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Original empirical article

IS THERE A RELATION BETWEEN MAXIMAL AND EXPLOSIVE LEG EXTENSORS ISOMETRIC FORCE?

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Abstract. *The aim of this research was to establish the relation between maximal isometric force and different indicators of isometric explosive force of leg extensors (iRFD). The sample consisted of 83 participants divided into 2 groups in terms of gender, males N=53 and females N=30. In order to assess the characteristics of the F-t isometric leg extensor force, tensiometric probes and the standardized "seated leg extension" test were used. The measurement range was defined by 6 variables for the contractile characteristics of the leg extensor isometric muscle force – 1) the level of achieved maximal force – FmaxLEGEXTISO, 2) the indicator of the basic (general) level of rate of force development – RFDBASICLEGEXTISO, 3) the indicator of the specific level of rate of force development – RFD50%LEGEXTISO, and three indicators for evaluating the special level of the explosive force development, i.e. leg extensor explosiveness, 4) measured at 250ms – RFD250msLEGEXTISO, 5) measured at 180ms – RFD180msLEGEXTISO, 6) measured at 100ms – RFD100msLEGEXTISO. The results of the linear regression in the males showed a positive correlation between FmaxLEGEXTISO and RFD50%LEGEXTISO F=16.298, p=0.000; and RFD250msLEGEXTISO F=40.754, p=0.000; and RFD180msLEGEXTISO F=18.660, p=0.000; and RFD100msLEGEXTISO F=5.430, p=0.024; in the females with RFDBASICLEGEXTISO F=10.099, p=0.004; with RFD50%LEGEXTISO F=13.585, p=0.001; with RFD250msLEGEXTISO F=35.469, p=0.000; with RFD180msLEGEXTISO F=14.698, p=0.001. The results of this study showed that the combination of the maximal exertion method, with the aim of developing maximal force or strength, and plyometrics, with the aim of developing the intensity of contraction in its different phases, from the aspect of training technology, is absolutely advisable and reasonable. This may have important practical implications when designing resistance training programs for specific sportsdeling.*

Key words: *isometric muscle force, rate of force development, relation, leg extensors.*

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INTRODUCTION

The training system represents a long-term process which involves several permanent cycles. Each cycle has its own general objective and several special objectives as well, which are logically and functionally connected to general objective of the training system – achieving the highest results, irrespective of the age-groups of the athletes (Milišić, 2007). Within the system for observing the development of physical abilities, the level of contractile characteristics, in addition to functional abilities, is the main objective training process (Zatsiorsky & Kreamer, 2006). Muscle force and lower extremity strength have a significant influence on executing competitive performance i.e. different technical-tactical demands in many sports (Hakinen, 1991; Aagaard et al., 2002; Ioakimidis et al., 2004; Rajić et al., 2008; McGuigan and Winchester, 2008; Dopsaj, 2010; Ivanović, 2010; Ivanović, 2010a; Ziv and Lidor, 2010; Čoh, 2010; Ivanovic et al., 2011) etc. As a result, adequate preparation of leg extensors is highly important especially in sports which involve different jumping techniques, frequent changes of direction in the frontal and lateral plane, numerous high and long jumps (Čoh, 2010; Čoh and Babić, 2010). Many researchers (Hakkinen, 1991; Mirkov et al., 2004; Haff et al., 2005; Zatsiorsky, 2006; Dopsaj et al., 2010) claim that diagnostics on physical preparation and athlete selection within the contractile abilities, verified with the basic parametres, i.e. using the level of maximal force development (F_{max}) or explosive force (RFD_{BASIC}), are very important for monitoring the efects of the training process from the aspect of basic indicators of contractile characteristic development.

The data on the values of the force development in the function of time generated during the isometric (static) muscle contraction, with its own characteristics (F-t curve characteristics) are the fundamental data on contractile ability. Therefore, data on the F-t curve characteristics of the muscle group represent the basic information on an athlete`s ability which is gathered with the intention of controling and monitoring athlete physical preparation (Haff et al., 2005; Dopsaj, 2005; Ikemoto et al., 2007; Rajić et al., 2008; Ivanović, 2010a). Elite athletes need 50 to 250ms to perform fast moves, while in order to develop absolute muscle force in most muscle groups, they need more time (300ms for the elbow flexors and knee extensors) (Andersen & Aagaard, 2006). Therefore, every increase of the RFD in the specific time interval is highly significant because it provides a high level intensity of force development in the early phase of muscle contraction (first 100–200ms), i.e. consequently efficient and faster motor performance. As the performance increases, the phenomenon of the intensification of the sports competition (game or race performance) can be observed, which consequently increases the movement speed, that is, decreases the time needed to perform the elements of technique, the role of specific characteristics of maximal and explosive force (Zatsiorsky & Kraemer, 2006). By analyzing the available literature, especially the studies that examined the relation between maximal isometric force of the leg extensors and the different characteristics of the rate of force development, it could be concluded that opinions are divided (Gruber & Gollhofer, 2004; Haff et al., 2005; Andersen & Aagaard, 2006; Ikemoto et al., 2007; Andersen et al., 2010). Besides, regarding the fact that there were only a few studies on the relation between maximal force and specific characteristics of explosiveness (Andersen & Aagaard, 2006; Andersen et al., 2010), this research will investigate the relationship between maximal isometric leg extensor force and the indicator of specific and special characteristics of explosive force.

Considering the current hypothesis, the indicators of explosiveness, i.e. the explosive maximal force (RFD) have the following analytical and diagnostic structure (Aagaard et al., 2002; Zatsiorsky and Kraemer, 2006; Dopsaj et al., 2010; Ivanović et al., 2011):

- RFD_{BASIC} – the general or basic indicator of explosive force development determined at the level of maximal contractile potential, i.e. F_{max} and tF_{max},
- $RFD_{SPECIFIC}$ – the specific indicator of explosive force development determined at 50% of maximal contractile potential i.e. 50% F_{max} and t50% F_{max},
- RFD_{SPECIJ} – the special indicator of explosive force development determined at the level of time necessary to conduct special competitive movement/movements, i.e. F_x and tF_x.

From the previous studies on the specificity of moving structure in competitive conditions and on defining time parameters for realizing the most characteristic motor tasks of movement techniques, the following typical time intervals can be isolated: 250ms as the time necessary to perform the stretch-shortening cycle, 180ms as the characteristic ground contact time during running in submaximal exertion regime, frequent changes of movement direction and vertical rebounds and 100ms as ground contact time during running in absolute maximal intensity (Hakkinen, 1991; Kraemer and Newton, 1994; Gruber and Gollhofer, 2004; Haff et al., 2005; Zatsiorsky and Kraemer, 2006; Ikemoto et al., 2007; Kraska et al., 2009; Čoh, 2010; Čoh and Babić, 2010).

