Serbian Journal of Sports Sciences
2008, 2(4): 131-139, www.sjss-sportsacademy.edu.yu
UDC 796.325.025-055.2(497.11) ISSN 1820-6301
612.766

Original article
Received: 24 Oct 2008
Accepted: 21 Nov 2008

BASIC AND SPECIFIC PARAMETERS OF THE EXPLOSIVE FORCE OF LEG EXTENSORS IN HIGH TRAINED SERBIAN FEMALE VOLLEYBALL PLAYERS: CHARACTERISTICS OF THE ISOMETRIC FORCE- TIME CURVE MODEL

Branislav Rajić [1], Milivoj Dopsaj [2] & Carlos Pablos Abella[3]

[1]*National Institute of Physical Education, Valencia, SPAIN.*
[2]*Faculty of Sport and Physical Education, Belgrade, SERBIA.*
[3]*Theory of Sport Training, National Institute of Physical Education, Valencia, SPAIN.*

Abstract One of the most important characteristics to define the quality of realization of human locomotion is the mechanical contractile muscle capacity to develop as much force as possible in the function of movement in time. This research was conducted with an objective to determine isometric characteristics of force-time curve model related to basic and specific parameters of the explosive force of leg extensors in highly trained Serbian female volleyball players. The sample consisted of eighteen female volleyball players - BH 1.777±0.0675 m, BW 67.36±9.10 kg, BMI 21.25±1.99 kg/m^2 who competed in Second Serbian division. The test of the isometric muscle contractile characteristics was made on leg extensors in standing position. The following contractile characteristics were evaluated: basic characteristics – $RFD_{FmaxIZO}$ = 781.61±534.91 (N/s); the relation between $RFD_{FmaxIZO}$ and the maximal force, $RFD_{FmaxIZO}/F_{maxIZO}$ = 0.7598±0.4971, expressed in index units; and specific characteristics – $RFD_{IZOF50\%}$ = 3208.72 ±2303.56 (N/s), as a start gradient characteristics represented by the generation of force at 50% of its maximum; RFD_{IZO}250ms = 2349.51±920.64 (N/s), as Stretch Shortening Cycle gradient characteristics represented by RFD reached at 250ms; RFD_{IZO}180ms = 2751.31±1137.88 (N/s), as RFD reached at 180ms; RFD_{IZO}100ms = 3403.82±1595.96 (N/s), as RFD reached at 100ms. According to the relative isometric contractile values of muscles tested, the obtained results were as follows: RFD_{IZOrel}100ms = 208.53±103.03 N^{-s}/kg $BM^{0.667}$; RFD_{IZOrel}180ms = 167.50±68.72 N^{-s}/kg $BM^{0.667}$; RFD_{IZOrel}250ms = 142.84± 55.22 N^{-s}/kg $BM^{0.667}$; $RFD_{IZOrelF50\%}$ = 198.51± 154.94 N^{-s}/kg $BM^{0.667}$; $RFD_{FrelIZO}$ = 47.46±32.40 N^{-s}/kg $BM^{0.667}$. The results of the research showed that the variables RFD_{IZO}100ms, RFD_{IZO}180ms, RFD_{IZO}250ms and $RFD_{IZOF50\%}$ surpassed absolute $RFD_{FmaxIZO}$ values by 4.35, 3.52, 3.01 and 4.11 times , and its relative values by 4.39, 3.53, 3.01 and 4.18 times. The coefficient of variation (cV%) of variables showed that the most homogeneous results occurred at the levels of 250 ms, 180 ms, and 100 ms (RFD_{IZO}250ms, RFD_{IZO}180ms and RFD_{IZO}100ms).
.

Key words: female volleyball players, isometric force, Rate of Force Development, F-t isometric curve

INTRODUCTION

Successful performance in elite volleyball requires from each player a high level of technical, tactical and physical preparation [12, 20, 24]. Besides, a very important role in the modern volleyball game belongs to time and space dimensions, as well as the structure of the competitive activity of each player [20].

Psychological and motoric requirements in the volleyball game include frequent changes of direction in frontal and lateral plane, numerous high and long jumps as well as jumps characteristic of volleyball [10, 15, 20]. Such characteristics require adequate preparation and high performance in terms of sport technique, tactics and both basic and specific physical preparation since there are several jumping techniques in volleyball. When compared to the Step close jump, the hop jump produces higher peak force, vertical acceleration and storage of elastic energy of the muscles during Stretch Shortening Cycle (SSC) of the leg extensors [2, 3, 12, 15, 21, 24, 30].

