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Research article

Relations between Lower Body Isometric Muscle Force Characteristics and Start Performance in Elite Male Sprint Swimmers

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Abstract
The aim of the present study was twofold. The first aim was to examine the influence of absolute and relative lower body muscle force on kinematic component which determine the start performance. The second aim was to create multiregressional model which could use as a tool for swimming coaches with the purpose to start performance control and improvement. Twenty seven high-level trained male competitive swimmers all members of the Serbian National Youth and Senior Swimming Team (Age = 21.1 ± 4.3 yrs., Height = 1.89 ± 0.10 m, Weight = 81.6 ± 8.4 kg, 50m freestyle – long course = 24.36 ± 0.86 s) performed two trials of standing leg extensors isometric muscle force testing and three swimming start trials corresponding to 10m distance. The average start time significantly correlated with variables of leg extensors maximum voluntary force (F_{max}, $r = -0.559$, $p = 0.002$), leg extensors relative muscle voluntary force (F_{rel}, $r = -0.727$, $p < 0.001$), leg extensors specific rate of force development ($RFD_{50\%}$, $r = -0.338$, $p = 0.047$) and leg extensors relative value of specific rate of force development ($RFD_{50\%rel}$, $r = -0.402$, $p = 0.040$). Regression equation for t10m prediction was defined by following variables: maximum voluntary isometric force of leg extensors muscles at absolute and relative level (F_{max} and F_{rel}), as well as a specific rate of force development of the same muscle groups ($RFD_{50\%}$ and $RFD_{50\%rel}$) at absolute and relative level too with 74.4% of explained variance. Contractile abilities indicators of the leg extensors muscles included consideration: F_{max}, $RFD_{50\%}$, F_{rel} and $RFD_{50\%rel}$ showed significant correlation with swimming start times on 10m. Additionally, the results suggest that swimmers, who possess greater isometric maximum force and specific rate of force development at absolute and relative levels, tend to be able to swim faster on initial 10m swim start perforamnce.

Key words: Start performance, maximum voluntary forces, and rate of force development.

Introduction

Swimming races include elements of a start, turn and clean swimming distance. The contribution of each of these segments to the final performance of the race, or performance prediction is significant and its importance depends on the race distance (Barbosa et al., 2008; Cossor and Mason, 2001; West et al., 2011). Start performance in swimming is the combination of reaction time, vertical and horizontal force off the block, and low resistance during underwater gliding. In the study of Cossor and Mason (2001), start times significantly correlated ($r = 0.84$) with total race performance on 50m freestyle in elite male swimmers, same authors also concluded that start has a higher contribution to the success in sprint races, compared to longer distance races (Cossor and Mason, 2001). For instance, at the Olympic Games “London 2012”, the 50m freestyle final was won with a time of 21.34 seconds with the swimmer in the eight placed finishing with a time of 21.98 seconds which makes difference of 0.64 seconds and represents 2.91% of winner's total race time (www.fina.org). At the Beijing Olympic Games (2008), the time separating the eight finalists in the men 50m freestyle final was 0.42 seconds, which represents 1.93% of the winner’s total race time (21.93 s) (www.fina.org). Hipothetically this differences in performance among the finalists may result from the time lost during the start phase. With regard to results of the temporal distribution analysis the start phase accounts for 7.7% to 15% of total race time in elite men 50m freestyle races (Arellano et al., 1994; Hay, 1993). This fact implies that it is necessary for each elite sprint swimmer to optimize aspects of efficient start performance.

Study of Croin and Hansen (2005) has shown that the key component of starting performance is the lower body strength and that improvement in lower body strength can play a major role in improvement of sprinting ability. Several studies have previously attempted to examine the relationship between starting performance and land tests using a variety of methods, which included different types of starts – grab (Benjanuvatra et al., 2007), track (West et al., 2011) and swing (Breed and Young, 2003) with lower body land tests. Strong positive correlations were found between the peak forces measured during the land tests and the peak forces measured on both main and wedge plates of the starting block suggesting that land tests can be used as an alternative to pool based tests for peak force (Arellano et al., 2005).