From the aspect of theory and technology of the training, it is extremely important to determine all of the characteristics of the relation between different physical properties in control, untrained, as well as in variously trained populations in terms of their gender, age, competitive level and different training stages. The more important thing is to determine all of the characteristics regarding the single physical property, for that is the way to develop basic and specific knowledge of training.

The aim of this study is to determine the characteristic relation between the basic contractile property – the level of muscle force demonstration under isometric conditions, as an indicator of the basic fitness level.

METHOD

The subject sample included 83 participants divided into 2 different groups on the basis of gender: males N=53 and females N=30. The participants represented a physically active population (students of the Faculty for Sport and Physical Education) and national level athletes (volleyball, handball, athletics, wrestling, judo, boxing and fencing) which were tested at The Serbian Institute for Sport in Belgrade. The following basic anthropomorphological characteristics of the tested sample were collected: Age_{FEMALE} = 23.82±3.55 years, body height - BH_{FEMALE} = 177.072±10.36cm, body weight - BW_{FEMALE} = 67.59±9.31 kg, body mass index - BMI_{FEMALE} = 21.49±1.85; Age_{MALE} = 24.78±5.73 years, BH_{MALE} = 182.15±6.61 cm, BW_{MALE} = 82.60±9.65 kg, BMI_{MALE} = 24.88±2.44. All of the tests were conducted in the specialized laboratory for assessing the basic motor status at the Serbian Institute for Sport, using the same standardized procedure and equipment. All the participants – athletes were tested in the similar training stage, i.e. at the beginning of the main precompetitive cycle in the summer season of 2010. Thus, we were able to execute the unification of the participants for the purpose of obtaining objective results.

Variables

The isometric basic F-t characteristics of the leg extensors were evaluated using 6 variables:

- the level of achieved maximal force – $F_{maxLEGEXTISO}$, expressed in N;
- the indicator of basic (general) level of the rate of force development of leg extensors was determined by applying the following procedure (Zatsiorsky and Kraemer, 2006; Ivanović et al., 2010; Dopsaj et al., 2010; Ivanović et al., 2011):

$$RFD_{BASICLEGEXTISO} = (F_{maxLEGEXTISO}/tF_{maxLEGEXTISO}) * 1000$$

Where: $RFD_{BASICLEGEXTISO}$ represents the basic (general) level of the rate of force development, expresed in $N \cdot s^{-1}$; $F_{maxLEGEXTISO}$ represents the maximal value of isometric leg extensor force achieved, expresed in N; $tF_{maxLEGEXTISO}$ represents the time necessary to reach it, expressed in ms.

- The indicator of specific isometric leg extensor explosive force or the S gradient of the leg extensor force, as a rate of force development measured at 50% of $F_{maxLEGEXTISO}$ was measured by applying the following procedure:

$$RFD_{50\%LEGEXTISO} = (F_{50\%LEGEXTISO} /tF_{50\%LEGEXTISO}) * 1000$$

Where: $RFD_{50\%LEGEXTISO}$ represents the specific level of the rate of force development, expresed in $N \cdot s^{-1}$; $F_{50\%LEGEXTISO}$ represents the value of the isometric force achieved at 50% of $F_{maxLEGEXTISO}$, expressed in N; $tF_{50\%LEGEXTISO}$ represents the time necessary to reach it, expressed in ms.

- The indicator of the special level of leg extensor explosive force development, measured in the time zone of the Stretch-Shortening Cycle, i.e. at 250 ms of $tF_{maxLEGEXTISO}$ was measured by applying the following procedure (Zatsiorsky and Kreamer, 2006; Rajić et al., 2008; Čoh and Babić, 2010):

$$RFD_{250msLEGEXTISO} = (F_{250msLEGEXTISO}/tF_{250msLEGEXTISO}) * 1000$$

Where: $RFD_{250msLEGEXTISO}$ represents the stretch-shorten cycle level of the rate of force development, expressed in $N \cdot s^{-1}$; $F_{250msLEGEXTISO}$ represents the value of the isometric force achieved at 250 ms of $tF_{maxLEGEXTISO,}$ expressed in N; $tF_{250msLEGEXTISO}$ represents time in ms necessary to achieve $F_{250msLEGEXTISO}$.

- The indicator of the special level of explosive force development, measured at 180 ms of $tF_{maxLEGEXTISO}$ was measured by applying the following procedure (Rajić et al., 2008; Ivanović et al., 2011):

$$RFD_{180msLEGEXTISO} = (F_{180msLEGEXTISO}/tF_{180msLEGEXTISO}) * 1000$$

Where: $RFD_{180msLEGEXTISO}$ represents the level of rate of force development, expressed in $N \cdot s^{-1}$; $F_{180msLEGEXTISO}$ represents the value of isometric force achieved at 180ms of $tF_{maxLEGEXTISO}$, expressed in N; $tF_{180msLEGEXTISO}$ represents the time in ms necessary to achieve $F_{180msLEGEXTISO}$.

- The indicator of the special level of explosive force development, measured at 100 ms of $tF_{maxLEGEXTISO}$ was measured by applying the following procedure (Rajić et al., 2008; Čoh, 2010):

$$RFD_{100msLEGEXTISO} = (F_{100msLEGEXTISO}/tF_{100msLEGEXTISO}) * 1000$$

Where: $RFD_{100msLEGEXTISO}$ represents the level of the rate of force development, expressed in $N \cdot s^{-1}$; $F_{100msLEGEXTISO}$ represents the value of the isometric force achieved at 100ms of $tF_{maxLEGEXTISO}$, expressed in N; $tF_{100msLEGEXTISO}$ represents time in ms necessary to achieve $F_{100msLEGEXTISO}$.

Measuring procedure

In order to assess the contractile characteristics of leg extensor isometric muscle force (bilateral), standardized equipment was used, i.e. a metal device for measuring leg extensor isometric force, a tensiometric probe and standardized "seated leg extension" test were used following the earlier described procedures (Ivanović, 2010a; Ivanović et al., 2010). The testing was carried out by means of a hardware-software system (Nikola Tesla Institute, Belgrade, Serbia) (Figure 1). The tensiometric probe was connected to the force reader (force indicator) and to the PC computer (Figure 1). The tests were carried out under isometric conditions of exertion with the knee joint at an angle of 120°, and with the ankle and hip joint at 90° (Figure 2). The participants performed their attempts after the sound signal. Each participant had four attempts, with one minute rest between the trials. The result was automatic, measured by the tensiometric sounding device and hardware-software system, recorded in a special database with the possibility of F-t curve inscription control. Best trial according to RFD_{Basic} was chosen for further statistical analysis.

