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THE INFLUENCE OF THE COMBINED METHOD ON THE DEVELOPMENT OF EXPLOSIVE STRENGTH IN FEMALE VOLLEYBALL PLAYERS AND ON THE ISOMETRIC MUSCLE STRENGTH OF DIFFERENT MUSCLE GROUPS

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Abstract. *The aim of this research is to determine the influence of the special model of explosive strength training applied on maximal mechanical strength characteristics under isometric conditions on muscle groups most involved in the game of volleyball. Eleven female volleyball players were examined for 3 days per week, over a training period of four weeks. The initial and final tests of the mechanical muscle characteristics were made under isometric conditions on four muscle groups: low back extensors, leg extensors, the calf muscles and flexors of the dominant hand. The following mechanical characteristics were evaluated: maximal muscle strength (F_{max}), the time necessary for reaching maximal strength (tF_{max}), the rate of strength development (RFD), the impulse of muscle strength ($I_{mp}F_{max}$) and the coefficient of the muscle activation velocity (C_{max}). The tests were conducted using hardware- software systems (Program Inžinjering, Beograd consisting of a tensiometric dynamometer of high sensibility. The MANOVA (Multiply Analysis of Variance) was applied to determine variability, as well as the student t-test for small groups to evaluate the means of the obtained results. Based on the results of the MANOVA analysis, a statistically significant difference was determined (Wilk's λ 0.000358, p=0.015). The most important differences were detected in maximal strength (F_{max}) and in the coefficient of the muscle activation velocity (C_{max}). The results of the student t-test demonstrated that the applied special model, according to the tested muscle groups, produced statistically significant differences only in the case of the calf muscles in regards to the impulse (p= 0.045), the time necessary for reaching maximal muscle strength tF_{max} (p= 0.004) and the coefficient of the muscle activation velocity (p= 0.031).*

Key words: *female volleyball players, isometric strength, plyometric training, the combined method of explosive strength training*

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1. INTRODUCTION

The successful performance of elite volleyball players requires from each player a high level of technical, tactic and physical preparation (Puhl et al., 1982). The structure of motor requests during the game consists of frequent changes of direction in the frontal and lateral planes, numerous jumps which are characteristic for the game of volleyball, as well as many high and long jumps (Harman et all., 1990; Kroon, 2000). The mentioned characteristics require adequate preparation and a high fidelity performance in terms of sport technique, tactics and basics and specific physical preparation (Puhl et al., 1982; Pablos Abella et al., 1999; Kroon, 2000).

Definitely the most frequent elements during the volleyball game are the different aspects of the vertical jump (Harman et all., 1990; Kroon, 2000). According to the obtained data, approximately 80 to 120 jumps are made during one game consisting of five sets of offensive and defensive tasks (Puhl et al., 1982; Kroon, 2000).

No matter what kind of vertical jump is being performed during the game, the muscle involvement is as follows: leg extensors 56%, calf muscles 22%, hip extensors 10%, ankle flexors 10% and neck extensors 2% (Jarić, 1987).

Considering the fact of how these motor tasks require a high level of preparation in terms of the speed and explosive strength of the leg extensors, as well as the other muscle groups involved in the elements of sport, during the process of preparation it is necessary to apply different methods for the development of those mechanical characteristics directly related to and adequate physical preparation as the basis of a player's high performance (Puhl et al., 1982). Many investigations have demonstrated that the most effective method of physical preparation is the plyometric model of training consisting of jumps of different heights, different methods of weightlifting of maximal and sub-maximal weights, weightlifting of light weights, as well as numerous combinations of the aforementioned methods (Zatsiorsky, 1995; Hewett at al. 1996; Gehri at al. 1998; Verkhoshansky, 1999; Pablos Abella et al., 1999; Scott, 1999; Rimmer, & Slievert, 2000).