The effectiveness of dive starts has been measured by the time to a set distance, ranging from 5m to 25m (Counsilman et al., 1988; Blanksby et al., 2002; Guimaraes and Hay, 1985). The study using elite subjects have shown that the best criterion measure of swim start performance is time to 10m (Blanksby et al., 2002).

Contractile abilities can be trained during several years of training process and performance quality basically depends on the neuromuscular and contractile potential (Dopsaj et al., 2010). F-t curve characteristics i.e. force and explosiveness are basic indicators of contractile abilities and it is assumed that the better they are developed the better athletic performance could be. In the track

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start, the movement action on the start block reveals two different stages: at the first one (from the signal until the take off of the hands), where the extension of the rear leg lead a higher muscle activities in the legs and greater forces on the block, and the second phase from the "rear leg off" until the take off of the block with the additional extension of the front leg (Vila-Boas et al., 2003). Due to mentioned, contractile abilities of the leg extensors muscles can be of the great influence for efficient start performance. It is assumed that the better the values of contractile characteristics of the leg extensors muscles are, the better the starting performance will be.

Most of the previous research has been studying relationship between strength and power characteristics with starting performance (Breed and Young, 2003; Croin and Hansen, 2005; Mason et al., 2007; Miyashita et al., 1992; West et al., 2011). There has been the lack of research studying relationship between absolute and relative lower body muscle force characteristics and starting performance.

The aim of the present study was twofold. The first aim was to examine the association of absolute and relative lower body muscle force characteristics (maximum muscle force and different rate of force development indicators), on kinematic component which determine the start performance in elite male swimmers. The second aim was to create prediction model which could use as a tool for swimming coaches with the purpose to start performance improvement in high-level male sprint swimmers by controlling or improving the contractile characteristics in the knee extensors muscles. It was hypothesized that: i) the swimmers with a higher level of contractile characteristics in the knee extensor muscles would be able to conduct a more effective start regarding to 10m distance and; ii) maximum voluntary isometric force of leg extensors muscles, basic and specific rate of force development of the same muscle groups at absolute and relative level could be predictors of efficient start performance.

Methods

Subjects

Study involved 27 high-level male competitive swimmers all members of the Serbian National Youth and Senior Swimming Team. The group was called "high-level" because tested swimmers were experienced international competitors at high-level competitions (Olympic Games, Senior and Youth European Championship, Senior and Youth Balkan Games, Mediterranean Games). The swimmers gave their informed written consent to participate in the study. All methods and procedures of this study were approved by the Serbian Swimming Federation Expert Advising Committee and by the ethical committee of the University of Belgrade Faculty of Sport and Physical Education, Serbia, and confirm with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Subjects' means(±SD) of age, height, body weight and personal best times over 50m freestyle were 21.1 ± 4.3 years, 1.89 ± 10.3 m, 81.6 ± 8.4 kg and 24.36 ± 0.86 sec, respectively.

Procedures

All tests were performed on the same day. The tests for muscle force characteristics were performed in the morning, while the tests for start performance were performed in the afternoon.

Muscle force testing

The testing of muscle force was measured under isometric conditions of muscle contraction with a Tensiometric Dynamometer (IMADA Z2H-1100-Japan) consisting of special cells ranging to 5000 N and with the sensitivity of 1.25 N. The conversion of the force/time ratio was evaluated at the frequency of 1 kHz, and all the data of muscle force produced from the beginning of muscle contraction to its maximal values for each attempt were recorded with a hardware-software system (WinWedge 3.4, TAL Technologies, Philadelphia, PA, USA). After standard basic warm-up phase, the subjects performed each test twice with a 2-minute rest between the trials. The evaluation of leg extensors was made by the following procedure: the athlete stands on the platform, holding the dynamometer connected with the platform behind and under the back, 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 120 degrees, on hearing the signal, the athlete executes maximal voluntary isometric contraction of the observed muscle group in order to extending the knees as much as possible for 5 seconds, maintaining his body in the same position, with no movements made in front and lateral planes (Dopsaj et al., 2010; McGuigan et al., 2008). Further analysis took into account the more successful trial, i.e. the trial in which the greater maximum force was achieved in the specified test.