Regardless of the kind of vertical jump performed during the game, muscle involvement of leg extensors is 56% [13]. Each player does an average of 22 offensive and defensive jumps per game [12, 30]. In successful teams, some elements of the volleyball game consisting of different jumps, such as the serve, can impact on the final result by its efficiency from 48.42 to 53.54%, as well as the element of block with its efficiency of 53.25% [20].

A great number of studies have demonstrated that the most effective method of physical preparation is the plyometric model of training consisting of jumps from different heights, weightlifting of maximal, sub-maximal and light weights, as well as numerous combinations of the methods mentioned. In addition, plyometric training improves lateral speed and forward sprints, as well as fitness characteristics that rely on strength and power reactions of leg push offs, such as lateral and forward sprints, drop jumps, and the maximal force produced [8, 11, 21, 25, 26, 27, 28, 29, 31, 32, 33].

There are a lot of techniques aimed at improving explosive strength. Both complex and compound trainings increase vertical jump height, but the minimum of three weeks' training is necessary for improving vertical leap and power components and output [18]. Special training also requires relative power, therefore it is suggested that power to weight ratio as well as plyometric training may be more effective for enhancing sport speed in elite players [3].

It has been demonstrated that the combined training of maximal weightlifting and depth jumps has more benefits in terms of the rate of force development (RFD) achieved than the method consisting of light weightlifting [21].

As a consequence of such special trainings, muscle strength is generated very fast, in between 100 ms and 200 ms, with a tendency of moving the force/time curve peak towards 100 ms. The peak of muscle force that exceeds 250 ms is not required in most sports. Sport performance of the highest level is based on neural and motoric changes of the muscle fibres and their reorganization, activating most of the motoric units in a very short time, and increasing the frequency of its activation [1, 33].

Some research conducted on elite female athletes including volleyball players has shown that the test of choice for estimating the specific fitness for the explosive strength of leg extensors is the ability of the muscle to realize the maximum gradient of the rate of force development in the time interval of 180 ms – RFD_{IZO}180ms [7].

A great number of studies that aimed to evaluate the vertical jump as a model for developing the contractile capacity applied, have assessed only the maximal muscle force and the rate of force development as the elements of great influence on complex motoric activities [13, 23, 32, 33, 34].

A certain time is necessary to develop a muscle force for a given motion. Isometrically, it is approximately between 0.3- 0.4 s and it usually takes longer than 0.4 s to reach peak force. As sport performance improves, the time of motion tends to shorten. The better the athlete's qualifications are, the greater the role of RFD in the achievement of high level performance is [25, 33].

The aim of the study was to define the basic and specific parameters of voluntary explosive isometric muscle force of leg extensors in highly trained Serbian female volleyball players. Different characteristics of explosive force in isometric conditions (RFD_{IZO}) can be determined through time intervals needed to develop capacities characteristic of jumping, as well as of special requirements of the volleyball game. These characteristics can be reached in 100 ms, 180 ms, or 250 ms, and at the level of 50% of the maximal muscle force (F100%). Beside aforementioned characteristics, the relationship between the rate of force development and maximal muscle force produced can also be relied on in order to define certain model parameters whose multifunctional role should be researched in future.

MATERIALS AND METHODS

SAMPLES

Eighteen female volleyball players, members of the A team of the volleyball club “MLADOST” Zemun, Belgrade, who competed in the Second division, took part in this research. Relevant statistical data with regard to the morphology of the tested group are presented in Table 1.

TESTING PROCEDURE

The testing was realized through the hardware-software system (ProIng, Belgrade) consisting of special cells ranging to 7500 N and with the sensitivity of 1.25 N. The A/D conversion of the force/time ratio was evaluated at the frequency of 100 KHz, and all the data of muscle force produced from the beginning of muscle contraction to its maximal values for each attempt were recorded in special databases. Recorded data presented muscle force recorded at each 1%, with all the characteristic moments of its development [6]. The test was made in isometric conditions on leg extensors, applying "Standing leg extension" test [4, 5, 6].

Table 1. Morphological characteristics of the sample

	MEAN	SD	CV%	MIN	MAX
Body Height (m)	1.777	0.067	3.76	1.624	1.860
Body Weight (kg)	67.36	9.10	13.51	49.05	87.00
BMI kg/m^2	21.25	1.99	9.34	18.35	26.12
Age (yrs)	20.15	2.95	14.64	17.20	25.8

The following mechanical characteristics were evaluated: the level of the maximal muscle force developed in Newton (N) - F_{max}, time necessary to reach maximal force in milliseconds (ms) - tF_{max}, and the rate of force development as the level of explosive capacity in Newton/second (N/s) - RFD_{max}. [5, 6, 21, 25, 32, 33]. Also, these characteristics were analyzed at the levels of 100 ms, 180 ms, and 250 ms, and at 50% of the maximal result [7, 33].