It has been determined that the light weightlifting model of special training (15 and 30% of 1PM[1]) shows great benefits when it comes to demonstrating maximal and explosive strength compared to classical sport training methods used by athletes, where no weightlifting is applied (Pablos Abella et al., 1999). Also, it has been demonstrated that the combined training method of maximal weightlifting and depth jumps shows more benefits in terms of the achieved rate of strength development (RFD) than the method consisting only of light weightlifting (Pablos Abella et al., 1999).

In much of the research carried out so far with aim of evaluating the vertical jump as a model for the development of the applied contractile capacity, only the maximal muscle strength and the rate of strength development were evaluated. The other mechanical characteristics that influence muscle strength like the impulse of muscle strength ($I_{mp}F$), the time necessary for reaching maximal muscle strength (tF_{max}) and the coefficient of the muscle activation velocity (C_{max}) were not recognized as factors which participate in a sports performance. The impulse of muscle strength represents the potential of movement as a consequence of the contractile capacity of the muscle groups involved. The time necessary for reaching maximal muscle strength is recognized as an absolute capacity of contractile muscle capacity in terms of the dynamics of its performance, and the velocity of muscle activation represents the level of intensity of muscle activation. These charac-

[1] 1PM -the weight that can be lifted only once (1RM - 1 repetition maximum)

teristics produced by muscle contractions are responsible for the different phases of performance in sport in terms of maintenance of intensity, the establishment and acceleration of each movement of complex motoric activities (Jarić 1987; Zatsiorsky, 1995; Young et al., 1995; Verkhoshansky, 1999; Potieger et al., 1999; Rimmer, & Slievert, 2000).

The aim of this research is to determine the influence of the combined method as a form of special training for the development of explosive strength on different aspects of muscle strength of particular muscle groups. The goal is to highlight changes in the different aspects of muscle strength due to a special model of training applied on those muscle groups which define the quality of a sports performance and are mostly affected by the mentioned model of training. Also, this research should actively participate in the development of existing methods of sports training in terms of improving contractile/mechanical characteristics of the aspects of muscle strength and should help to define the most efficient model of sports training for female volleyball players in terms of specific stamina and physical preparation.

2. Methods

The studied athletes

Eleven female volleyball players, BH given in m = 1.780 ± 0.0731; BW given in kg = 68.19 ± 9.73; AGE given in years = 19 ± 2.19; BMI given in kg/m² = 21.43 ± 2.13; sport EXPERIECE given in years = 6.39 ± 1.8, members of the A team, of the "MLADOST" volleyball club in Zemun, Belgrade, who competed in the Second division, took part in this research.

The Training Procedure

The model applied in this research consisted of micro cycles of two basic methods, weightlifting (sub-maximal weights), and other methods of plyometric training (drop jumps from different heights) for the development of explosive strength of the studied muscle groups. The entire model consisted of four micro cycles (seven days each): on Mondays, Wednesdays and Saturdays (Table 1.) it was carried out in the weight room, and on other days, the training process was carried out in the Sports centre "PINKI", in Zemun. Sunday was the day off. Twelve experimental training sessions took place and this structure is presented in Table 1.

Method of testing

Procedure

The entire process consisted of two phases: the first lasted for four weeks and had as its aim to improve the level of basic physical preparation. When finalized, the initial procedure of testing took part in the laboratory of the Special Physical Education Department of the Police Academy in Belgrade.

The second phase, the experimental one, lasted for four weeks during which time the special model of training was implemented. When finalized, the final procedure of testing was organized in accordance with the initial testing made a few weeks before.

Table 1. Structure of the model of training applied

The general structure of the applied training		
Introduction	Main part	Cooling down
Basic and specific warming up, (exercising while running, jumps, warming up with the20 kg bar) aprox. 15 min.	One set of warming up with 50% of 1RM, afterwards implementation of the training model, aprox. 30 min.	Cooling down, stretching, massages or self massage, aprox. 10 min.

