ORIGINAL ARTICLE

Effects of combined and classic training on different isometric rate of force development parameters of leg extensors in female volleyball players: Discriminative analysis approach

Rajić Branislav, Dopsaj Milivoj[1], Carlos Pablos Abella[2], Vicente Caratalla Deval, Karišik Siniša[3]
Faculty of Sport and Physical Education, University of Valencia, Spain, [1]Faculty of Sport and Physical Education, University of Belgrade, Serbia, [2]Institute of Sport and Physical Education, Catholic University of Valencia, Spain, [3]Faculty of Sport and Physical Education, University of Eastern Sarajevo, Bosnia and Hercegovina

Background: The aim of this study is to verify the effects of the combined and classic training of different isometric rates of force development (RFD) parameters of legs. **Materials and Methods:** Three groups of female athletes was tested: Experimental group (N = 12), classically trained group (N = 11), and control group (N = 20) of athletes. The isometric "standing leg extension" and "Rise on Toes" tests were conducted to evaluate the maximal force, time necessary time to reach it and the RFD analyzed at 100 ms, 180 ms, 250 ms from the onset, and 50-100% of its maximal result. **Results:** The maximal RFD of legs and calves are dominant explosive parameters. Special training enhanced the RFD of calves of $GROUP_{SPEC}$ at 100 ms (P = 0.05), at 180 ms (P = 0.039), at 250 ms (P = 0.039), at 50% of the F_{max} (P = 0.031) and the F_{max} (P = 0.05). Domination of $GROUP_{SPEC}$ toward $GROUP_{CLASS}$ and $GROUP_{CONTROL}$ is in case of legs at 100 ms (P = 0.04); at 180 ms (P = 0.04); at 250 ms (P = 0.00); at 50% of the F_{max} (P = 0.01) and at the F_{max} (P = 0.00); in case of calves at 100 ms (P = 0.07); 180 ms (P = 0.001); at 250 ms (P = 0.00); at 50% of the F_{max} (P = 0.00) and at F_{max} (P = 0.000). **Conclusion:** Dominant explosive factors are maximal RFD of leg extensors and calves, and legs at 250ms. Specific training enhanced explosiveness of calves of $GROUP_{SPEC}$ general and partial domination of $GROUP_{SPEC}$ by 87% over $GROUP_{CLASS}$, and 35% over $GROUP_{CONTROL}$.

Key words: Calf muscles, isometric rate of force development, leg extensors, plyometric training, volleyball

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INTRODUCITON

Successful performance in modern elite volleyball demand from each player excellent physical, technical, and tactical preparation,[1,2,6-8,14,25,26,28,32,33] in order to execute certain elements of volleyball game in as short as possible time intervals. Numerous studies have demonstrated that the most effective method for explosive strength enhancement is the plyometric method consisted of jumps from different heights; weightlifting method consisted of maximal, submaximal and light weights as well as a combination of these methods.[3,8,19,21,23,27,29,35,37,38]

Elite volleyball athlete's performance is based on neural changes of the muscle fibers and their reorganization, peaking most possible achieved level of muscle force to the time interval from 250 ms to 300 ms from the onset of muscle contraction. In the case of volleyball, the most of the motor units are activated in a very short time, constantly increasing the frequency of its neural activation.[1-4,10,12,13,16,24,30,34,38]

The effects of specific training of explosive strength have a strong impact on the rates of force development (RFD),[1,10,19,35] enhancing the muscle force peaked on 30, 50, 100 and 200 ms of the onset of muscle contraction.

Some research conducted on elite female athletes including volleyball players demonstrated that the test of choice for estimating specific leg extensors specific abilities is the capacity to realize the most possible RFD,[11] peaked on 100, 180 and 250 ms from the onset of the muscle contraction. Explosive muscle force generated in these time intervals significantly surpassed the maximal generated muscle force of the same muscle groups.

The aim of this study is to verify and analyze the efficiency of specific, combined method of explosive force volleyball training on different RFD in isometric conditions of leg extensors of female volleyball players, and to compare it with classic method of training in order to provide exact information to coaches and help them to design new training methods toward

Address for correspondence: Dr. Rajić Branislav, 92-40 Vukasovićeva Street, 11090 Belgrade, Serbia. E-mail: branislav.rajic@flp.co.rs
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enhancement of explosive force parameters required in modern volleyball game.