The evaluation of leg extensors was made by the following procedure: the athlete stands on the platform, takes the cell and connects with the platform; the back and the arms remain straight; the feet are in parallel position and as wide apart as to align with the shoulder width; the legs are in semi-squat position at approximately 130 degrees; on hearing the signal, the athlete executes maximal voluntary isometric contraction of the observed muscle group in order to extend the legs as much as possible, maintaining her body in the same position, with no movements made in front and lateral planes [6, 25, 26].

Methods of Calculating the Mechanical Characteristics of Isometric Muscle Force

The research applied the testing procedure in laboratory conditions as an experiment with one group in order to define the initial descriptive status of the variables observed [9]. There were two parameters that defined explosive force on the basic level: the rate of force development of the maximal strength generated in isometric conditions ($RFD_{FmaxIZO}$), as well as the relationship between the rate of force development of the maximal strength generated in isometric conditions and the maximal muscle force generated in isometric conditions ($RFD_{FmaxIZO}/F_{maxIZO}$). These parameters were calculated by the following formula:

- Basic explosive force representative [19, 33] –

$$RFD_{FmaxIZO} = (F_{maxIZO} / tF_{maxIZO}) \cdot 1000$$

  - where F_{maxIZO} represents the maximal value of force achieved, and tF_{maxIZO} represents the time in ms necessary to reach it, expressed in N/s.

- Coefficient for evaluating the participation of the level of explosive capacity compared to the maximal muscle force generated in the same activity [19] –

$$RFD_{FmaxIZO}/F_{maxIZO} = RFD_{FmaxIZO} / F_{maxIZO}$$

  - where $RFD_{FmaxIZO}$ represents the basic parameter of explosiveness, while F_{maxIZO} represents the maximal value of force achieved, expressed in index number.

Other four parameters defined the cluster of specific parameters of the explosive muscle capacity since they described the force/time curve in its initial period, i.e. in the early phases of the initiation of contraction of the tested muscle groups [7, 14, 32, 33].

These parameters were:

- The Rate of Force Development peaked at 100 ms ($RFD_{IZO}100ms$) -

$$RFD_{IZO}100ms = (F_{100msIZO} / tF_{100ms}) \cdot 1000$$

  - where $F_{100msIZO}$ represents the value of force achieved for 100 ms, and tF_{100ms} represents the time in ms necessary to reach it, expressed in N/s.

- The Rate of Force Development peaked at 180 ms ($RFD_{IZO}180ms$) -

$$RFD_{IZO}180ms = (F_{180msIZO} / tF_{180ms}) \cdot 1000$$

- where $F_{180msIZO}$ represents the value of force achieved for 180 ms, and tF_{180ms} represents the time in ms necessary to reach it, expressed in N/s.

- The SSC Rate of Force Development peaked at 250 ms ($RFD_{IZO}250ms$) –

$$RFD_{IZO}250ms = (F_{250msIZO} / tF_{250ms}) \cdot 1000$$

- where $F_{250msIZO}$ represents the value of force achieved for 250 ms, and tF_{250ms} represents the time in ms necessary to reach it, expressed in N/s.

- The S gradient or Rate of Force Development peaked at 50 % of F_{maxIZO} ($RFD_{IZOF50\%}$) -

$$RFD_{IZOF50\%} = (F_{50\%IZO} / tF_{50\%ms}) \cdot 1000$$

- where $F_{50\%IZO}$ represents the value of force achieved for 50 % of F_{maxIZO}, and $tF_{50\%ms}$ represents the time in ms necessary to reach it $F_{50\%IZO}$, expressed in N/s.

All results are expressed in absolute (N/s) and relative (N^{-s}/kg $BM^{0.667}$) values. Also, all relative values were calculated using the method of partialization, based on the allometric relationship [16].

STATISTICAL ANALYSIS

All the obtained results were statistically evaluated by the method of descriptive statistics (Mean, SD, cV%, Min, Max) [9]. All statistical operations were made using the SPSS for Windows (Release 10.0 - Standard Version, Copyright©SPSS Inc., 1999).

RESULTS

Basic absolute values of statistical data of isometric explosive force muscle characteristics are presented in Table 2.