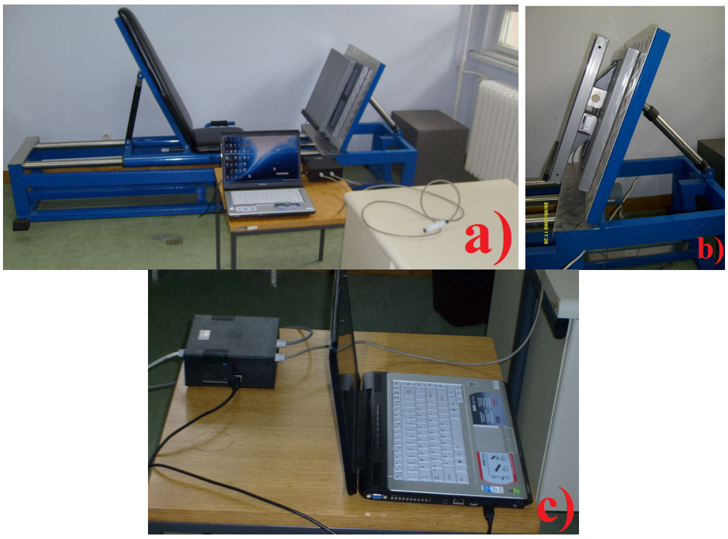

Fig. 1. The measuring device for assessing maximal leg extensor isometric force with the hardware-software system (a), the tensiometric sounding device within foot platform (b), force reader connected with the PC computer (c).

Fig. 2. A participant's position during measuring procedure

Statistical procedure

All the results were processed using descriptive statistics and the relation in the observed contractile characteristics was afterwards defined by applying the regression analyses method (Hair et al., 1998). The model of dependency in the observed variables ($F_{maxLEGEXTISO}$ and the variables of explosiveness) was defined using the general equation: $y = ab^x$. All the statistical operations were carried out by applying the Microsoft ® Office Excel 2007 and the SPSS for Windows, Release 17.0 (Copyright © SPSS Inc., 1989–2002).

RESULTS

Table 1 shows results for the descriptive statistic of the observing indicators while Table 2 shows the results of the linear regression analysis between $F_{maxLEGEXTISO}$ and different indicators of explosive force.

Table 1. The descriptive statistics

The descriptive statistic of the observed indicators					
F-t indicators	Mean	SD	cV%	Min	Max
MALES N=53					
$F_{maxLEGExtISO}$ in N	4330.68	1081.95	24.98	2505.73	7472.67
$RFD_{BASICLEGExtISO}$ in $N \cdot s^{-1}$	4861.42	2547.78	52.41	2377.45	12686.67
$RFD_{50\%LEGExtISO}$ in $N \cdot s^{-1}$	13532.06	3919.94	28.97	4558.74	21395.69
$RFD_{250msLEGExtISO}$ in $N \cdot s^{-1}$	12076.63	3165.21	26.21	3610.35	19996.26
$RFD_{180msLEGExtISO}$ in $N \cdot s^{-1}$	12979.31	3984.05	30.70	2712.36	20184.42
$RFD_{100msLEGExtISO}$ in $N \cdot s^{-1}$	12251.00	4861.34	39.68	2304.12	21900.81
FEMALES N=30					
$F_{maxLEGExtISO}$ in N	3135.96	891.04	28.41	1571.26	5302.80
$RFD_{BASICLEGExtISO}$ in $N \cdot s^{-1}$	4042.21	1677.08	41.49	1137.47	7939.66
$RFD_{50\%LEGExtISO}$ in $N \cdot s^{-1}$	8996.41	3649.07	40.55	1584.39	18827.09
$RFD_{250msLEGExtISO}$ in $N \cdot s^{-1}$	8202.19	2912.03	35.49	1542.95	15970.96
$RFD_{180msLEGExtISO}$ in $N \cdot s^{-1}$	8546.36	3324.89	38.89	1385.80	18530.73
$RFD_{100msLEGExtISO}$ in $N \cdot s^{-1}$	7860.42	3620.97	46.06	1470.01	18335.30

Table 2. Linear regression between $F_{maxLEGExtISO}$ and different indicators of explosive force in the males and females

Linear regression models - $F_{maxLEGExtISO}$ and different indicators of explosive force					
RFD indicators	general equation	% of probability	R^2	Anova F	p
MALES N=53					
$RFD_{BASICLEGExtISO}$	y = 0.117x + 4353	2.0	0.002	0.127	0.723
$RFD_{50\%LEGExtISO}$	y = 1.782x + 5810	24.2	0.242	16.298	0.000
$RFD_{250msLEGExtISO}$	y = 1.949x + 3633	44.4	0.444	40.754	0.000
$RFD_{180msLEGExtISO}$	y = 1.905x + 4725	26.7	0.267	18.660	0.000
$RFD_{100msLEGExtISO}$	y = 1.393x + 6214	9.6	0.096	5.430	0.024
FEMALES N=30					
$RFD_{BASICLEGExtISO}$	y = 0.969x + 1003	26.5	0.265	10.099	0.004
$RFD_{50\%LEGExtISO}$	y = 2.340x + 1656	32.6	0.326	13.585	0.001
$RFD_{250msLEGExtISO}$	y = 2.443x + 540.6	55.8	0.558	35.469	0.000
$RFD_{180msLEGExtISO}$	y = 2.189x + 1680	34.4	0.344	14.698	0.001
$RFD_{100msLEGExtISO}$	y = 1.306x + 3764	10.3	0.103	3.226	0.083

Figures 1–5 show the directions of the regression regarding the relation between $F_{maxLEGExtISO}$ and different indicators of explosive force in the males and females.