The main part of the experimental schedule	
1. Session	1. Deep squat with the bar upon the shoulders, 3 sets of 6 reps, intensity 85- 90% of 1RM, break 4 min 2. Upper body push ups from the knees, 3 sets of 10 reps, break between sets 2 min.
2. Session	1. Fast parallel squat with the bar upon the shoulders, 3 sets of 8 reps, intensity 80% of 1 RM, break 4-5 min. 2. Low back hyperextensions, 5 sets of 20, break between sets 1 min. 3. Sit ups, 5 sets of 20, break between sets 1 min.
3. Session	1. Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1 RM, break 5 min. 2. Parallel squat- maximal jump with the bar upon the shoulders, 3 sets of 8 reps, intensity of 50 % of 1RM, break 3 min. 3. Lat pull downs, 3 sets of 10 reps, break between sets 2 min.
4. Session	1. Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1 RM, break 5 min. 2. Parallel squat- maximal jump with the bar upon the shoulders, 3 sets of 6 reps, intensity 50 % of 1RM, break 3 min.
5. Session	1. Half squat- maximal jump with the bar upon the shoulders, 2 sets of 8 reps, intensity 70 % of 1RM, breaks 3 min. 2. Preparation and spike in 2-3 steps (IMITATION), 2 sets of 8 reps, break between sets 2 min. 3. Low back hyperextension, 5 sets of 20, break between sets 2 min. 4. Sit ups, 5 sets of 20, break between sets 1 min.
6. Session	1. Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1 RM, break 5 min. 2. Preparation and spike in 2-3 steps (IMITATION), 2 sets of 8 reps, break between sets 4 min, between attempts 30 sec. 3. Low back hyperextension, 5 sets of 20, break between sets 1 min. 4. Sit ups, 5 sets of 20, break between sets 1 min.
7. Session	1. Drop jumps arm swings from 50 cm, 2 sets of 8 reps; breaks between sets 4 minutes, between attempts 20 sec. 2. Preparation and spike in 2-3 steps (IMITATION), 2 sets of 8 reps; breaks between sets 4 minutes, between attempts 20 sec. 3. Bench press, 3 sets of 10 with the bar (20 kg), breaks between sets 2 min. 4. Pull-over, 3 sets of 10 reps, break between sets 2 min.
8. Session	1. Drop jumps with arm swings from 70 cm, 2 sets of 8 reps; breaks between sets 4 minutes, between attempts 20 sec. 2. Preparation and spike in 2-3 steps (IMITATION), 2 sets of 10 reps. break between sets 4 min, between attempts 20 sec. 3. Lat pull-downs, 3 sets of 10 reps (pulling at the front); breaks between sets 3 min. 4. Low back hyperextension, 4 sets of 25 reps; break between sets 2 min.
9. Session	1. Parallel squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1 RM, break 5 min. 2. Drop jumps with arm swings from 75 cm, 2 sets of 10 reps; breaks between attempts 30 sec., between sets 6 min. 3. Sit ups, 5 sets of 20 (Upper), 5 sets of 20 (low abs), break between sets 1 min.
10. Session	1. Drop jumps with arm swings from 75 cm, 2 sets of 10 reps; breaks between attempts 30 sec., between sets 6 min. 2. Drop jump with arm swings from 110cm, 2 sets of 10 reps. Break 30sec; between sets 8-10 min. 3. Lat pull downs, 3 sets of 10 reps (pulling at the front), 3 sets of 12 reps; break between sets 2 min. 4. Low back hyperextension, 4 sets of 25, break between sets 1 min.
11. Session	1. Parallel squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1 RM, break 5 min. 2. Drop jump with arm swings from 75 cm, 2 sets of 10 reps; breaks between sets 6 minutes, between attempts 30 sec.
12. Session	1. Drop jump with arm swings from 75 cm, 2 sets of 10 reps. breaks between sets 6 minutes, between attempts 30 sec. 2. Drop jump with arm siwngs from 110 cm, 3 sets of 10 reps; breaks between sets 8 minutes, between attempts 30 sec.