Table 2. Basic statistical data of isometric explosive force muscle characteristics – absolute values

Leg extensors	*MEAN*	*SD*	*cV%* (%)	*Min*	*Max*
$RFD_{IZO}100ms$ (N/s)	3403.82	1595.96	46.89	1535.65	6831.77
$RFD_{IZO}180ms$ (N/s)	2751.31	1137.88	41.36	1052.97	5848.51
$RFD_{IZO}250ms$ (N/s)	2349.51	920.64	39.18	959.41	4780.73
$RFD_{IZOF50\%}$ (N/s)	3208.72	2303.56	71.79	752.52	8873.26
$RFD_{FmaxIZO}$ (N/s)	781.61	534.91	68.44	154.46	2190.56
$RFD_{FmaxIZO}/F_{maxIZO}$ (index)	0.7598	0.4971	65.42	0.2038	2.2694

The obtained results showed that in the time interval of 100 ms ($RFD_{IZO}100ms$) the subjects were able to reach the intensity of muscle force development of 3403.82±1595.96 N/s, while the coefficient of variation reached 46.89 %.

Considering the contractile potential of the isometric muscle force of leg extensors peaked at 180 ms ($RFD_{IZO}180ms$), the subjects reached the average rate of force development of 2751.31±1137.88 N/s, while the coefficient of variation reached 41.36%.

At the level of time of 250 ms ($RFD_{IZO}250ms$) the subjects reached the average rate of force development of 2349.51± 920.64 N/s, while the coefficient of variation reached 39.18%.

Analyzing the rate of force development at 50% of its maximal isometric muscle force of leg extensors produced ($RFD_{IZOF50\%}$), the average results obtained were 3208.72± 2303.56 N/s and the coefficient of variation reached 71.79%.

The rate of force development at maximal isometric muscle force ($RFD_{FmaxIZO}$) of leg extensors reached 781.61±534.91 N/s, while the coefficient of variation was 68.44%, and all the results ranged between 154.46 for MIN and 2190.37 N/s for MAX.

The relationship between RFD at maximal muscle force and maximal muscle force, both generated in isometric conditions, showed that the players had more explosive potential towards the potential of the maximal force at the level of 75.98 %. More precisely, as for average results obtained, the level of maximal muscle force was suppressed by 24.02% of the basic explosive potential.

All relative values of basic statistical data of isometric muscle explosive force characteristics are presented in Table 3.

Table 3. Basic statistical data of isometric muscle explosive force characteristics – relative values

Leg extensors	*MEAN*	*SD*	*cV%* (%)	*Min*	*Max*
RFD_{IZOrel}100ms (N^{-s}/kg $BM^{0.667}$)	208.53	103.03	49.41	97.37	464.48
RFD_{IZOrel}180ms (N^{-s}/kg $BM^{0.667}$)	167.50	68.72	41.02	66.77	316.13
RFD_{IZOrel}250ms (N^{-s}/kg $BM^{0.667}$)	142.84	55.22	38.66	58.18	258.41
$RFD_{IZOrelF50\%}$ (N^{-s}/kg $BM^{0.667}$)	198.51	154.94	78.05	42.92	661.34
$RFD_{FrelIZO}$ (N^{-s}/kg $BM^{0.667}$)	47.46	32.40	68.28	8.40	132.15

According to the relative isometric contractile values of the tested muscles, the obtained results showed that in the time interval of 100 ms (RFD_{IZOrel}100ms) the subjects were able to reach the intensity of muscle force per kg of body mass at the level of 208.53±103.03 N^{-s}/kg $BM^{0.667}$, while the coefficient of variation reached 49.41 %.

Considering the contractile potential of the relative isometric muscle force of leg extensors that peaked at 180ms (RFD_{IZOrel}180ms), the subjects reached the average rate of force development per kg of body mass at the level of 167.50±68.72 N^{-s}/kg $BM^{0.667}$, while the coefficient of variation reached 41.02%.

At 250ms (RFD_{IZOrel}250ms) the subjects reached the average rate of force development per kg of body mass at the level of 142.84± 55.22 N^{-s}/kg $BM^{0.667}$, while the coefficient of variation reached 38.66%.

Analyzing the rate of force development at 50% ($RFD_{IZOrelF50\%}$) of maximal isometric muscle force of leg extensors produced per kg of body mass, the average results obtained were 198.51± 154.94 N^{-s}/kg $BM^{0.667}$ and the coefficient of variation reached 78.05%.

The relative value of basic rate of force development level ($RFD_{FrelIZO}$) of leg extensors reached 47.46±32.40 N^{-s}/kg $BM^{0.667}$, while the coefficient of variation was 68.28%, and all the results ranged from 8.40 for MIN to 132.15 N^{-s}/kg $BM^{0.667}$ for MAX.