MATERIALS AND METHODS

Subjects

All testing procedures were completed at the Serbian National Police Academy in Belgrade in 2009, in which 33 female athletes took part in accordance to the type of volleyball training, being divided into three groups: Specifically trained group of female volleyball players-starters ($GROUP_{SPEC}$) (*N* = 12) of the volleyball club "Mladost," Zemun, who competed in I Serbian female division; classically trained group ($GROUP_{CLASSIC}$) (*N* = 11) of starters of the volleyball club "Komete" who competed in Ib Serbian female division; and control group (*N* = 20) consisted of healthy female subjects of the University of Belgrade ($GROUP_{CONTROL}$). The differences in structure of training and athlete's performance level can be explained by the differences in muscle tissue and maximal nervous activation of muscles during the specific training, i.e., adaptation to specific training.[11,17]

Strength characteristics of starters and non-starters demonstrates significant differences in limbs strength especially in specific playing status.[28] Guided by the University ethics policy, written informed consent was obtained from athletes and parents/guardians prior to any form of participation. The paper was realized as part of the project "The effects of physical activity to locomotive, metabolic, psycho-social, and pedagogic state of the population in the Republic of Serbia" under number III 47015, and as part of the subproject "The effects of applied physical activity to locomotive, metabolic, psycho-social, and pedagogic state of athletes population in Serbia," which was sponsored by the Ministry of science and technological development in the Republic of Serbia — Cycle of scientific projects 2011-2014. This paper is original and not submitted elsewhere. Relevant statistical data with regards to the morphology of the tested groups are presented in Table 1.

Testing procedure

The testing was realized through the hardware-software system (ProIng, Belgrade) consisted of special cells ranging to 7500N and with sensitivity of 1.25N. The analog/digital, converter of force/time ratio was evaluating at the frequency of 100 KHz, and all data of muscle force produced from the onset of muscle contraction to its maximal values for each attempt were recorded in special databases. Recorded data presented muscle force storage at each 1%, with all the characteristic moments and its development.[9] All tests were made in isometric conditions applying "standing leg extension," and "Sitting Rise on Toes."[10,34,35]

The following mechanical characteristics were evaluated: The level of the maximal muscle force developed in Newton (N) - F_{max}, time necessary time to reach the maximal force in milliseconds - t_{Fmax}; the RFD as a parameter of explosive force muscle capacity in Newton/second (N/s)-the RFD of the muscle force in isometric conditions.[[9,20,31,35,36,38] Furthermore, these characteristics were analyzed on the level of 100 ms, 180 ms, 250 ms, and 50% of its maximal result as well as on the maximal muscle force level.[11,24,35,38]

The evaluation of the leg extensors was made by the following procedure: Upon 5 min of individual warm up phase, the athlete stands on the platform, takes the cell and connects with the platform; the back remain straight as well as arms; feet are in parallel position separated as shoulders are wide; legs are in semi squat position approximately 120°; hearing the signal, the athlete tries to make maximal intensive isometric contraction trying to extend legs as much as possible maintaining body in the same position; no movements are allowed in front and lateral plane.[9,33-35] Two measures were implemented with a 3 minute break between tests; better result considering the achieved muscle force was taken for further statistical analysis.

The evaluation of the calf muscle was made by the following procedure: The athlete sits on the chair, puts both feet on the platform so at least 2/3 feet are on the platform and heals are in the air; the athlete takes the cell and connects with the platform by putting knees under the cell; the back remain straight as well as arms; feet are in parallel position separated as shoulders are wide; knees are in position approximately 90°; hearing the signal, the athlete tries to make maximal intensive isometric contraction by rising on toes as much as possible maintaining body in the same position; no movements are allowed in front and