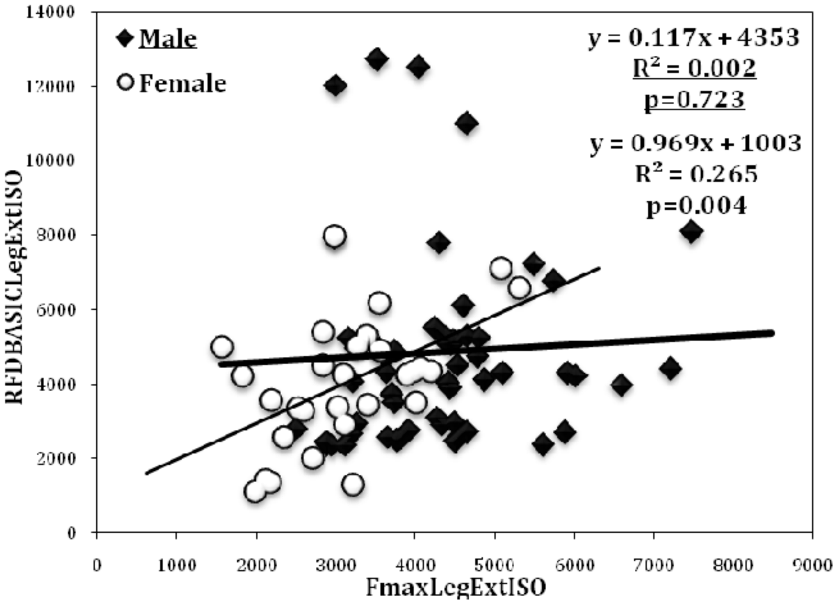

Fig. 1. Relation between $F_{maxLegExtISO}$ and $RFD_{BASICLegExtISO}$ in the males and females

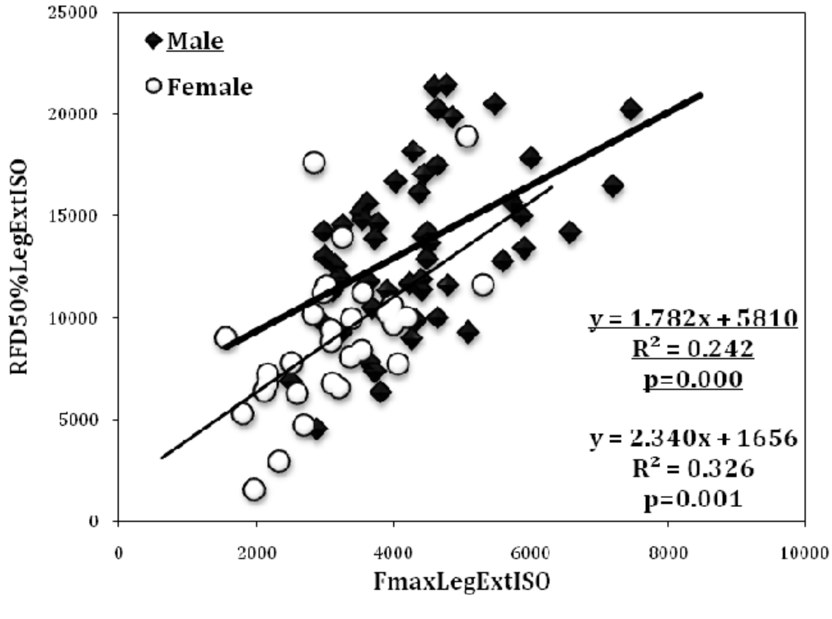

Fig. 2. The relation between $F_{maxLegExtISO}$ and $RFD_{50\%LegExtISO}$ in the males and females

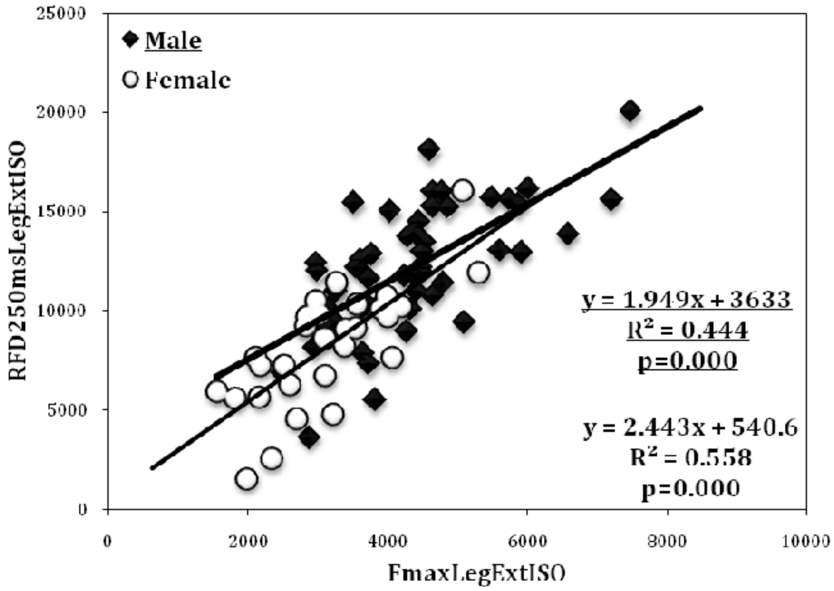

Fig. 3. The relation between $F_{maxLegExtISO}$ and $RFD_{250msLegExtISO}$ in the males and females

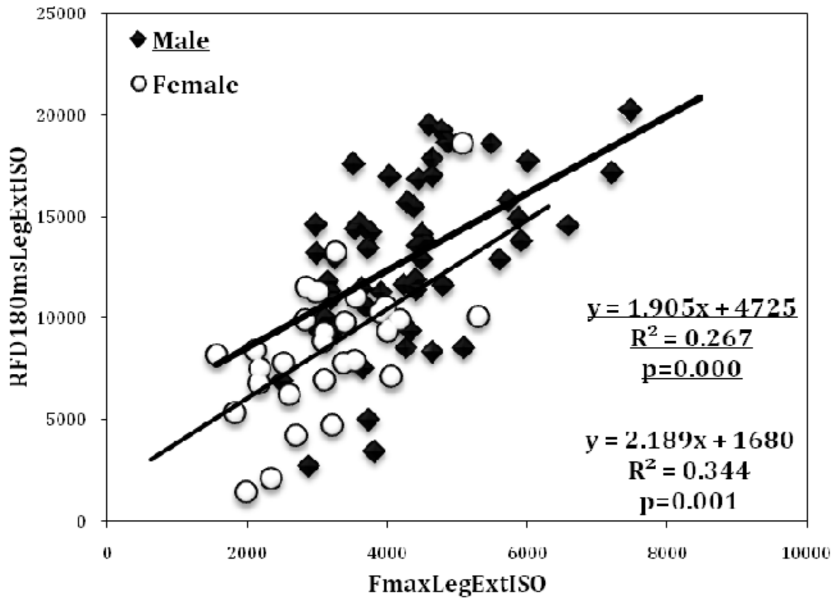

Fig. 4. The relation between $F_{maxLegExtISO}$ and $RFD180_{msLegExtISO}$ in the males and females