The testing was carried out by the hardware- software system (ProIng, Belgrade) consisting of special cells with a range of 7500 N and a sensibility of 1.25 N. The A/D conversion of the ratio strength/time was evaluated on a frequency of 100 kHz, and all the data regarding the produced muscle strength from the beginning of the muscle contractions to the maximal values for each attempt was recorded in special databases. The recorded data presented muscle strength recorded for every 1%, with all the characteristic moments of its development (Dopsaj et al., 2001). All the tests were carried out under isometric conditions on the following muscle groups: the extensors of the lower back by means of the "Dead lift" test – DEAD; the muscles flexors of the dominant hand by means of the "Hand grip" test – HAND; the leg extensors, by means of the "Standing leg extension" test – LEG, and the calf muscles extension from a sitting position by means of "Sitting Calf muscles extension" the – CALF (Desrosiers et al., 1998; Dopsaj et al., 2000; Dopsaj et al., 2001).

The following mechanical characteristics were measured: the level of the maximal developed muscle strength, in Newtons (N) – F_{max}, the time necessary for reaching maximal strength, in milliseconds (ms) - tF_{max}, the rate of strength development as a level of the explosive capacity, in Newton/ second (N/s) - RFD_{max}, the impulse of the strength developed, in Newton · second (Ns) – $ImpF_{max}$, and the coefficient of the muscle activation velocity, using the index – C_{max} (Zatsiorsky, 1995; Verkhoshansky, 1999; Pablos Abella et al., 1999; Dopsaj et al., 2000; Dopsaj et al., 2001).

After a short warm up of three minutes, it was explained to the athletes what each particular test was, and after that the participants made their initial/probe attempts. After a five-minute break two measures were taken for every muscle group following the procedure explained below (Desrosiers et al., 1998; Dopsaj et al., 2000; Dopsaj et al., 2001).

The evaluation of the lower back extensors was carried out by means of the following procedure: the athlete stands on a platform, feet parallel and at shoulder width, caches the short bar and moves the upper body hooking the lower part of the cell to the platform; her back remains straight along with her arms and legs; hearing the signal, the athlete makes a voluntary contraction of the lower back extensors remaining in the same position (Figure 1, upper left frame).

The evaluation of the flexors of the dominant hand was carried out by means of the following procedure: standing, the athlete holds the cell, while her arm remains straight and 5- 10 cm away from the body; hearing the signal she voluntary squeezes her hand, remaining in same position (Figure 1, upper right frame).

The evaluation of the leg extensors was carried out by means of the following procedure: the athlete stands on the platform, takes the cell and connects it with the platform; her back remains straight along with her arms; her feet are parallel and separated at shoulder width; her legs are in a semi-squat position, at approximately 130 degrees; hearing the signal, she extends her legs as much as possible, keeping her body in the same position; no movements are made in the front and lateral planes (Figure 1, low-left frame).

The evaluation of the ankle extensors was carried out by means of the following procedure: the athlete sits on the chair putting her feet on the platform; her feet remain parallel and separated at shoulder width; the cell is connected to the platform; the upper part of the cell goes over the knees which are protected from mechanical injures by a soft sponge; the athlete secures the cell by holding it; hearing the signal she voluntary contracts the calf muscles making the bi-lateral plantar extension of her ankles (Figure 1, low-right frame).

Fig. 1. The position of the athlete during the tests

The methods of calculating the mechanical characteristics of isometric muscle strength

The velocity of the motor units' activation was calculated using the following formula (Dopsaj et al., 2001):

$$C_{max} = -(\mathrm{Ln}\,(1 - F_{(t)} / F_{max}) / t_{(F)})$$

- where: F(t) 1%, 2%, 3%,….99% represents the percentage of the maximal developed strength, F_{max} represents the maximal value of the achieved strength, and $t_{(F)}$ represents the time it takes to reach maximal strength $F_{(t)}$. Ln is a standard mathematic symbol for a logarithm.