Variables for muscle force

The characteristics of muscle force at knee extensors were represented by maximum voluntary force F_{max} (in N), rate of force development (RFD in $N \cdot s^{-1}$) as the indicator of basic (general) level of the rate of force development of leg extensors (Ivanović and Dopsaj, 2013; Zatsiorsky and Kraemer, 2006):

$$RFD_{basic} = (F_{max}/tF_{max}) \cdot 1000 \quad (1)$$

Where: RFD_{Fmax} represents the basic (general) level of the rate of force development, expressed in $N \cdot s^{-1}$; F_{max} represents the maximum value of isometric leg extensor force, expressed in N; tF_{max} 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_{max}, was measured by applying the following procedure (Zatsiorsky and Kraemer, 2006; Ivanović and Dopsaj, 2013):

$$RFD_{50\%} = (F_{50\%} / tF_{50\%}) \cdot 1000 \quad (2)$$

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

The relative values of lower body muscle force characteristics: the relative voluntary force F_{rel} (in

$N/kg^{0.67}$), the relative basic rate of force development $RFD_{basicrel}$ (in $N/kg^{0.67}$) and the relative specific rate of force development $RFD_{50\%rel}$ (in $N/kg^{0.67}$) were obtained by using the allometric methods proposed by Jaric (2002) and Astrand et al. (2003).

Start performance testing

The subjects completed a warm up, based on their pre-race routine, which consisted of sprint, and dive drills to ensure the athletes were ready to perform at their maximum capacity. The participants were instructed to perform a maximum effort dive and maximum underwater fly kick swim to the 10m mark. The subjects performed three track starts, with a 5 min rest after each trial. The fastest trial (time on 10m) was taken for further analysis. The starting block (SO2-X, Alge Timing - Austria) specifications were as follows: the height above the water surface was 0.72m; the starting platform was 0.56m wide × 0.56m long, with a 8º slope; the pedal used as a back plate was set 0.44m from the front edge of the platform at a 30º angle to the platform; the timing plate (TP24, Alge Timing - Austria) was set on 10m mark with one side attached to the lane line and the other to the edge of the swimming pool.

Variables for swim start

The kinematic characteristic of start performance was represented as: (t10) Time at 10m - time from the starting signal to the moment when the swimmer touches the timing plate at 10m (in 0.01 s);

Statistical analysis

Means and standard deviations were calculated for each variable. Pearson's correlation was used to quantify the association between the variables we used in the research (t10m and selected force variables). The model of dependency in the observed variables (t10m with the variables of maximum voluntary muscle force, basic rate of muscle force development, specific rate of muscle force development, relative values of muscle voluntary force, basic rate of force development, specific rate of force development relative values) was defined using the multiple regression analysis (backward method). All the statistical operations were performed using software SPSS 15.0. (Chicago, IL, USA) and level of significance was set at $p \leq 0.05$.

Results

Table 1 shows results for the descriptive statistic of the observing indicators, the results of Pearson correlation are presented in Table 2. The time at 10m (4.12 ± 0.59 s) was significantly inversely related to maximum voluntary force (1238.40 ± 420.88 N) with correlation values of (r = -0.559, p = 0.002), and to leg extensors specific level of rate of force development (1408.73±1018.30 $N \cdot s^{-1}$) with correlation values (r = -0.338, p = 0.047). The 10m start time elicited a moderate but statistically significant relationship (r = -0.402, p = 0.040) with leg extensors relative value of specific rate of force development (89.66 ± 71.95 $N \cdot s^{-1}$). The highest correlation coefficient (r = -0.727, p < 0.001) was obtained between the time at 10m and leg extensors relative values of maximum muscle voluntary force (78.36 ± 31.77 $N/kg^{0.67}$).

Table 3 shows the results of the Multiple regression analysis (Backward method) between Time at 10m and different indicators of muscle force.

As shown in Table 3, the best model to predict time on 10m included consideration: maximum voluntary force, specific rate of force development, relative voluntary force and relative specific rate of force development (R^2 adjusted = 0.747). In relation to time at 10m, it was possible to estimate a predictable time at 10m from the maximum voluntary force, specific rate of force development, relative voluntary force and relative specific rate of force development.