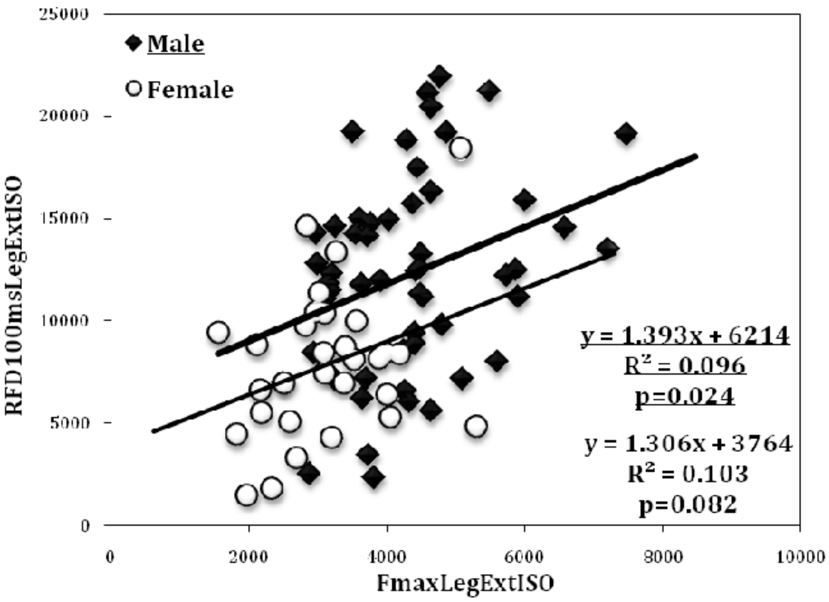

Fig. 5. The relation between $F_{maxLEGEXTISO}$ and $RFD_{100msLEGEXTISO}$ in the males and females

DISCUSSION

Explosive muscle force or isometric rate of force development (RFD) is a term used to describe the ability to rapidly develop muscular force, and can be measured as the slope (relation) of the force-time curve obtained under isometric conditions. Conflicting results have been reported regarding the relationship between contractile RFD and various physiological parameters. One reason for this discrepancy may be that RFD in various time intervals from the onset of the contraction is affected by different physiological parameters. However, selective adaptations of RFD and maximum force capacity have been reported for specific training regimens. For example, Hakkinen (Hakkinen & Komi 1986) has shown that resistance training primarily leads to an enhanced maximum force whereas explosive training results in adaptations basically related to the RFD. In accordance with these classical training studies Gruber (Gruber & Gollhofer, 2004) found similar effects: sensorimotor training increased the RFD without enhancing maximum strength. In line with the study presented by Aagaard et al. (2002), Gruber (Gruber & Gollhofer, 2004) found concurrent increases in the RFD and the F_{max} in the earliest time phases of muscular action. The aim of Andersen & Aagaard's (2006) study was to investigate the relationship between RFD in time intervals of 0–10, 0–20, ..., 0–250 ms from the onset of the contraction and two main parameters: (1) voluntary maximal muscle strength and (2) electrically evoked muscle twitch contractile properties. The main finding was that voluntary RFD became increasingly more dependent on F_{max} and less dependent on muscle twitch contractile properties as time from the onset of the contraction increased. At time intervals later than 90 ms from the onset of the contraction, maximal muscle strength could account for 52–81% of the variance in the voluntary RFD. In the very early time interval (<40 ms from the onset of the contraction) the voluntary RFD was moderately correlated to the twitch contractile properties of the muscle and was related to F_{max} to a lesser extent.

Because the traditional methodology for training weightlifters focuses around the utilization of explosive exercises performed with various intensities, this relationship between F_{max} and RFD may not be totally unexpected (Haff et al., 2005). Since weightlifters use a training modality that varies between low-force/high-velocity, high-force/low-velocity, and high force/high-velocity movements during a training year, one might expect an optimization of the force-time curve in that F_{max} and RFD would be interrelated. In the previously mentioned study the F_{max} and RFD were very strongly correlated (r = 0.70, r^2 = 0.49), thus lending support to the contention that weightlifters rely on a combination of Peak Force and RFD when performing isometric or dynamic muscle actions.

In the study of Ikemoto et al., (Ikemoto et al., 2007), force-time parameters, except for the time needed to reach average force at the level 90% of peak force in the explosive isometric grip, showed fair or good correlations with F_{max} (r=0.60–0.89). The levels around average force to peak force and integrated area until 2s showed a high relation with F_{max}. Ikemoto suggested that the phases before and after the change point (inflection point) of the rising force speed in the explosive isometric grip evaluate different muscle functions, and reported that the parameters evaluating the phase after the inflection point relate closely to F_{max}. Force-time parameters such as integrated area or average force around a peak force are considered to largely reflect F_{max}.

On the other hand, Demura et al. (2001) reported that the relationship between maximal isometric force and peak increase in force during the rising force phase was low (r=0.100–0.273). Demura et al. (2001) suggested that the individual difference during the rising phase in the explosive isometric contraction is reflected on the different muscle functions. In general, many researchers have suggested that the rising force phase of the force-time curve in an explosive isometric contraction can be used to evaluate different muscle functions such as maximal strength, explosive strength (power) and muscle contraction speed.

In our research, based on the data of the tested sample of young, healthy and well trained individuals, both male and female, when compared to men, the following was established:

- No statistically significant relation between maximal force ($F_{maxLEGEXTISO}$) and the indicators of basic (general) level of explosive force development ($RFD_{BASICLEGEXTISO}$) was established in the subsample of males – R^2 = 0.002, F = 0.127, p = 0.723 (Table 1, Figure 1);
- However, a statistically significant correlation was established between maximal force ($F_{maxLEGEXTISO}$) and all the other measured indicators of explosive force – specific explosiveness ($RFD_{50\%LEGEXTISO}$), special explosiveness ($RFD_{250msLEGEXTISO}$, $RFD_{180msLEGEXTISO}$ and $RFD_{100msLEGEXTISO}$) – R^2 = 0.242, F = 16.298, p = 0.000; R^2 = 0.444, F = 40.754, p = 0.000; R^2 = 0.267, F = 18.660, p = 0.000 and R^2 = 0.096, F = 5.430, p = 0.024, respectively (Table 1, Figure 1).

Based on the obtained results for the male subsample, it can be concluded that the ability of maximal force demonstration and its intensity in the time unit, i.e. basic explosive force, were not in correlation. For the mentioned variables, the common variance is only 0.2%, while the difference is at the level of 99.8%. From the practical point of view, it means that the participant who had a highly developed leg extensor maximal force, did not have a proportionally developed basic explosive force. In regard to the training aspect of the given variables, and based on the gained results, it was possible to conclude that the training technology for the development of maximal force and basic explosive force must be different in terms of applied training methods (Radovanović and Ignjatović, 2009) because, as we mentioned before, the two variables did not correlate.