The results of this research showed that the RFD_{IZO}100ms surpassed $RFD_{FmaxIZO}$ of the maximal isometric muscle force of leg extensors by 4.35 times. RFD_{IZO}180ms surpassed $RFD_{FmaxIZO}$ by 3.52 times. At 250 ms, the peaked RFD_{IZO}250ms surpassed the $RFD_{FmaxIZO}$ by 3.01 times, while $RFD_{IZOF50\%}$ surpassed $RFD_{FmaxIZO}$ of the leg extensors by 4.11 times; these results are expressed in absolute values (Figure 1).

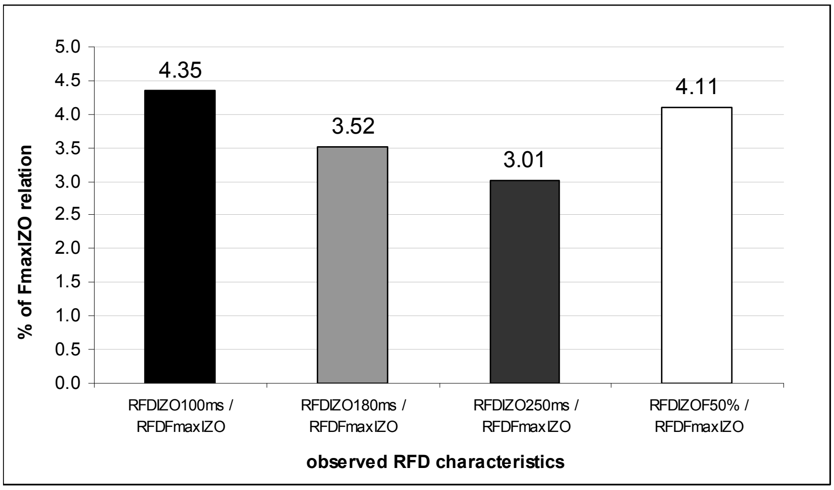

Figure 1. Index values of the relationship between specific and basic isometric RFD characteristics expressed in absolute values

The relative values of explosiveness are the same as those defined for absolute values. The results of this research showed that the rate of $RFD_{IZOrel}100ms$ surpassed $RFD_{FrelIZO}$ of the maximal isometric muscle force of leg extensors by 4.39 times. $RFD_{IZOrel}180ms$ surpassed $RFD_{FrelIZO}$ by 3.53 times. At the level of 250 ms, peaked $RFD_{IZOrel}250ms$ surpassed $RFD_{FrelIZO}$ by 3.01 times, while $RFD_{IZOrelF50\%}$ surpassed $RFD_{FrelIZO}$ of the leg extensors by 4.18 times (Figure 2).

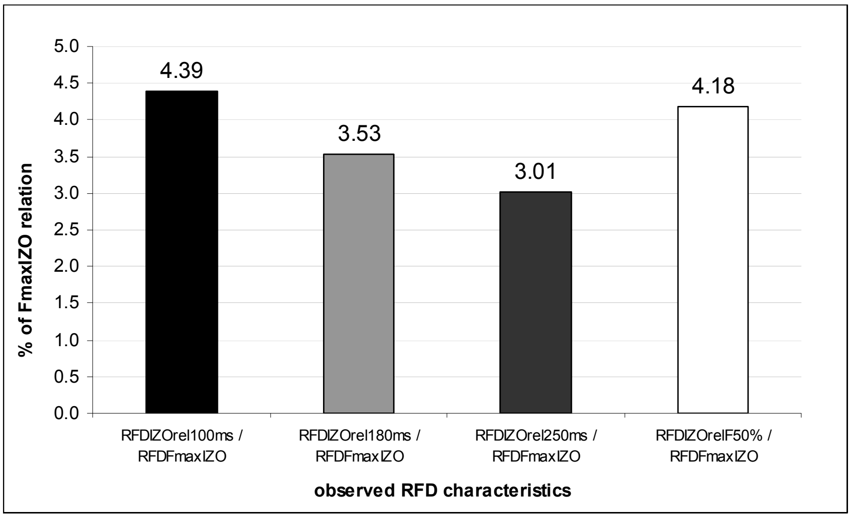

Figure 2. Index values of the relationship between specific and basic isometric RFD characteristics expressed in relative values

DISCUSSION

As mentioned above, one of the motoric elements most often applied in the volleyball game is a great variety of jumps [2, 20, 24, 30]. It can be maintained that during the preparation phase in female volleyball players coaches use different methods for developing contractile capacity of muscle strength of leg extensors, such as plyometric or dynamic weight lifting training [8, 12, 15, 21, 23, 25, 26, 27, 28, 31].