Table 1: Morphological characteristics of personal data of three sample groups

Variable	Mean	SD	cV%	Max	Min
$GROUP_{SPEC}$					
Height (mm)	1783.75	80.22	4.49	1860	1630
Weight (kg)	68.42	10.84	15.84	84.55	50.1
BMI (kg/m^2)	21.42	2.22	10.38	25.24	18.56
Age (years)	20.16	3.49	17.34	27	16
$GROUP_{CLASSIC}$					
Height (mm)	1770.83	50.88	2.87	1840	1670
Weight (kg)	64.51	5.66	8.78	73.25	55.8
BMI (kg/m^2)	20.53	1.14	5.58	22.35	19.29
Age (years)	15.66	0.94	6.01	17	14
$GROUP_{CONTROL}$					
Height (mm)	1668.05	51.96	3.11	1720	1550
Weight (kg)	58.73	5	8.52	67.3	49.05
BMI (kg/m^2)	23.78	18.34	21.1	1.51	7.15
Age (years)	22.5	3.25	14.45	27	18

lateral plane.[9,33-35] Two measures were implemented with a 3 minute break between tests; better result considering the achieved muscle force was taken for further statistical analysis.

Training procedure

Prior to application of four 4 week specific model of training,[36] two micro cycles (one 1 week each) were realized as a form of basic and specific preparation for it.

The model of training of $GROUP_{SPEC}$ implemented in this research consisted of four high intensity pre-competitive 7 days cycles,[34-36] and its implementation started approximately 8 weeks before the pre-competition cycle and 10 weeks before the official competition.[36] All training sessions were carried out in the weight room. The content of training sessions consisted of squats and squat-jumps of sub-maximal and maximal intensity of external weight as well as of counter movement jump from different heights, supported by core power exercise, presented in the Table 2.

The model of training of $GROUP_{CLASSIC}$ consisted of core power exercise, exercise for stamina, speed, and agility enhancement by repeating specific moments from the volleyball game.[22,25,38] No plyometric exercises were applied at all. The control group carried out physical activity twice a week,[38] mostly consisted of aerobic exercise and sport games. The variables obtained from both specific and classically trained group were compared with results of the control group in order to demonstrate the benefits of specially designed training for volleyball players and enhanced parameters due to applied activities.

Calculation the isometric muscle force characteristics was performed based on other studies of the basic, specific, and special parameters of the RFD of the muscle force developed in isometric conditions.[10,11,33,35]

Statistical procedures

All statistical analyses of data were carried out by the SPSS for Windows (Release 17.0-Standard Version, Copyright© SPSS Inc., 1999) using a significance level of 0.05. Descriptive statistics was used to evaluate samples (mean, SD, cV%, min, max).[15] A multivariate analysis of variance MANOVA was used to determine differences of the RFD of three tested groups of subjects at initial and final test on the general level. Test of mean comparisons with Bonferroni correction was performed to determine differences of the RFD between groups. The canonical discriminate functions analysis was performed to define the most dominant variables impact on performance of initial and final test.

RESULTS

The results of descriptive statistics of basic, specific, and special parameters of the RFD of leg extensors and calf muscle are presented in Table 3. MANOVA demonstrated differences between groups at initial test (Wilk's Lambda = 0.044; F = 10.608; P = 0.000) as well as in the final test, (Wilk's Lambda = 0.032; F = 12.764; P = 0.000) on the general level. The statistically important differences on partial level [Table 4]

Table 2: Schedule of specific model of training applied[36]

General model of applied training		
Introduction	**Main part**	**Cooling down**
Basic and specific warming up, (exercising while running, jumps, warming up with the 20 kg bar) approx. 15 min	One set of warming up with 50% of 1RM, afterwards implementation of the training model, approx. 30 min	Cooling down, stretching, massages or self-massage, approx. 10 min
The main part of experimental schedule		
1st session Deep squat with the bar upon the shoulders, 3 sets of 6 reps, intensity 85-90% of 1RM, break 4 min		
	Upper body push-ups from the knees, 3 sets of 10 reps, break between sets 2 min	
2nd session Fast parallel squat with the bar upon the shoulders, 3 sets of 8 reps, intensity 80% of 1RM, break 4-5 min		
	Low back hyperextensions, 5 sets of 20, break between sets 1 min	
	Sit ups, 5 sets of 20, break between sets 1 min	
3rd session Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1RM, break 5 min		
	Parallel squat-maximal jump with the bar upon the shoulders, 3 sets of 8 reps, intensity of 50% of 1RM, break 3 min	
	Lat pull-downs, 3 sets of 10 reps, break between sets 2 min	