The correlation between maximal force and specific and special indicators of explosive force, in regard to the tested male subsample was statistically significant (Table 1, Figures 2–5). The common variance of $F_{maxLEGEXTISO}$ with $RFD_{50\%LEGEXTISO}$ was 24.2%, with $RFD_{250msLEGEXTISO}$ was 44.4%, with $RFD_{180msLEGEXTISO}$ was 26.7%, and with $RFD_{100msLEGEXTISO}$ was 9.6%, respectively (Table 1). The obtained results indirectly confirm Aagaard et al.'s study (2002) which determined that the increases in the early phase of muscle contraction (0–200 ms time interval) as an early explosive muscle force and strength (contractile RFD and impulse) were observed after heavy-resistance strength training. These findings could be explained by an enhanced neural drive, as evidenced by marked increases in the EMG signal amplitude and the rate of the EMG rise in the early phase of muscle contraction.

The data obtained in the research on hand extensors (Bench Press Action) are worth mentioning. The authors determined the correlation values between F_{max} and RFD_{BASIC} from r=0.385, p=0.077 for the first position, the bar was fixed at a 2-5cm distance from the chest to r=0.458, p=0.032 for the second position where the elbow joint angle was 135º (Ignjatović et al., 2009). The mentioned correlation values represent an analogy of 14.82 and 20.98% of the explained variance of conditionality F_{max} and RFD_{BASIC} for the Bench Press exercise, which were significantly higher in regard to one in this research on leg extensors. As both studies tested male participants from the Faculty of Sport and Physical Education, it was possible to create a hypothesis that in regard to the tested muscle group F_{max} and RFD_{BASIC} correlate differently, because of the different anatomical-functional and muscle-structural specific contractile characteristics of the tested muscle group. This assumption certainly needs to be examined further.

Regarding the female subsample, different results were determined:

- There was a statistically significant relation between maximal force ($F_{maxLEGEXTISO}$) and the indicators of basic (general) level of explosive force development ($RFD_{BASICLEGEXTISO}$) – R^2 = 0.265, F = 10.099, p = 0.004 (Table 1, Figure 1);
- Also, between the maximal force ($F_{maxLEGEXTISO}$) and following measured indicators of the explosive force – specific explosiveness ($RFD_{50\%LEGEXTISO}$), as well as the indicators of special explosiveness ($RFD_{250msLEGEXTISO}$, $RFD_{180msLEGEXTISO}$ and $RFD_{100msLEGEXTISO}$), a statistically significant correlation was established – R^2 = 0.326, F = 13.585, p = 0.001; R^2 = 0.558, F = 35.469, p = 0.000; and R^2 = 0.344, F = 14.698, p = 0.001, respectively (Table 1, Figure 2-4);
- However, no statistically significant correlation between the maximal force ($F_{maxLEGEXTISO}$) and indicator of special explosive force at 100 ms ($RFD_{100msLEGEXTISO}$) was established – R^2 = 0.103, F = 3.226, p = 0.083 (Table 1, Figure 5).

Based on the obtained results for the female subsample, it can be concluded that the ability of maximal force demonstration and its intensity in the time unit, i.e. basic explosive force were in a correlation. For the mentioned variables the common variance is 26.5%. From the practical point of view, it means that in the case of the participants who had a highly developed maximal force of leg extensors, 26.5% were found to have proportionally developed basic explosive force.

Similar to the male subsample, the correlation between maximal force and specific and special indicators of explosive force in the tested female subsample was statistically significant (Table 1, Figures 2–4). The common variance of $F_{maxLegExtISO}$ with $RFD_{50\%LegExtISO}$ was 32.6%, with $RFD_{250msLegExtISO}$ was 55.8%, while with $RFD_{180msLegExtISO}$ was 34.4%, respectively (Table 1). There was no statistically significant correlation between $F_{maxLegExtISO}$ and $RFD_{100msLegExtISO}$, although the correlation was at the level of 10.3%.

Regarding the correlations determined in the male subsample, the conditionality of the maximal force and the tested indicators of explosive force in the female subsample is 26.3 % higher, absolutely, in $F_{maxLegExtISO}$ vs $RFD_{BASICLegExtISO}$, 8.4% in $F_{maxLegExtISO}$ vs $RFD_{50\%LegExtISO}$, 11.4% in $F_{maxLegExtISO}$ vs $RFD_{250msLegExtISO}$, 7.7% in $F_{maxLegExtISO}$ vs $RFD_{180msLegExtISO}$, and 0.7% in $F_{maxLegExtISO}$ vs $RFD_{100msLegExtISO}$, i.e. on average 24.13% is higher, relatively, in regard to special and specific indicators of explosive force.

The difference established in regard to the male subsample refers to the existence of a correlation between $RFD_{BASICLegExtISO}$ and $F_{maxLegExtISO}$, but also to the absence of a statistically significant correlation between $F_{maxLegExtISO}$ and $RFD_{100msLegExtISO}$.

The reason for establishing a correlation between the variables $F_{maxLegExtISO}$ and $RFD_{BASICLegExtISO}$ (R^2=0.265, F=10.099,p=0.004) in the females and not in the males (R^2=0.002, F=0.127, p=0.723) could possibly be explained by the fact that the females have lower absolute force indicators, i.e. the absolute force indicators in the females are at a level of 68.64% in comparison to the males (Dopsaj et al. 2010, pp. 284), the respectively lower indicators of explosive force at the level of 29.51% in the trained, i.e. 55.80% in untrained females in comparison to the males (Ivanović, 2010a). Those differences possibly appear as an anatomic-functional-physiological result of lower muscle mass in the females, as a result of different structures in muscle fibers, lower neural contractile capacity, adverse hormonal status in regard to contractile potential, but also as a result of many other qualitative muscular factors (glycolytic ability, motor coordination, and motor unit activation) (Viitasalo et al., 1981; Häkkinen, 1991; Häkkinen & Häkkinen, 1991; Radovanović & Ignjatović, 2009). However, some studies established that the level of trainability, especially from the aspect of force and strength in the females is lower than in the males (Häkkinen, 1991; Ivanović, 2010a).

For example, it was established that the sexual dimorphism of the general indicator of explosive force (RFD_{BASIC}) in leg extensors and in the untrained population 0.7921 (RFD_{BASIC} Female 1628.23 $N \cdot s^{-1}$ vs Male 2917.89 $N \cdot s^{-1}$ i.e. a 79.21% higher level of explosive force), while in a specific trained population (volleyball players) is at the level of 238.88% (RFD_{BASIC} Female 2481.47 $N \cdot s^{-1}$ vs Male 8409.12 $N \cdot s^{-1}$). In other words, volleyball training improved the observed contractile characteristic 1.524 times in the females and 2.882 times in the males (Ivanović, 2010a) in regard to the untrained population. In regard to the tested female subsample, the participants who had a higher level of $F_{maxLegExtISO}$ have proportionally developed $RFD_{BASICLegExtISO}$ (possibly for the lower contractile potential in the female population), while in the men that was not the case (one better developed contractile ability, does not necessary mean proportionally developed other contractile abilities).