The rate of strength development was calculated using the following formula (Dopsaj et al., 2001)

$$RFD = (F_{max} / tF_{max}) \cdot 1000$$

- where: F_{max} represents the maximal value of the achieved strength and tF_{max} represents the necessary time to achieve it and 1000 is a constant.

The impulse of the developed strength was calculated using the following formula (Dopsaj et al., 2001):

$$ImpF = \sum_{n=1}^{100} F_n \bullet \Delta t_n$$

- where: $\Delta t_n = t_n - t_{(n-1)}$, n represents 1%, 2%, 3%,......, 100% of the muscle strength and the time necessary for its production. F_n represents 1%, 2%, 3%,......, 100% of the produced muscle strength.

All the obtained results were statistically evaluated by means of descriptive statistics (; (mean), SD, cV% (coefficient of variation). Total variability as well as the differences between particular results during the tests were analyzed using MANOVA (Hair et al., 1998). The analysis of the means was determined by the Student *t* - test for small groups (Perić, 1996). All statistical operations were carried out on a Pentium PC I of 160 MHz and by applying the SPSS for Windows (Release 10.0 - Standard Version, Copyright©SPSS Inc., 1999).

3. THE RESULTS

All the results obtained are presented in Table 2. The coefficient of variation (cV%), ranges from 0.07 to 0.17 for F_{max}, from 0.28 to 0.75 for the tF_{max}, from 0.33 to 0.77 for the RFD_{max}, from 0.32 to 0.65 for $I_{mp}F_{max}$, and from 0.14 to 0.69 for the C_{max}. The analysis of the coefficient of variance demonstrates the range from an extremely compact to a non-compact group, but this fact permits further parametric statistical analysis (Perić, 1996).

Generally, the ratio final result/initial result shows a significant improvement in $F_{max,}$ from 2.270 to 4.472, or an average of 3.49% (Table 3). The tF_{max} was reduced from 11.908 to 25.972, creating an average of 16.6%. RFD increased from 21.384 to 52.096, but not in the case of the LEG which was reduced by 11.157%; the results of the impulse showed a reduction from 1.502 to 18.203, or an average 9%. The C_{max} increased from 17.225 to 33.139, an average of 18.7%.

Table 2. The basic statistical data gathered at the initial and final tests

	Initial tests – TEST 1 (Mean±SD)				
	F_{max} (DaN)	t_{max}(ms)	RFD_{max} (DaN/s)	$ImpF_{max}$ (DaNs)	C_{max}
DEAD	108.99 ± 8.42	1522.5 ± 813.4	95.49 ± 57.79	130.52 ± 64.35	10.87 ± 7.59
HAND	37.43 ± 4.16	1099.0 ± 400.7	38.83 ± 15.32	31.16 ± 11.90	30966 ±4343
LEG	103.49 ± 18.0	1616.4 ±1216.4	95.36 ± 61.04	123.19 ± 80.31	5.91 ± 3.64
CALF	249.2 ±44.44	1924.8 ± 540.2	138.92 ± 46.40	378.45 ± 135.80	4.03 ± 1.31
	Final tests – TEST 2 (Mean±SD)				
DEAD	113.86 ± 11.8	1315.2 ± 554.2	115.91 ± 89.44	123.45 ± 53.45	12.74 ± 6.24
HAND	38.82 ± 4.64	935.2 ± 444.0	50.60 ± 25.31	32.22 ± 15.39	30923 ±5855
LEG	107.13 ± 13.7	1423.8 ± 572.4	84.72 ± 29.92	121.34 ± 41.56	7.37 ± 4.87
CALF	254.86 ± 42.8	1424.9 ± 508.1	211.29 ±110.59	309.56 ± 149.17	5.36 ± 1.48

Table 3. The percentages of particular test results (Final test / Initial test)

%Δ	F_{max}	tF_{max}	RFD_{max}	$I_{mp}F_{max}$	C_{max}
DEAD	4.472	–13.613	21.384	–5.419	17.225
HAND	3.716	–14.908	30.298	–10.897	–0.139
LEG	3.522	–11.908	–11.157	–1.502	24.774
CALF	2.270	–25.972	52.096	–18.203	33.139

The results of multi- variant analysis are presented in Tables 4. and 5.