Table 2: Schedule of specific model of training applied[36] (*Continued*)

The main part of experimental schedule

4th session Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1RM, break 5 min	
	Parallel squat-maximal jump with the bar upon the shoulders, 3 sets of 6 reps, intensity 50% of 1RM, break 3 min
5th session Half squat-maximal jump with the bar upon the shoulders, 2 sets of 8 reps, intensity 70% of 1RM, breaks 3 min	
	Preparation and spike in 2-3 steps (imitation), 2 sets of 8 reps, break between sets 2 min
	Low back hyperextension, 5 sets of 20, break between sets 2 min
	Sit ups, 5 sets of 20, break between sets 1 min
6th session Deep squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1RM, break 5 min	
	Preparation and spike in 2-3 steps (imitation), 2 sets of 8 reps, break between sets 4 min, between attempts 30 s
	Low back hyperextension, 5 sets of 20, break between sets 1 min
	Sit ups, 5 sets of 20, break between sets 1 min
7th session Drop jumps arm swings from 50 cm, 2 sets of 8 reps; breaks between sets 4 min, between attempts 20 s	
	Preparation and spike in 2-3 steps (imitation), 2 sets of 8 reps; breaks between sets 4 min, between attempts 20 s
	Bench press, 3 sets of 10 with the bar (20 kg), breaks between sets 2 min
	Pull-over, 3 sets of 10 reps, break between sets 2 min
8th session Drop jumps with arm swings from 70 cm, 2 sets of 8 reps; breaks between sets 4 min, between attempts 20 s	
	Preparation and spike in 2-3 steps (imitation), 2 sets of 10 reps. break between sets 4 min, between attempts 20 s
	Lat pull-downs, 3 set of 10 reps (pulling at the front); breaks between sets 3 min
	Low back hyperextension, 4 sets of 25 reps; break between sets 2 min
9th session Parallel squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1RM, break 5 min	
	Drop jumps with arm swings from 75 cm, 2 sets of 10 reps; breaks between attempts 30 s, between sets 6 min
	Sit ups, 5 sets of 20 (upper), 5 sets of 20 (low abs), break between sets 1 min
10th session Drop jumps with arm swings from 75 cm, 2 sets of 10 reps; breaks between attempts 30 s, between sets 6 min	
	Drop jump with arm swings from 110 cm, 2 sets of 10 reps. break 30 s; between sets 8-10 min
	Lat pull-downs, 3 sets of 10 reps (pulling at the front), 3 sets of 12 reps; break between sets 2 min
	Low back hyperextension, 4 sets of 25, break between sets 1 min
11th session Parallel squat with the bar upon the shoulders, 2 sets of 3, intensity 95% of 1RM, break 5 min	
	Drop jump with arm swings from 75 cm, 2 sets of 10 reps; breaks between sets 6 min, between
	Attempts 30 s
12th session Drop jump with arm swings from 75 cm, 2 sets of 10 reps. breaks between sets 6 min, between attempts 30 s	Drop jump with arm swings from 110 cm, 3 sets of 10 reps; breaks between sets 8 min, between attempts 30 s

Table 3: Results of descriptive statistics of basic, specific, and special isometric rates of the force development of leg extensors