The existence of a statistically significant difference was established in the males (R^2 = 0.096, F = 5.430, p = 0.024), but not in the females (R^2 = 0.103, F = 3.226, p = 0.083) in terms of the correlation between $F_{maxLegExtISO}$ and $RFD_{100msLegExtISO}$, although a similar amount of the common variance was established in both subsamples (9.5% vs 10.3%, respectively). The difference probably appears for statistic and methodological reason (the research included 53 male and 30 female participants).

Generally speaking, the obtained results indirectly confirmed the results of Aagaard (Aagaard et al., 2002) who determined increases in the early phase of muscle contraction (0–200 ms time interval), as early explosive muscle force and strength (contractile RFD and impulse) were observed after heavy-resistance strength training. And yet, from the practical point of view, it means that a statistically significant correlation is functionally strong and physiological dependent between maximal force and the indicators of the explosive force, namely in the early phases of muscle contraction – 250ms, 180ms and 100ms (Table 1, Figures 2–4). Also, the results of this study showed that the combination of the maximal exertion method, applied in order to develop maximal force or strength, along with plyometrics, with the aim of developing the intensity of the contraction in its different phases, from the aspect of training technology, is absolutely advisable and reasonable.

Conclusion

The results of this research showed the existence of a statistically significant correlation between the maximal isometric force and the indicators of explosive force in the early phases of muscle contraction: in the males between the maximal force ($F_{maxLegExtISO}$) and specific explosive force ($RFD_{50\%LegExtISO}$) – $R^2 = 0.242$, $F = 16.298$, $p = 0.000$, as the indicator of special explosive force ($RFD_{250msLegExtISO}$, $RFD_{180msLegExtISO}$ and $RFD_{100msLegExtISO}$) – $R^2 = 0.444$, $F = 40.754$, $p = 0.000$; $R^2 = 0.267$, $F = 18.660$, $p = 0.000$ and $R^2 = 0.096$, $F = 5.430$, $p = 0.024$, respectively; in the females between maximal force ($F_{maxLegExtISO}$) and the basic (general) level of explosive force development ($RFD_{BASICLegExtISO}$) – $R^2 = 0.265$, $F = 10.099$, $p = 0.004$, as well as in the indicators of specific explosive force ($RFD_{50\%LegExtISO}$) and special explosive force ($RFD_{250msLegExtISO}$ and $RFD_{180msLegExtISO}$) – $R^2 = 0.326$, $F = 13.585$, $p = 0.001$; $R^2 = 0.558$, $F = 35.469$, $p = 0.000$; and $R^2 = 0.344$, $F = 14.698$, $p = 0.001$, respectively.

In regard to the correlation determined in the males, the conditionality of maximal muscle force and the tested indicators of explosive force in the females are 26.3% higher, absolutely, in $F_{maxLegExtISO}$ vs $RFD_{BASICLegExtISO}$, 8.4% in $F_{maxLegExtISO}$ vs $RFD_{50\%LegExtISO}$, 11.4% in $F_{maxLegExtISO}$ vs $RFD_{250msLegExtISO}$, 7.7% in $F_{maxLegExtISO}$ vs $RFD_{180msLegExtISO}$, and 0.7% in $F_{maxLegExtISO}$ vs $RFD_{100msLegExtISO}$, i.e. on average they are 24.13% higher, relatively, in regard to special and specific indicators of explosive force.

The results of this study showed that a combination of the maximal exertion method, with the aim of developing maximal force or strength, and plyometrics, with the aim of developing the intensity of the contraction in its different phases, from the aspect of training technology, is absolutely advisable and reasonable.

REFERENCES

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Poulsen P. D. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology*, 93, 1318–1326.

Andersen L. L., & Aagaard P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology*, 96, 46–52.

Andersen L. L., Andersen, J. L., Zebis, M. K., & Aagaard, P. (2010). Early and late rate of force development: differential adaptive responses to resistance training? *Scandinavian Journal of Medicine & Science in Sports*, 20 (1), 162-169.

Blazevich, A.J, Gill, N., & Newton, R. U. (2002). Reliability and validity of two isometric squat tests. *Journal of Strength and Conditioning Research*, 16 (2), 298-304.

Demura. S., Yamaji, S., Nagasawa, Y., Ikemoto, Y., & Shimada, S. (2001) Force developmental phase and reliability in explosive and voluntary grip exertions. *Perceptual and Motor Skills*, 92, 1009–1021.

Dopsaj, M. (2005). *Constituting diagnostic-prognostic system in order to evaluate characteristics of isometric force in different muscle groups in the function of gender, gender, age and competitive achievement*. Scientific-Research Project: Republic institute for sport, Belgrade.

Dopsaj, M. (2010). F-t characteristics curves: Analytical and diagnostic significance in sport, In Stanković, R. (Ed.). *XIV International Scientific Symposium_FIS Communications 2010 in the physical education, sport and recreation*, (pp. 36-51). Niš: Faculty of Sport and Physical Education, University of Niš.

Dopsaj, M., Blagojević, M., Koropanovski, N., & Vučkovič, G. (2010). Structural analysis of basic leg extensor F-t curve characteristics in male athletes in different sports measured in standing position. In Duncan, M., & Lyons, M. (Eds.). *Trends in Human Performance Research*, (pp. 53-70). Nova Science Publisher. Inc., Hauppauge, NY, USA.

Dopsaj, M., Blagojević, M., Marinković, B., Miljuš, D., Vučković, G., Koropanovski, N., Ivanović, J., Atanasov, D., & Janković, R. (2010). *Characteristic patterns (models) of basic antropometric indicators and motor abilities healthy and well trained young people both genders in Serbia – populations indicators in the Republic of Serbia*. Beograd: Academy for Criminalistic and Police studies.

Dopsaj, M. (2010). Pulling force characteristics of 10 s maximal tethered eggbeater kick in elite water polo players: A pilot study. In: Per-Ludvik Kjendlie, Robert Keig Stallman, Jan Cabri (Eds.). *Proceedings of XI Biomechanics and Medicine in Swimming*, (pp. 69-72), Oslo: Norwegian School of Sport Science.

Gruber, M., & Gollhofer, A. (2004). Impact of sensorimotor training on the rate of force development and neural activation. *European Journal of Applied Physiology*, 92, 98–105.

Haff, G. G., Carlock, J. M., Hartman, M. J., Kilgore, J. L., Kawamori, N., Jackson, J. R., Morris, R. T., Sands, W. A., & Stone, M. H. (2005). Force-time characteristics of dynamic and isometric muscle actions of elite women Olympic weightlifters. *Journal of Strength and Conditioning Research*, 19, 741-748.