Table 4. MANOVA Results (General linear model)

	Wilk's lambda	F-ratio	p-value
All the results	0.000358	2794.310	0.015
F_{max}	0.01	307.725	0.000
RFD_{max}	0.44	8.076	0.570
C_{max}	0.05	79.074	0.020
tF_{max}	0.14	27.176	0.100
$I_{mp}F$	0.29	12.663	0.300

Generally, on the basis of the MANOVA results (Table 4) a total variability of the aspects of the muscle groups analyzed confirms the statistical differences of Wilk's lambda 0.000358 and the p- value 0.015. Particularly, the statistically significant changes occurred in maximal strength (F_{max}) and the coefficient of muscle activation velocity (C_{max}).

Table 5. Results of the Student t - test for the pending samples

Δ difference – Ratio initial/ final result		t-ratio	p-value
F_{max}	DEAD	1.658	0.128
	HAND	1.528	0.158
	LEG	1.088	0.302
	CALF	0.418	0.658
RFD_{max}	DEAD	0.932	0.373
	HAND	1.134	0.272
	LEG	–0.627	0.545
	CALF	2.105	0.062
C_{max}	DEAD	1.211	0.254
	HAND	–0.300	0.977
	LEG	1.363	0.207
	CALF	2.502	**0.031**
tF_{max}	DEAD	1.054	0.317
	HAND	0.931	0.374
	LEG	0.762	0.464
	CALF	3.758	**0.004**
$I_{mp}F_{max}$	DEAD	0.371	0.718
	HAND	0.630	0.543
	LEG	0.085	0.934
	CALF	2.289	**0.045**

Based on the results of the Student's *t* - test (Table 5) which evaluates the different aspects of muscle strength, it can be concluded that the applied combined training model caused statistically significant changes in the case of the calf muscles (CALF) in the following aspects: the impulse of muscle strength ($I_{mp}F_{max}$) at p = 0.045, the time necessary for reaching maximal strength (tF_{max}) at p = 0.004 and the coefficient of the muscle activation velocity (C_{max}) at p = 0.031.

4. DISSCUSION

Much of the research that has been carried out has proven that the plyometric method of training consisting of drop-jumps from different heights and combined with the weightlifting of maximal and sub-maximal weights improves the characteristics of leg extensors in terms of maximal muscle strength and the time necessary for reaching it (Zatsiorsky, 1995; Hewett at al. 1996; Gehri at al. 1998; Verkhoshansky, 1999; Pablos Abella at al., 1999; Scott, 1999; Rimmer, & Slievert, 2000).

Improvement of the maximal muscle strength of the leg extensors, as a consequence of the applied plyometric training, is a result of the combined mechanism of inter-muscular coordination along with the enlarged lateral section of muscle tissue of the activated muscles (Potteiger at al., 1999).

By investigating the effects of a special training of explosive strength over a period of nine weeks on samples of 26 male volleyball and basketball players (Pablos Abella at al., 1999) it has been proven that the plyometric training model (drop-jumps of 40 and 60 cm combined with weightlifting of sub-maximal intensity (80% of 1 RM)) produced better explosive strength results under dynamic conditions than the weightlifting of light weights (15 and 30% of 1 RM). Both applied methods improved muscle strength under dynamic conditions. This research demonstrated that during a four-week training period, the intensity of weightlifting was 50, 70, 90-95% of 1 RM, including the drop-jumps of 50, 75 and 110 cm. The mentioned combinations were chosen in accordance with previous research which proved that at a height of 75 cm, explosive strength, during a drop-jump from 110cm, is recommended for the development of maximal muscle strength (Verkhoshansky, 1999).