A great deal of research has proved that plyometric method of training consisting of drop- jumps from different heights and combined with weightlifting of maximal and sub-maximal weights improves the characteristics of leg extensors in terms of maximal muscle force and time necessary to reach it [8, 11, 21, 25, 26, 27, 28, 32, 33].

Under the eccentric or plyometric muscle action in the productive phases of motion, the generated muscle force can easily exceed maximal isometric strength of an athlete by 50-100%, and sometimes the eccentric force may reach twice the zero velocity of the isometric force [33].

It is very important to emphasize that all the results have shown, from the aspect of the index of coefficient of variation (cV%), which presents an index of homogeneity of variables evaluated, that the most homogeneous results in terms of explosiveness of female volleyball players reached, when compared to absolute results, were at the levels of 250 ms, 180 ms, as well as at the level of 100 ms ($RFD_{IZO}250ms$, $RFD_{IZO}180ms$ and $RFD_{IZO}100ms$). The values for the coefficient of variation of 39.18, 41.36 and 46.89 % represent the variation between the results of an individual athlete and the average results of the entire group (Table 2).

The coefficient of variation of the variables $RFD_{IZOF50\%}$, $RFD_{FmaxIZO}$, and $RFD_{FmaxIZO}/F_{maxIZO}$ ranged from 65.42% to 71.79 %, which is considered as a non-homogeneous group [22]. Exactly the same results were obtained in comparison to relative values where it was shown that the coefficient of variation of $RFD_{IZOrel}250ms$, $RFD_{IZOrel}180ms$ and $RFD_{IZOrel}100ms$ reached 38.66%, 41.02% and 49.41 % of homogenity, respectively, while the variation of variables $RFD_{FrelIZO}$ and $RFD_{IZOrelF50\%}$ reached 68.28% and 78.05 %, respectively. These results do not belong to the category of a non-homogeneous group (Table 3).

It is well known that the concept of sport training is based on two biological mechanisms: the process of homeostasis and adaptation of an athlete [1, 17, 32, 33]. Since the female volleyball players were members of the same club, and they were trained using the same or similar procedures (methods, intensities and models of training), it is most probable that the lower level of variation as well as greater homogeneity of special characteristics of explosiveness (RFD_{IZO}250ms, RFD_{IZO}180ms and RFD_{IZO}100ms), average 61.38 % of the absolute and average 70.03 % of the relative values, as compared to other parameters of explosiveness ($RFD_{IZOF50\%}$, $RFD_{FmaxIZO}$, and $RFD_{FmaxIZO}/F_{maxIZO}$), could be attributed to a mechanism of special adaptation.

Also, the applied model of training improved the athletes' physical capacity of leg extensors in terms of explosiveness in time intervals of 100 ms, 180 ms and 250 ms to become equalised. As a consequence of specific model of training applied, special parameters of all the female volleyball players became more homogeneous in terms of explosiveness in time intervals mostly recognized as typical of the volleyball game and of the realization of specific volleyball elements.

All of the data obtained in this research are in accordance with the conclusions of other authors [8, 11, 21, 27, 28, 32, 33] in terms of the influence of plyometric training consisting of drop-jumps and weightlifting, where the reduction of time necessary to reach the specific level of force or maximal force of involved muscles is notable. Analyzing the force-time curve, the special method moves the curve to the left, that is, reduces the time of muscle force generation in the range of 200-350 ms [1]. Also, this special model of training improves the crucial moment of stretch-shortening cycle of contraction (SSC), that is, reduces the time necessary to switch from concentric to eccentric muscle contraction synchronizing the muscle units [14].

It is necessary to emphasize that only few previous studies of explosiveness have determined the correct specific time interval for evaluating explosiveness in female athletes in group sports, which is the time interval of 180 ms. It means that the level of explosiveness reached in that time interval statistically describes specific characteristics of female top athletes, as compared to well-trained athletes and non-trained groups [7].

CONCLUSIONS

In summary, the results obtained in this research can lead to a conclusion that the applied model of training implemented during four weeks' cycle produced significant changes in the explosive capacity of leg extensors at the levels of 100 ms, 180 ms and 250 ms.

The results have also shown that the rate of force development produced in isometric conditions at the levels of 100 ms, 180 ms, and 250 ms, as well as at the level of 50% of maximal force, significantly surpassed the rate of force development of the maximal strength in isometric conditions.

According to relative values of explosiveness, they are identical to those defined for absolute values. Our results have shown that the rate of RFD_{IZOrel}100ms, RFD_{IZOrel}180ms, RFD_{IZOrel}250ms and $RFD_{IZOrelF50\%}$ significantly surpassed the relative rate of force development of the maximal force in isometric conditions.