Obtained model significantly explains criterion (start time at 10m) with standard error of the estimate level of ±29.94 ms (F = 20.201, p < 0.001, Table 3). The equation for predictable time at 10m was obtained:

$$t10 = 485.991-(F_{max} \cdot 0.098)-(RFD_{50\%} \cdot 0.101)-(F_{rel} \cdot 1.272)-(RFD_{50\%rel} \cdot 1.321) \quad (3)$$

Table 1. Descriptive statistics of start and muscle force characteristics (n=27).

Variables	Mean (SD)	Min-Max
Time at 10m (s)	4.12 (.59)	2.96-5.28
Leg extensors maximum voluntary force - F_{max}(N)	1238 (421)	566 - 2315
Leg extensors basic level of rate of force development -RFD_{basic} ($N \cdot s^{-1}$)	1721 (1286)	610-6668
Leg extensors specific level of rate of force development -$RFD_{50\%}$ ($N \cdot s^{-1}$)	1409 (1018)	435-4757
Leg extensors relative values of maximum muscle voluntary force -F_{rel} ($N/kg^{0.67}$)	78.4 (31.8)	30.0-145.3
Leg extensors relative value of basic level of rate of force development – $RFD_{basicrel}$ ($N \cdot s^{-1} \cdot kg^{0.67}$)	101.7 (66.6)	41.7-353.5
Leg extensors relative value of specific level of rate of force development - $RFD_{50\%rel}$ ($N \cdot s^{-1} \cdot kg^{0.67}$)	89.7 (72.0)	23.3-346.0

Abbreviations: Mean = Arithmetic mean, SD = Standard Deviation, Min = Minimum value, Max = Maximum value.

Table 2. Pearson's correlation coefficient between start and muscle force characteristics (n=27).

Variables	t10m (s)	p
Leg extensors maximum voluntary force - F_{max}(N)	-.559	.002
Leg extensors basic level of rate of force development - RFD_{basic} ($N \cdot s^{-1}$)	-.245	.081
Leg extensors specific level of rate of force development - $RFD_{50\%}$ ($N \cdot s^{-1}$)	-.338	.047
Leg extensors relative values of maximum muscle voluntary force- F_{rel} ($N/kg^{0.67}$)	-.727	< .001
Leg extensors relative value of basic rate of force development - $RFD_{basicrel}$ ($N \cdot s^{-1} \cdot kg^{0.67}$)	-.317	.071
Leg extensors relative value of specific rate of force development - $RFD_{50\%rel}$ ($N \cdot s^{-1} \cdot kg^{0.67}$)	-.402	.040

Abbreviations: t10m = Time at 10m, p = Pearson's correlation coefficient level of significance.

Table 3. Backward method multiple-regression analysis of the associations of time at 10m with significant predictor variables in high-level male swimmers (n = 27).

Variables	*Unstd. Beta*	*Beta*	*t*	*p*	*R*	*R^2_{adjust}*	*Std. Err. Est.*	*F*	*P*
F_{max}(N)	-.098	-.678	-2.870	.009					
$RFD_{50\%}$ ($N \cdot s^{-1}$)	-.101	-.518	-2.596	.016					
F_{rel} ($N/kg^{0.67}$)	-1.272	-1.677	-5.085	<.001					
$RFD_{50\%rel}$ ($N \cdot s^{-1} \cdot kg^{0.67}$)	-1.321	-1.596	-5.029	<.001	.887	.747	29.941	20.201	<.001

Abbreviations: F_{max} = leg extensors maximum voluntary force, $RFD_{50\%}$ = Leg extensors specific level of rate of force development, F_{rel} = leg extensors relative values of maximum muscle voluntary force, $RFD_{50\%rel}$ = leg extensors relative value of specific rate of force development , Unstd.Beta = Unstandardized regression coefficients values, Beta = Standardized regression coefficients values, t = Standardized regression coefficients significance tests, p = Standardized regression coefficients level of significance, R= Multiple correlation coefficient, R^2_{adjust} = Adjusted determination coefficient, Std. Err. Est. = Standard error of the estimate, F= Multiple regression analysis significance tests, P = Multiple correlation level of significance.