Hakkinen, K., & Komi, P.V. (1986). Training-induced changes in neuromuscular performance under voluntary and reflex conditions. *Eur J Appl Physiol Occup Physiol*, 55:147–155

Hakkinen, K. (1991). Force production characteristics of leg extensor, trunk flexor and extensor muscles in male and female basketball players. *Journal of Sports Medicine and Physical Fitness*, 31, 325−331.

Häkkinen, K., & Häkkinen, A. (1991). Muscle cross-sectional area, force production and relaxation characteristics in women at different ages. *European Journal of Applied Physiology and Occupational Physiology*, 62 (6), 410-414.

Hair, J., Anderson, R., Tatham, R., & Black, W. (1998). *Multivariate Data Analysis (Fifth Ed.)*. New Jersey, USA: Prentice - Hall, Inc.

Ioakimidis, P., Gerodimos, V., Kellis, E., Alexandris, N., & Kellis, S. (2004). Combined effects of age and maturation on maximum isometric leg press strength. *Journal of Sports Medicine and Physical Fitness*, 44(4), 389-397.

Ikemoto, Y., Demura, S., Yamaji, S., Minami, M., Nakada, M., & Uchiyama, M. (2007). Force-time parameters during explosive isometric grip correlate with muscle power. *Sport Science and Health*, 2, 64–70.

Ignjatović, A., Stanković, R., Herodek, K., & Radovanović, D. (2009). Investigation of the relationship between different muscle strength assessments in bench press action. *FACTA UNIVERSITATIS Series: Physical Education and Sport*, 7 (1), 17 – 25.

Ivanović, J. (2010). Isometric F-t characteristics of leg extensors in top level volleyball players in regard to different trained and untrained persons. *Unpublished MSci thesis: Faculty of Sport and Physical Education*, *Belgrade.*

Ivanović, J. (2010a). Characteristics of Indicators for Evaluating Leg Extensors Explosiveness in the Elite Volleyball Players in Serbia of both Genders. *Faculty of sport and physical education Yearbook*, 16,159−185.

Ivanović, J., Dopsaj, M., Nešić, G. & Stanković, R. (2010). Sexual dimorphism in different indicators for evaluating isometric leg extensors explosive force. *Physical Culture, Journal of sport Science & Physical Education.* 64(1),46−62.

Ivanović, J., Dopsaj, M., & Nešić, G. (2011). Factor structure differences of indicators for evaluating isometric leg extensors explosive force in female volleyball athletes and different trained female population. *British Journal of Sports Medicine*, 45, 542.

Kraemer, W. J., & Newton, R.U. (1994). *Training for improved vertical jump*. Sport Sciences Exchange, Gatorate Sports Science Institute, 7:53-57.

Kraska J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Ston, M. E., & Ston, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance*, 4(4), 461 – 473.

McGuigan, M. R., & Winchester, J. B. (2008). The relationship between isometric and dynamic strength in college football players. *Journal of Sports Science and Medicine*, 7 (1), 101-105.

Milišić, B. (2007). Efficiency in sport and training management theory. *Serbian Journal of Sports Sciences*, 1 (1-4), 7-13.

Mirkov, D. M., Nedeljkovic, A., Milanovic, S., & Jaric, S. (2004) Muscle strength testing: evaluation of tests of explosive force production. *European Journal of Applied Physiology*, 91, 147–154.

Radovanović, D., & Ignjatović, A. (2009). *Physiological basis of force and strength training.* Niš: Faculty of Sport and Physical Education, University of Niš.

Rajić, B., Dopsaj, M. & Abela, C. P. (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. *Serbian Journal of Sports Sciences*, 2(4), 131–139.

Viitasalo, J. T., Hakkinen, K., & Komi, P.V. (1981). Isometric and dynamic force production and muscle performance in man. *Journal of Human Movement Studies*, 7, 199−209.

Zatsiorsky, V. M., & Kraemer W. J. (2006). *Science and practice of strength training (Sec. Ed.)*. Champaign, IL: Human Kinetics.

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players: a review of observational and experimental studies. *Journal of Science and Medicine in Sport*, 13, 332–339.

Čoh, M. (2010). Biomechanical characteristics of take off action in high jump – a case study. *Serbian Journal of Sports Sciences*, 4(4), 127-135.

Čoh, M., & Babić, V. (2010). Biodynamic characteristics of maximum speed development. *FACTA UNIVERSITATIS Series: Physical Education and Sport*, 8(2), 141 – 148.

POSTOJI LI ODNOS IZMEĐU MAKSIMALNE I EKSPLOZIVNE SILE EKSTENZORA NOGU?

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Cilj rada bio je utvrditi relacije maksimalne izometrijske sile i različitih pokazatelja izometrijske eksplozivne sile (iRFD) ekstenzora nogu. Uzorak je činilo 83 ispitanika podeljenih u 2 grupe u odnosu na pol, muškarci N=53 i žene N=30. Za procenu F-t karakteristika izometrijske sile ekstenzora nogu korišćena je standardizovana oprema, tenziometrijska sonda i standardizovan test u sedećoj poziciji. Merni opseg je definisan na osnovu 6 varijabli u odnosu na kontraktilne karakteristike izometrijske sile ekstenzora nogu – 1) nivo ostvarene maksimalne sile – FmaxLEGEXTISO, 2) opšti ili bazični pokazatelj razvijenosti eksplozivne sile - RFDBASICLEGEXTISO, 3) specifični pokazatelj razvijenosti eksplozivne sile – RFD50%LEGEXTISO, i tri indikatora za procenu specijalnog nivoa razvijenosti eksplozivne sile tj. eksplozivnosti opružača nogu 4) izmeren na 250ms - RFD250msLEGEXTISO, 5) izmeren na 180ms - RFD180msLEGEXTISO, 6) izmeren na 100ms - RFD100msLEGEXTISO. Rezultati linearne regresije su pokazali pozitivnu korelaciju između FmaxLEGEXTISO i skoro svih praćenih varijabli sem kod RFDBASICLEGEXTISO kod muškaraca i RFD100msLEGEXTISO kod žena. Rezultati ove studije su pokazali da je sa aspekta tehnologije sportskog treninga, kombinacija metoda maksimalnog naprezanja, u svrhu razvoja maksimalne sile ili snage, sa pliometrijom, u svrhu razvoja intenziteta kontrakcije u ranim fazama iste, apsolutno poželjna i opravdana, što može imati važne praktične implikacije pri programiranju treninga snage za specifične sportske grane.

Ključne reči: *izometrijska mišićna sila, eksplozivnost, relacije, opružači nogu.*