Parameter	Test	$GROUP_{SPEC}$ Mean±SD	$GRUOP_{CLASSIC}$ Mean±SD	$GRUOP_{CONTROL}$ Mean±SD
$RFD_{100msLEG}$ (N/s)	Initial test	3920.95±1680.92	2778.58±910.13	3687.45±1882.73
	Final test	4362.69±1633.53	2408.52±848.62	3763.13±1887.55
P value		0.385	0.414	0.79
$RFD_{180msLEG}$ (N/s)	Initial test	2929.10±1333.58	2518.53±1160.06	2813.20±1643.86
	Final test	3372.37±1039.62	1799.54±773.20	2874.32±1676.49
P value		0.295	0.167	0.655
$RFD_{250msLEG}$ (N/s)	Initial test	11576.44±3916.62	7810.73±3907.60	2270.60±990.25
	Final test	11577.37±2864.39	6370.75±2686.90	2260.35±935.26
P value		0.941	0.405	0.571
$RFD_{50\%LEG}$ (N/s)	Initial test	3932.10±2497.75	2297.34±1566.86	2907.72±2139.80
	Final test	4889.51±3454.43	1547.90±989.46	3003.38±2166.46
P value		0.352	0.272	0.158
$RFD_{FmaxLEG}$ (N/s)	Initial test	896.53±437.24	561.31±240.51	538.31±260.79
	Final test	864.33±285.02	331.84±99.77	551.54±204.91
P value		0.92	0.000	0.911
$RFD_{100msCALF}$ (N/s)	Initial test	5901.88±2548.72	4289.63±1988.44	7954.28±2057.90
	Final Test	7780.09±2693.21	5459.52±1975.71	8202.10±1898.93
P value		0.05	0.257	0.905
$RFD_{180msCALF}$ (N/s)	Initial test	4910.25±2056.20	3778.66±2536.71	6005.96±998.36
	Final test	6604.09±2204.23	3957.44±1056.51	6095.00±859.20
P value		0.039	0.857	0.788
$RFD_{250msCALF}$ (N/s)	Initial test	4503.36±1732.98	2628.35±909.63	5366.57±889.87
	Final test	5883.47±1696.92	3526.14±827.30	5430.80±765.84
P value		0.039	0.05	0.811
$RFD_{50\%CALF}$ (N/s)	Initial test	4940.56±2101.51	3437.94±3463.68	5664.98±1508.01
	Final test	6845.53±2522.07	3038.01±1093.12	5919.77±1429.64
P value		0.031	0.76	0.488
$RFD_{FmaxCALF}$ (N/s)	Initial test	1337.44±520.94	370.16±106.26	1349.69±242.97
	Final test	1789.23±736.72	814.33±269.65	1354.76±234.14
P value		0.05	0.001	0.765

of three groups of subjects of initial and final test on partial level were analyzed by multiple comparisons by Bonferroni.

The most dominant variable and the second most dominant variable of both initial and final test were defined by the canonical discriminate functions, presented in the Table 5 by the variable coefficient saturation. The most important factor that defines explosive force is the RFD of the leg extensors peaked on 250 ms from the onset of contraction in initial and final test. The second most dominant parameter of the initial test is the RFD of the maximal muscle force of the calf muscle while the second most dominant parameters of the final test are the RFD of the maximal muscle force of leg extensors and calves. Centroid positions of initial and final test results are presented ([Chart 1 and Table 6.)] by group centroid values.

DISCUSSION

Enhanced jumping performance and the RFD of limbs is to be expected as a result of combined training consisted of plyometric exercise and power-oriented strength training,[37] no matter if it is being implemented during the pre-competitive season[5,8,34,35] or during the competition season.[29]

The MANOVA revealed in this research that the four four week special training has produced significant changes of the tested athletes in the initial test (F = 10.608; P = 0.000) and final test (F = 12.764; P = 0.000) among groups on the general level. The isometric peaks of force as well as dynamic peaks of the RFD strongly correlate with vertical jump performance.[20] Results of this research demonstrated that $GROUP_{SPEC}$ has developed more explosiveness by 81.1% of the RFD of leg extensors reached at 100 ms than $GROUP_{CLASSIC}$, and 15.9% more that the control group. The RFD of leg extensors reached at 180 ms of the $GROUP_{SPEC}$ surpassed by 87.4% the same parameter of $GROUP_{CLASSIC}$, and by 17.3% of $GROUP_{CONTROL}$. The RFD of leg extensors reached at 250 ms of the $GROUP_{SPEC}$ surpassed by 81.7% of the $GROUP_{CLASSIC}$, and by 512% surpassed the same parameter of the $GROUP_{CONTROL.}$ The RFD of leg extensors reached at 50% of the maximal force of $GROUP_{SPEC}$ surpassed by 316% the same parameter

Table 4: Results of test of multiple comparisons of the isometric rates of the force development of leg extensors of three tested groups by Bonferroni

