordance with the results of similar research projects which studied the effects of plyometric training, as well as the fact that explosive leg strength and jumping agility are in a significant correlation. This has been confirmed by the same or similar effects that plyometric had both on explosive leg strength and on jumping agility. In order to prove a high correlation between explosive strength and jumping agility, it is necessary to further explain the mechanisms and cause and effect relations which connect the two motor skills and which have been proven in previous theories and research. Jumping speed is in many ways determined by the morphological characteristics of the players (height, weight, length of the extremities and the like), the physiological characteristics of the players (the speed of muscle fiber shortening), as well as the abilities acquired through the training process (the extent of the force, the proper technique for the movement-jump and the like). The speed of performance is significant for jump height, whose factors are explosive strength of the leg extensors, the extent of the reactive swing momentum transfer, the running start, the extent to which the legs are bent, the position of the feet, the mount as well as the degree of the mutual effects of the cited elements of the jump height.

In addition to the cited facts, the functional mobility of the shoulder belt and the length of the feet - as a lever, are also important. The timely performance of a jump is an essential parameter for the performance of the jump movement structure (Čanaki & Birkić, 2009). It is very important that while performing a jump, the volleyball player moves at a precise time (in a timely fashion) upwards, forwards or to the side, which means that he should come in contact with the ball at the moment when he has achieved the greatest height or just before he achieves it (Stojanović et al., 2005). What should be added is also the knowledge that the most important factors of jumping ability and the speed of the jump are the muscular and nervous system. It is well-known that the extent of explosive strength is determined by the abilities for a summary effort of a great many muscle groups which take part in the movement, under the conditions of complete inter and intra-muscular coordination and the most suitable relation between the components of speed and strength. The extent and intensity of the load which can be used for the most effective transformations of the factors of explosive strength and jumping agility is based on the components of force and speed, where the exercises are performed in sets with maximum speed or movement frequency. For that reason, the loads are maximum and submaximum, that is, they are at the level which enables significant transformational effects, since only

with an emphasized component of intensity (force and speed) within the performance of a certain training task can explosive strength and jumping agility undergo development.

For plyometric training there are common principles in regards to the muscle work regime for overcoming load, but it is necessary to create an individual program for each volleyball player. Jumping ability and jumping speed are individual characteristics, and it is based on them that exercises should be selected and their intensity and extent determined. One of the more significant conditions for the use of the plyometric method are the age characteristics of each of the volleyball players in turn.

### CONCLUSION

Following the general principles for the use of the plyometric method in experimental research on a sample of cadets, individual plans were created for each of the players. It has been experimentally proven that a six-week training program based on the plyometric method has a statistically significant effect on the increase of explosive leg strength, and thus on the increase in jumping agility. In addition, it has been determined that the use of the TTP program, to a lesser extent in comparison to the experimental group, affects the development of jumping agility. Using an analysis of covariance we have determined that the difference in the obtained jumping agility is significant in favor of the experimental group. For this reason we recommend individually custom-made plyometric programs as a more effective tool for the development of jumping agility in the case of cadets.

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## **EFEKTI PLIOMETRIJSKOG TRENINGA NA RAZVOJ SKAKAČKE AGILNOSTI KOD ODBOJKAŠA**

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*Sa ciljem da se ispituju efekti pliometrijskog treninga na razvoj skakačke agilnosti organizovano je eksperimentalno istraživanje na uzorku od 38 odbojkaša kadetskog uzrasta. Rukovodeći se opštim principima za pliometrijski trening sačinjeni su individualni planovi treninga. Za procenu efekata pliometrijskog treninga na razvoj skakačke agilnosti primenjene su šest varijable. Za potrebe ovog istraživanja validirano je svih šest testova za procenu skakačke agilnosti. Eksperiment je realizovan u drugom delu pripremnog perioda, a trajao je šest nedelja sa po dva do tri treninga. Kontrolna grupa je trenirala primenjujući tehničko taktičke sadržaje. Podaci su obrađeni univarijantnim i multivarijantnim analizama i analizom kovarijanse. Na osnovu rezultata istraživanja i diskusije može se pouzdano zaključiti da je primenjeni model vežbi, kao osnovni faktor u eksperimentalnoj grupi, doprineo statistički značajnoj razlici u povećanju skakačke agilnosti u odnosu na kontrolnu grupu koja je za razvoj skakačke agilnosti koristila tehničko-taktičke sadržaje.*

Ključne reči: *pliometrijski trening, skakačka agilnost, eksperiment, odbojkaši.*