Special parameters of all female volleyball players became more homogeneous in terms of explosiveness in time intervals mostly recognized as typical of the volleyball game and of the realization of specific volleyball elements. The applied model of training improved their physical capacity of leg extensors in terms of explosiveness in time intervals of 100 ms, 180 ms and 250 ms.

According to our research, in terms of the coefficient of variation (cV%), the most homogeneous results regarding explosiveness and as compared to absolute results were at the levels of 250 ms, 180 ms, as well as at the level of 100 ms.

Exactly the same results were obtained for relative values, where it was shown that the coefficient of variation of RFD_{IZOrel}250ms, RFD_{IZOrel}180ms and RFD_{IZOrel}100ms was considered as homogeneous, while the variation of variables $RFD_{FrelIZO}$ and $RFD_{IZOrelF50\%}$ was considered as non-homogeneous. This conclusion could be considered as a consequence of the mechanism of special adaptation to the applied model of sport training.

Based on the conclusions from previous research that showed that the explosiveness in female athletes in group sports is determined by the time interval of 180 ms. This means that the level of explosiveness reached in that time interval statistically describes specific characteristics of female top athletes, as compared to well-trained athletes and non-trained groups.

PRACTICAL APPLICATION

Practical application of this research provides an additional explanation to the characteristics of the elite female volleyball players, yielding the initial data for future research of these characteristics, as well as the effects of this and other training procedures that include explosive muscle force. It is also possible to compare the results and set up correlation of the obtained parameters of the motoric capacity and an aspect of volleyball performance in terms of efficiency in the game, as well as to ensure other longitudinal and transversal research in sport training.