Dependent variable	(I) groups	(J) groups	Mean difference initial test	*P* initial test	Mean difference final test	*P* final test
RFD$_{100msLEG}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1142.37	0.43	1954.17*	0.04*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	233.50	1.00	599.56	0.98
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	908.87	0.61	1354.61	0.17
RFD$_{180msLEG}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	410.57	1.00	1572.83*	0.04*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	115.89	1.00	498.05	0.97
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	294.67	1.00	1074.78	0.20
RFD$_{250msLEG}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	3765.71*	0.01*	5206.61*	0.00*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	9305.83*	0.00*	9317.01*	0.00*
	GROUP$_{CLASSIC}$	GROUP$_{CONTROL}$	5540.12*	0.00*	4110.40*	0.00*
RFD$_{50\%LEG}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1634.76	0.31	3341.60*	0.01*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	1024.37	0.60	1886.12	0.13
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	610.38	1.00	1455.48	0.50
RFD$_{FmaxLEG}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	335.22	0.08	532.48*	0.00*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	358.21*	0.012*	312.78*	0.001*
	GROUP$_{CLASSIC}$	GROUP$_{CONTROL}$	22.99	1.00	219.70	0.06
RFD$_{100msCALF}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1612.25	0.352	2320.57	0.07
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	2052.37*	0.045*	422.01	1.00
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	3664.62*	0.001*	2742.58*	0.014*
RFD$_{180msCALF}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1131.59	0.47	2646.65*	0.001*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	1095.70	0.27	509.09	1.00
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	2227.30*	0.012*	2137.56*	0.003*
RFD$_{250msCALF}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1875.01*	0.005*	2357.32*	0.00*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	863.21	0.173	452.66	0.84
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	2738.22*	0.000*	1904.66*	0.001*
RFD$_{50\%CALF}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	1502.61	0.41	3807.52*	0.00*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	724.42	1.00	925.75	0.48
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	2227.03	0.058	2881.76*	0.001*
RFDF$_{maxCALF}$	GROUP$_{SPEC}$	GROUP$_{CLASSIC}$	967.28*	0.000*	974.90*	0.000*
	GROUP$_{SPEC}$	GROUP$_{CONTROL}$	12.24	1.000	434.47*	0.036*
	GROUP$_{CONTROL}$	GROUP$_{CLASSIC}$	979.52*	0.000*	540.42*	0.020*

Table 5: Results of canonical discriminate functions of evaluated parameters with single variable saturation coefficient according to the functions

Dependent variable	Initial test		Final test	
	Funtion 1	Function 2	Function 1	Function 2
RFD$_{250msLEG}$	0.64*	0.02	0.65*	0.04
RFD$_{FmaxLEG}$	0.19*	0.16	0.04	0.57*
RFD$_{FmaxCALF}$	−0.12	0.75*	0.05	0.57*
RFD$_{250msCALF}$	−0.21	0.47*	0.19	0.51*
RFD$_{100msCALF}$	−0.22	0.28*	0.03	0.51*
RFD$_{180msCALF}$	−0.16	0.23*	0.12	0.50*
RFD$_{50\%CALF}$	−0.10	0.21*	−0.04	0.36*
RFD$_{100msLEG}$	0.00	0.16*	0.04	0.30*
RFD$_{50\%LEG}$	0.07	0.15*	0.04	0.29*
RFD 1$_{80msLEG}$	0.01	0.06*	0.10	0.29*

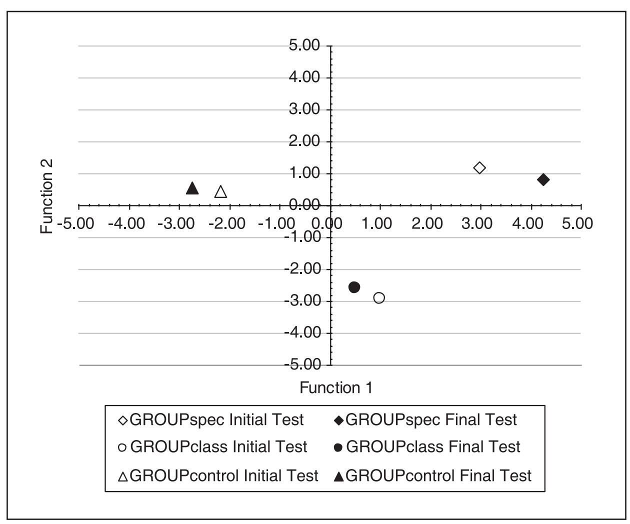

Chart 1: Centroid position of initial and final test among three groups

of GROUP$_{CLASS}$ as well as surpassed by 162% the same parameter of the control group. Modern volleyball defines the basic indicator of leg explosiveness as the RFD of leg extensors peaked on 50% and 100% of the muscle force, responsible for the second part of the force-time curve.[11]