Discussion

The aim of this study was to determine the connection between the contractile ability of the leg extensor muscles, which can be described with isometric F-t relationship (F-t curve), and to determine whether the level of maximum and relative muscle voluntary force (F_{max} and F_{rel}) and the levels of general and specific rates of force development (RFD_{basic}, $RFD_{basicrel}$, $RFD_{50\%}$, $RFD_{50\%rel}$) are related to the efficiency of start performance (t10m). It must be emphasized that there have not been similar published studies. Previously published papers have examined the relationship between contractile ability in relation to different strength and power characteristics and start variables (Benjanuvatra et al., 2007; Breed and Young, 2003; Mason et al., 2007; Miyashita et al., 1992; West et al., 2011).

Correlation results showed a statistically significant association between the start efficiency (t10m) and the variables of F_{max} (r = -0.559, p = 0.002), F_{rel} (r = -0.727, p < 0.001), $RFD_{50\%}$ (r = -0.338, p = 0.047) and $RFD_{50\%rel}$ (r = -0.402, p = 0.040). The obtained results showed significant correlation between maximum voluntary force of leg extensors muscles measured on land in standing position and start times measured on 10m (r = -0.559, p = 0.002). In the study of West et al. (2011), start time in elite swimmers was significantly related to lower body 1RM squat strength (r = -0.74). In a group of 57 US national selected swimmers and Japanese Olympic team swimmers, Miyashita et al. (1992) found statistically significant relationship between start time and leg extension power (r = -0.675, p = 0.01).

McGuigan et al. (2008) in the study on a group of elite athletes, found significant correlation between maximum voluntary force (F_{max}) measured under isometric conditions of knee extensors muscles and 1RM squat strength ($0.61 \leq r \leq 0.71$, $p < 0.05$). The authors suggest that isometric testing provides a good indicator of an athlete dynamic performance during 1RM testing including back squat. It must be emphasized that swimming start represents the element where movement of arms and legs are implemented in dynamic conditions and the characteristics of power are predominantly expressed (Benjanuvatra et al., 2007; Breed and Young, 2003; Croin and Hansen, 2005; West et al., 2011). However, power development achieved through the combined use of heavy resistance training and explosive type resistance training (Hakkinen et al., 1985), as well as with vibration training method (Humphries et al., 2004; Lamont et al., 2010) primary develops dynamic characteristics and secondary affects on the improvement of isometric force (Hakkinen et al., 1985). Therefore, evaluating isometric force-time curve with testing protocol as used in the present investigation has the potential to provide information that would increase start training performance. This suggests that it is possible to use both testing methods (isometric and dynamic) for the determination of relationship between contractile characteristics of leg extensor muscles and start performance. Relative values of maximum voluntary force (F_{rel}) also showed significant association with 10m start times (r = -0.727, p < 0.001). In the study of West et al. (2011), authors found significant correlation between start performance and relative power of knee extensor muscles (r = -0.624). Mason et al. (2007) found that the characteristic most closely observed in excellent starting ability that is linked to efficient start performance was peak power normalized to body mass, average power and maximum horizontal propulsive force normalized to body mass. The results of this study showed that swimmers with higher relative force values were able to be faster on 10m-mark then the swimmers with lower relative force values. The reasoning for these observations can be derived by the fact that the swimmers with a greater ability to generate force per kg/BM showed greater potential for faster start performance.

Early-phase of RFD ($RFD_{50\%}$) or S gradient was significantly correlated with start time (r = -0.338, p = 0.047). The ability to produce force quickly, as measured by the time to achieve 50% of maximum voluntary contraction showed a significant predictive value related to sprinting performance on 10m (Table 4). The obtained results indicate that high level intensity of force development in the early phase of muscle contraction is a significant predictor of faster 10m start times. Andersen and Aagaard, (2006) found that every increase of the RFD in the in the early phase of muscle contraction (first 100ms), enables efficient and faster motor performance. Slawinski et al. (2010) found that during the pushing phase on the starting block, the maximal acceleration was reached when the rear foot pushed on the rear end and in very short time, less then 0.15 seconds. Average block times for track start observed in elite swimmers were 0.94 ± 0.07 s (Vilas-Boas et al., 2003) consequently such short times may not allow maximal force to be reached. As a result, any increase in contractile $RFD_{50\%}$ becomes highly significant because it allows a higher level of muscle force to be reached in the early phase of muscle contraction. Thus $RFD_{50\%}$ showed to be a significantly important parameter in the ability of faster start performance. In addition to $RFD_{50\%}$, another important muscle force parameter is the $RFD_{50\%rel}$ that can be produced within a given contraction time for kg of body mass. The capability of knee extensor muscles to produce the highest force intensity per kg of body mass obviously represents better explosiveness capacity of the knee extensor muscles in high-level sprint swimmers which was manifested through faster start performance.