REFERENCES

1. Bompa, T. (2000). *Periodizacion del entrenamiento deportivo*. Espana: Editorial Paidotribo.
2. Coutts, K. D. (1982). Kinetic differences of two volleyball jumping techniques. *Med Sci Sports Exerc*., 14(1): 57-59.
3. Cronin, J. B., & Keir, T. H. (2005). Strength and power predictors of sport speed. *J Strength Cond Res*., 19(2): 349-357.
4. Desrosiers, J., Prince F., Rochette, A., & Raiche, M. (1998). Reliability of lower extremity strength measurements using the Belt-resisted method. *J Aging Phys Activity*., 6: 317-326.
5. Dopsaj, M., Milošević, M., & Blagojević M. (2000). An analysis of the reliability and factorial validity of selected muscle force mechanical characteristics during isometric multi-join test. In Hong, Y. & Johns, D. (Eds). *Proceedings of XVIII International Symposium on Biomechanics in Sport, Vol. I* (p. 146-149). Hong Kong: The Chinese University of Hong Kong.
6. Dopsaj, M., Milošević, M., Vučković, G., & Blagojević, M. (2001). Metrological values of the test to assess mechanical characteristics of maximal isometric voluntary knee extensors muscle force from standing position. *NBP-Journal of Police Academy*, Belgrade, 6(2):119-132.
7. Dopsaj, M., Rajić, B., Koropanovski, N., & Milošević, M. (2004). The structure of different indicators of leg-extensor explosiveness in the top-level female athletes in selected sports. In Kellis, E., Amiridis, I & Vrabas, I. (Eds). *4th International Conference on Strength Training: Book of Abstracts* (p. 263-264). Serres, Greece: Aristotle University of Thessaloniki, Department of Physical Education and Sport Science at Serres.
8. Gehri, D., Ricard, M., Kleiner, D., & Kirkendall, D. (1998). A comparison of plyometric training techniques for improving vertical jump ability and energy production. *J Strength Cond Res*., 12(2): 85-89.
9. Hair, J., Anderson, R., Tatham, R., & Black, W. (1998). *Multivariate data analysis with readings (Fifth Ed.)*. New Jersey: Prentice-Hall International, Inc.
10. Harman, A. E., Rosenstein, M. T., Frykman, P. N., & Rosenstein, R. M. (1990). The effects of arms and countermovement on vertical jumping. *Med Sci Spotrs Exerc*., 22(6): 825-833.
11. Hewett, T., Stroupe, A., Nance, T., & Noyes, F. (1996). Plyometric training in female athletes. *Am J Sports Med*., 24(6): 765-775.
12. Hedrick, A. (2008). Training for high level performance in women's collegiate volleyball: Part II: Training program. *Strength Cond J*., 30(1): 12-21.
13. Jarić, S. (1987). Biomechanical studies of maximal counter movement jump and their implication in practice. *Physical Culture*, Belgrade, 41(1): 30-37. (in Serbian).
14. Komi, P.V. (1992). Stretch-shortening cycle. In: *Strength and Power in Sport*. In Komi, P. V. (Eds). The Encyclopaedia of Sports Medicine (p. 169-179). Oxford: Blackwell Scientific Publications.
15. Kroon, S. (2000). Vertical jump ability of elite volleyball players compared to elite athletes in other team sports. *www.Faccioni.com/ reviews* (20.3.2002).
16. Markovic, G., & Jaric, S. (2005). Scaling muscle power to body size: the effects of stretch-shortening cycle. *Eur J Appl Physiol*., 95(1): 11-19.
17. Milišić, B. (2007). Efficiency in sport and training management theory. *Serb J Sports Sci*., 1(1-4): 1-7.
18. Mihalik, J. P., Libby, J. J., Battaglini, C. L., & McMurray, R. G. (2008). Comparing short term complex and compound training on vertical jump height and power output. *J Strength Cond Res*., 22(1): 47-53.
19. Mirkov, D. M., Nedeljkovic, A., Milanovic, S., & Jaric S. (2004). Muscle strength testing: evaluation of tests of explosive force production. *Eur J Appl Physiol*., 91(2-3): 147-154.
20. Nešić, G. (2008). The structure of the competitive activities of female volleyball players. *Annual of Faculty of Sport and Physical Education,* 14: 89-112. (in Serbian).
21. Pablos Abella, C. M., Navarro Cabello, E., Salvador Fernández-Montejo, S., Benavent Mahiques, J., González Bono, E., Chillarón García, E., Cervera Torres, L., Giner Garrido, A., & Martí Calatayud, M.T. (1999). Efectos sobre la mejoría de la fuerza y el ratio testosterona/cortisol de dos métodos de entrenamiento de fuerza explosiva del tren inferior en el periodo competitivo de deportes de equipo. Efectos e implicaciones de variables fisiológicas sobre el entrenamiento. *ICD*., 3: 95-132.
22. Perić, D. (1996). *Statistical application in physical culture research*. Belgrade: FINE-Graf. (in Serbian).
23. Potteiger, J., Lockwood, R., Haub, M., Dolezal, A., Almuzaini, S., Schroeder, M., & Zebas, J. (1999). Muscle power and fibre characteristics following 8 weeks of plyometric training. *J Strength Cond Res*., 13(3): 275-279.
24. Puhl, J., Case, S., Fleck, S., & Van Handel, P. (1982). Physical and physiological characteristics of elite volleyball players. *Res Quart Exerc Sport*., 53(3): 257-262.
25. Rajić, B. (2003). *Efectos del entrenamiento específico de fuerza explosiva de miembros inferiores sobre las dimensiones máximas de la fuerza explosiva de los distintos grupos musculares en jugadoras de voleibol: Trabajo de Investigación*. Valencia, España: Facultad de Ciéncies de l' Activitat Física I l' Esport.
26. Rajić, B., Dopsaj, M., & Pablos Abella, C. (2004). 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. *FACTA UNIVERSITATIS: Series Phys Education Sport*., 2(1): 1-12.
27. Rimmer, E., & Slievert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *J Strength Cond Res*., 14(3): 295-301.

28. Scott, G. (1999). Off-season strength, power, and plyometric training for Kansas State volleyball. *National Strength Cond Assoc*., 21(5): 49-55.
29. Salonikidis, K., & Zafeiridis, A. (2008). The effects of plyometric, tennis drills, and combined training on reaction, lateral and linear speed, power and strength in novice tennis players. *J Strength Cond Res*., 22(1): 182-191.
30. Tillman, M. D., Hass, C. J., Brunt, D., & Bennet, G. R. (2004). Jumping and landing techniques in elite women's volleyball. *J Sport Sci Med*., 3(1): 30-36.
31. Triccoli, V., Lamas, L., Carnevale, R., & Ugrinowitsch, C. (2005). Short term effects on lower body functional power development: Weightlifting vs. vertical jump training process. *J Strength Cond Res*., 19(2): 433-437.
32. Verkhoshansky, Y. (1999). *Todo sobre el método pliométrico*, Barcelona, España: Editorial Paidotribo.
33. Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and practice of strength training (Sec. Ed.)*. Champaign, IL: Human Kinetics.
34. Young, W., McLean, B., & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness*., 35(1): 13-19.

Address for correspondence:

Rajic Branislav, MSci.
Institute of Physical Education,
c/ Gasco Oliag 3,
46010 Valencia, Spain.
Home: Vukasoviceva 92/40,
11090 Beograd, Serbia
home phone: +381 (11) 35 94 265;
mobile: +381 65 3970 123,
E-mail:: banerajic@yahoo.com