The results obtained in this research (Table 4 and 5) demonstrated a general positive change in the aspects of muscle strength of all the muscle groups involved on level of Wilk's lambda 0.000358 and the p-value of 0.015 (Table 4). Considering the different characteristics of muscle strength, statistically significant changes were produced in maximal isometric strength (p = 0.000) and the coefficient of muscle activation velocity (p = 0.020), (Table 4).

By analyzing the aspects of maximal isometric muscle strength, a statistically significant improvement occurred on a general level, or precisely, in the shape of a total variability of results of all the analyzed muscle groups. While analyzing the particular muscle groups, no changes occurred. The applied model of sports training in this research had generally improved the muscle strength of the analyzed muscle groups, but had had no influence on the particular variability of maximal strength of each muscle group individually.

The major statistical changes were recognized in the case of the calf extensors (Table 5), which participated with a 22% in the height achieved in the vertical jump as the most frequently used element in a volleyball game. Statistically significant changes occurred in the coefficient of muscle activation velocity (p = 0.031), the time necessary for reaching maximal strength was reduced ($p = 0.004$) and the impulse of muscle strength was improved ($p = 0.045$).

All of the data obtained in this research is in accordance with the conclusions of other authors (Zatsiorsky, 1995; Hewett at al. 1996; Gehri at al. 1998; Verkhoshansky, 1999; Pablos Abella at al., 1999; Scott, 1999; Rimmer, & Slievert, 2000), in terms of the influence of the plyometric training model consisting of drop- jumps and weightlifting where the reduction in the time necessary for reaching maximal strength of the muscles involved is notable. Analyzing the strength-time curve, the special applied method moves the curve to the left, that is, reduces the time necessary for the production of muscle strength within the 200- 350ms range (Bompa, 1999). Also, this special model of training improves the crucial moment of the stretch-shortening cycle of contraction (SSC[2]), that is, reduces the time it takes to switch from concentric to exocentric muscle contractions which synchronize the muscle units.

Surprisingly, no statistically significant changes occurred in the case of the leg extensors, not to mention that the applied model had not improved the rate of strength development or its explosive component. The maximal result of the rate of strength development of this muscle group was even reduced (Table 2 and 3).

These results could be explained by the following: during the first four weeks, the combined model for explosive strength was probably too short to adapt the nervous and locomotor system to the weights used in training. Also, the mentioned period was too short to allow the accumulation of positive changes due to the training process. Other authors, who raised the same issues, reached the same conclusion: special models caused similar changes but were implemented during periods lasting from six to twelve weeks (Hewet et al., 1996; Gehri at al., 1998; Pablos Abella at al., 1999; Potteiger et al., 1999; Verkhoshansky, 1999).

Considering the total amount of work and the relatively short period of implementation time, it is obvious that during the first two weeks the loads were of sub-maximal intensity and were followed by drop jumps. Also, the total amount of work consisting of 2-3 sets of sub-maximal weightlifting followed by two-week 3-4 set drop jumps, was not enough to stimulate muscles and register the statistically significant changes in the aspects of muscle strength and the rate of strength development of the tested muscle groups. Other research (Pablos Abella at al., 1999; Verkhoshansky, 1999) also included a special model of explosive strength training consisting of 4 to 6 sets of weightlifting of sub-maximal intensity followed by 3-4 sets of drop jumps.

It is important to highlight that the final testing took place in the beginning of the phase where the cumulative effect of the implemented training was being created, when the real physiological response of the body to the workout was still not recognized (no super-compensation), that is, the results were obtained during the negative phase of the body's adaptation. According to Verkhoshansky, (Verkhoshansky 1999), the optimal results, as a consequence of the special model of explosive strength training, should be recognized after eight or nine weeks from the beginning of its implementation.

As it was mentioned previously in regards to the evaluated muscle groups, the most significant changes were detected in the calf extensors in terms of the impulse of muscle strength, the time necessary for reaching maximal muscle strength as well as the coefficient of the muscle activation velocity, while such changes were not detected in the other evaluated muscle groups. This fact leads us to conclude that a specific relation exists

[2] SSC - stretch-shortening cycle

between the velocity and intensity of adaptation of different muscle groups from the point of view of the applied model. The final results show that the velocity and level of muscle adaptation depend on many factors such as different structures of muscle tissue, the size of the muscle group or the specific frequency of intensity (in terms of quantity and intensity) of particular muscle groups in relation to the implemented model of sport training.