The results of this study provide encouraging support for the efficiency of muscle force testing under isometric conditions of muscle contraction to predict the time on 10m-mark in highly trained elite male sprint swimmers. The major advantage of this finding exists in its practical application, offering an statistically accurate, safe and time efficient testing method for predicting starting efficiency (R^2_{adjust} = 0.747, Std. Err. Est. = 29.94 ms, F = 20.201, P < 0.000, Table 4). Equation for t10m prediction is defined by variables that measured the development of maximum voluntary isometric force of leg extensor muscles at absolute and relative level (F_{max} i F_{rel}), as well as the variables that measured the development of a specific explosiveness of the same muscle groups ($RFD_{50\%}$ and $RFD_{50\%rel}$) at absolute and relative level too (equation 3). Thus by means of the testing model applied in this paper, i.e. by inserting values of F_{max}, F_{rel}, $RFD_{50\%}$ and $RFD_{50\%rel}$ in the obtained equation, coaches can calculate the time required by a particular swimmer to cover a 10m distance upon start, at the probability level of 74.7% and prediction accuracy range of ± 29.94 ms. Any possible differences, realized as time underestimation (slower swimming than predicted), as overestimation (faster swimming than predicted), or proper time, indicate to lower or higher start technique efficiency, or coherence of the leg extensor muscle force with the efficiency of the start technique. All of the above mentioned provide a coach with information on the type of swimmer in relation to the measured physical ability aimed at efficient start performance (high-force/low-force/adjusted-force level in relation to the start technique level), and it also provide guidance for coach towards goals of future training work from the aspect of improved elements of start performance technique (direction and extent of development of a given force characteristics for providing conditions for start improvement). Obtained model represents one of the possible helping tools which coaches can use to control and improve the start training process. The fact is that with the defined equation of the specification, along with the help of used force characteristics of the leg extensors muscles (F and RFD), 74.7% of efficiency can be predicted while performing start (t10m). However, the obtained model and the applied method for measuring the force, represents available technology, which can be used for start performance improvement and development. Limiting factors of this study are lack of F-t curve data for hip, ankle and back extensors muscles, as well as lack of kinematical data for more precise start technique determination. Further work to extend analysis to include a more complete biomechanical analysis should be considered.

Conclusion

The outcomes of this study show that muscle force characteristics obtained by performing the simple muscle force tests measured on land do relate to swimming start performance and can be used by swimmers and coaches to improve the start performance. Contractile abilities indicators of the leg extensors muscles included consideration: $F_{max,}$ $RFD_{50\%}$, F_{rel} and $RFD_{50\%rel}$ showed significant correlation with swimming start times on 10m. By analyzing the obtained model the higher the values of $F_{max,}$ $RFD_{50\%}$, F_{rel} and $RFD_{50\%rel}$ in a group of high-level trained swimmers the faster the time on 10m is. Much greater influence on the starting time measured on 10m showed relative values of muscle force characteristics (F_{rel} and $RFD_{50\%rel}$) compared to absolute values ($F_{max,}$ $RFD_{50\%}$) of muscle force characteristics i.e. swimmers with a greater ability to generate force per kg/BM and specific explosiveness per kg/BM showed greater potential for faster start performance.

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Key points

In high-level male swimmers:

- Leg extensors maximum voluntary force, leg extensors relative value of maximum muscle voluntary force, leg extensors specific rate of force development and leg extensors relative value of specific rate of force development positively associated with the start time measured on 10m-mark.
- Time at 10m-mark was not associated with legs extensors basic level of rate of force development at absolute and relative level.
- Obtained multi-regressional model is defined by variables which measure the development of maximum voluntary isometric leg extensor muscle force on the absolute and relative level, as well as variables which measure the development of specific explosive force of the same muscle group on absolute and relative level, this could use as a tool for swimming coaches to control the direction and extent of development of a given force characteristics for providing conditions for start improvement in highly trained elite male sprint swimmers.

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