The maximal RFD of leg extensors of GROUP$_{SPEC}$ was 25.9% higher than GROUP$_{CLASSIC}$, and 56.8% higher than the GROUP$_{CONTROL}$. This finding correlates with the conclusion

Table 6: Centroid values of the most dominant functions of initial and final test of three tested groups of subject

Group	Initial test		Final test	
	Funtion 1	Function 2	Function 1	Function 2
$GROUP_{SPEC}$	2.98	1.20	4.24	0.81
$GROUP_{CLASSIC}$	0.99	−2.93	0.51	−2.59
$GROUP_{CONTROL}$	−2.18	0.45	−2.75	0.55

that the RFD in a late phase of muscle contraction increases in response of high intensity training.[5] Plyometric method combined of vertical jumps and weightlifting enhances the muscle force and reduces the time of muscle contraction of calves,[18,34,35] enhancing the coefficient of the velocity of muscular activation.

Results achieved in this study demonstrated that the combined method implemented in this research enhanced the explosiveness of calves of $GROUP_{SPEC}$ at 100 ms from the onset of muscle contraction (31%), at 180 ms (34%), at 250 ms (30%), at 50% of the maximal force (38%) as well as of explosiveness of the maximal muscle force (33%). These findings are in agreement with previous research that shows that some plyometric exercises, such as quick movement jumps, produce higher RFD while slower jumps have lower RFD.[19]

The explosiveness in female athletes in group sports is determined by time intervals from 180 ms to 250 ms. This period of time during which the muscle force is being generated also shows the most homogeneous results regarding explosiveness compared to absolute results,[35] of the muscle force of leg extensors.

Statistical procedures have defined the RFD of leg extensors peaked at 250 milliseconds from the onset of muscle contraction as a first dominant variable of initial and final test explaining 64% of the total variance in initial, and 65% of the total variance in the final test. The general effect of special model of sport training applied in this research is the enhancement of explosiveness of leg extensors of specially trained group by 87% comparing classically trained group as well as the enhancement of 35% comparing to control group. This finding correlates with the conclusion of Ivanovic,[11] that leg extensors explosiveness is responsible, from the motor aspect, for realization of specific technical and tactical requirements, frequent changes of direction in frontal and lateral plane, and high and long jumps in modern volleyball.

The second dominant factor of explosiveness of the initial test is the RFD of maximal muscle force of calves that explains 75% of the total variance realized by this parameter. The most dominant parameters of the explosiveness of final test were maximal RFD of leg extensors and calves, participating by 57% in variance of all achieved results of final test. At time intervals later that 90 ms from the onset of muscle contraction, maximal muscle strength could count on 52-81% of the total variance in voluntary RFD.[2,3]

Vertical jump time allowed to develop force during isometric muscle contraction is approximately 300 ms to reach the maximum muscular force.[4,38] Therefore, vertical jump performance would be expected to depend on RFD,[1] during the later phase of contraction or muscle voluntary contraction.[19]

Practical application

From the practical point of view, jumping performance ability is primarily determined by maximal shortening velocity or muscle fiber type of lover limbs, but still there is a huge potential to develop explosive strength by using specially designed methods of training. Practical application of this research defines the most important time intervals in which explosive muscle force lower limbs muscles, which needs to be developed. Particularly, RFD of maximal strength of legs and calves as well as the RFD of legs at 250 ms from the onset are dominant factors of explosiveness of female volleyball players. The individual approach to each athlete could define right volume and intensity of this specially designed volleyball explosive strength enhancement program. Therefore, results of this paper could benefit coaches to analyze force-time curve in details for each athlete and to set up adequate volume/intensity ratio in order to stimulate physiological adaptation of neuromuscular system and lead athlete to best possible motoric performance, compare the same parameters between different sports that require explosiveness of limbs and compare performance between different levels of athletes.

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