Eight trained athletes (Haff at al., 1997) underwent the analysis of the strength- time curve during the "Dead lift" test with 80, 90, and 100% of 1RM: under dynamic and isometric conditions the production of the rate of strength development as a representative of explosive strength was demonstrated in the same way. Therefore, the possibility of statistical error in terms of experimental training processes implemented under dynamic, and tests implemented under isometric conditions was eliminated. (In this research the analysis of muscle strength was made under isometric conditions while the special model of sport training was realized under dynamic conditions).

5. CONCLUSION

Summarizing the results obtained in this research it can be concluded that the applied model of training implemented during a four-week cycle produced a selective statistical improvement of calf muscles in terms of the coefficient of muscle activation velocity, a reduction in the time necessary for reaching maximal strength and the muscle strength impulse. It is necessary to continue analyzing the strength-time curve, especially its first part regarding the characteristics of muscle strength of the muscle groups involved in this research.

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UTICAJ KOMBINOVANOG METODA ZA RAZVOJ EKSPLOZIVNE SNAGE ODBOJKAŠICA NA IZOMETRIJSKU MIŠIĆNU SILU RAZLIČITIH MIŠIĆNIH GRUPA

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Istraživanje je obavljeno sa ciljem da se utvrdi uticaj primenjenog modela treninga za razvoj eksplozivne snage na promene maksimalnih pokazatelja mehaničkih karakteristika izometrijske mišićne sile kod različitih mišićnih grupa koje trpe najviše opterećenja tokom odbojkaške igre. Model treninga je primenjen na uzorku od 11 kategorisanih odbojkašica tokom četvoronedeljnog mezociklusa sa učestalošću primene datog treninga od tri puta nedeljno. Inicijalno i finalno merenje datih karakteristika sile je izvršeno u izometrijskim uslovima nad četiri mišićne grupe: opružači mišića ledja, nogu i skočnog zgloba, kao i nad pregibačima prstiju šake. Posmatrane su sledeće karakteristike sile: maksimalna sila (F_{max}), vreme potrebno za postizanje F_{max} (tF_{max}), gradijent prirasta sile tj. eksplozivnost (RFD), impuls sile ($I_{mp}F_{max}$) i vrednost indeksnog pokazatelja brzine uključenja mišića (C_{max}). Testiranje je izvršeno pomoću hardversko-softverskog sistema (ProIng, Beograd) sastavljenog od tenziometrijskih sondi visoke osetljivosti. Razlike varijabiliteta između sveukupnog prostora merenja su procenjivane primenom multivarijatne tehnike MANOVE. Procena razlike srednjih vrednosti praćenih pojedinačnih varijabli između merenja je utvrđena primenom Studentovog t-testa za male uzorke iste grupe. Na osnovu rezultata $MANOVA_{-e}$ može se tvrditi da između merenja postoji generalna statistički značajna razlika na nivou Wilk's lambde 0,000358 i p-vrednosti 0,015. U odnosu na posmatrane karakteristike mišićne sile generalne statistički značajne promene desile su se kod pokazatelja F_{max} i C_{max}. Rezultati Studentovog t-testa pokazali su da je primenjeni model treninga na parcijalnom nivou u funkciji posmatranih mišićnih grupa doveo do statistički značajnih promena samo kod opružača skočnog zgloba ($LIST_{sed}$) i to kod karakteristika $I_{mp}F_{max}$ ($p = 0,045$), tF_{max} ($p = 0,004$) i C_{max} ($p = 0,031$).

Ključne reči: *odbojkašice, izometrijska sila, kombinovani metod treninga ekspozivnosti, pliometrija*